Basaltic-rock procurement systems in the southern levant: case studies from the chalcolithic-early bronze I and the late bronze-iron ages

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Basaltic-rock procurement systems in the southern Levant: Case studies from the Chalcolithic-Early Bronze I and the Late Bronze-Iron Ages

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Abbreviations

The following abbreviations are used throughout this thesis:

PPN	Pre-pottery Neolithic
PN	Pottery Neolithic
EBA	Early Bronze Age (subdivided into EBI to IV)
MBA	Middle Bronze Age
LBA	Late Bronze Age (subdivided into LBI and II)
IA	Iron Age (subdivided into IAI and II)
ICP-AES	Inductively coupled plasma-atomic emission spectroscopy
ICP-MS	Inductively coupled plasma-mass spectrometry (including Laser Ablation or Multi-Collector)
K-Ar	Potassium-argon dating
NAA	Neutron activation analysis
XRF	X-ray fluorescence (Energy Dispersive or Wavelength Dispersive)
HFSE	High field strength elements
REE	Rare earth elements
TAS	Total alkali-silica diagram
MORB	Mid-ocean ridge basalt (Normal, Enriched or Plume)
OIB	Ocean island basalt
VAB	Volcanic arc basalt
WPB	Within plate basalt
Ma	million years ago
ppb	parts per billion
ppm	parts per million
ASOR	American Schools of Oriental Research
BAR	British Archaeological Reports
BASOR	Bulletin of the American Schools of Oriental Research
IAA	Israel Antiquities Authority
JOAS	Journal of Archaeological Science
NIV	New International Version of the Bible
NRSV	New Revised Standard Version of the Bible

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Chapter 1: Introduction

"Quinquireme of Nineveh from distant Ophir
Rowing home to haven in sunny Palestine,
With a cargo of ivory,
And apes and peacocks,
Sandalwood, cedarwood, and sweet white wine."
(from Cargoes, *by J. Masefield)*

As Masefield's poem illustrates, the procurement of goods which are not locally available is an important human activity. However, as *Cargoes* also reveals, there has generally been a tendency to concentrate on exotic goods from distant shores, rather than on non-local goods which are available at a regional level. This has also been true of archaeological investigations, despite the fact that it is probable that these intra-regional procurement systems were at least as important for the maintenance of social groups as inter-regional networks. Nonetheless, work has begun on the examination of these intra-regional procurement systems, including those of basaltic rock in the southern Levant. Basaltic rocks were used in the manufacture of a wide variety of artefacts, including bowls, statues, and royal inscriptions, as well as for more utilitarian artefacts such as quern-stones, pestles and mortars (as will be discussed in Chapter 6). Whereas igneous rocks are only located in certain parts of the southern Levant (cf. Fig 1.3; see Chapter 4 for more detail), these artefacts are much more widely distributed. Clearly, these artefacts must have been transported up to several hundred kilometres from their source outcrop. This is of great archaeological interest due to the potential information offered to questions relating to inter-group contacts and how past societies operated and were organised.

A large variety of goods were probably procured intra-regionally, but are generally not amenable to provenancing. Textiles, spices and oils were widely distributed, but have usually perished. There have been a number of attempts to provenance metals, but these have met with problems due to the potential for the mixing of sources. Rock artefacts have a far greater potential for provenance studies, as they are relatively common, virtually indestructible and do not generally undergo chemical or physical changes during their manufacture, use or subsequent deposition (Rapp and Hill 1998:135). Given these advantages, there have been a number of attempts to provenance the basaltic-rock artefacts of the southern Levant, which will be discussed below and in Chapter 2. It is the aim of this thesis to expand and refine these studies and also, hopefully, to draw more general conclusions which may be of relevance to other intra-regional procurement studies or to the understanding of past periods of the southern Levant.

The rest of this introduction will present a discussion of the terminology and definitions used throughout this thesis, an outline of the theoretical understanding that, at least implicitly, informs this thesis, and a summary of the periods from which artefacts were analysed. It concludes with a critique of the two studies by Philip and Williams-Thorpe (1993 and 2001) that this thesis is based on, and an outline of the structure of the rest of the thesis.

Terminology and definitions

As is frequently the case, a number of the terms regularly used in the study of basaltic ground stone artefacts are mired in confusion or controversy (and, not infrequently, both). This section attempts to clarify what the terms will mean in this thesis. The first term which requires definition is that of ‘basalt’ itself. Bunbury (2000:64) comments that:

> “ ‘Basalt’ is a term widely used and abused. It has been employed both as a specific rock name … and as a general term for almost any dark, fine-grained igneous rock … Not all rocks of basaltic composition are, however, dark and fine-grained, nor are all dark, fine-grained, igneous rocks of basaltic composition. While the term ‘basalt’ remains a useful field name, it should be borne in mind that whole books have been written on the finer details of the sub-classification of rocks of basaltic composition.”

In previous archaeological work, ‘basalt’ has primarily been used as a general term to refer to any “dark, fine-grained, igneous rock”. However, as discussed in Chapter 3, this may well obscure important differences between similar-looking dark, fine-grained, igneous rocks. It can also cause confusion if ‘basalt’ is used as both a general and specific term. Furthermore, the geological term ‘mafic’ refers to dark igneous rocks (Allaby and Allaby 1999:327), whilst Le Maitre (2002:39,61) recommends that the terms ‘basaltoid’ or ‘basaltic rock’ be used for fine-grained rocks “tentatively identified as basalt”. Therefore, these terms will be used where appropriate, whilst ‘basalt’ will only be used as a specific rock name (as defined in Chapter 3), except in direct quotations from previous authors. Therefore, unless the authors have shown that they have attempted to geologically classify the ‘basalt’ rocks, ‘basaltic’ will be substituted when discussing their reports. It is also important to remember that neither the general or specific definition of ‘basalt’ represents past conceptual categories, with Stol (1979:85) arguing that “our general term ‘basalt’ was unknown in Antiquity”; instead, a variety of different words were used, which appear to have been based on the different physical properties exhibited. An examination of these physical properties may therefore lead to an understanding of the conceptual categories employed in the past.

Second, the geographical region in question should be defined. In this thesis the term ‘southern Levant’ will be used to refer to the modern states of Israel and Jordan, the Occupied Territories, and the Sinai peninsula. To subdivide this region the term ‘Transjordan’ will be used to refer to the area east of the Dead Sea Fault (delineated by the Hulah Valley, the Sea of Galilee, the Jordan Valley, the Dead Sea and the Wadi Araba), whilst the term ‘Cisjordan’ will be used to refer to the area west of this line. These terms are used as they are the most politically neutral terms available. When referring to specific geographical features the most commonly used names in English publications have been used. This includes using the term ‘Sea of Galilee’ instead of ‘Lake Tiberias’ or ‘Lake Kinneret’ and ‘Golan’ instead of ‘Jaulan’. The use of these names is not intended as a geopolitical statement. Other areas will be defined in the text as necessary.

Third, it is necessary to define the chronological periods which are under investigation. The previous work by Philip and Williams-Thorpe (1993 and 2001) focused on the Chalcolithic and Early Bronze I, which will also be examined in this thesis. However, the Late Bronze Age and Iron Ages will also be examined. As artefacts from a number of different sites have been examined from each period it is hoped that both synchronic and diachronic changes in the procurement systems will be revealed. The dates of the periods used throughout this thesis are shown in Table 1.1.

Table 1.1: Chronology

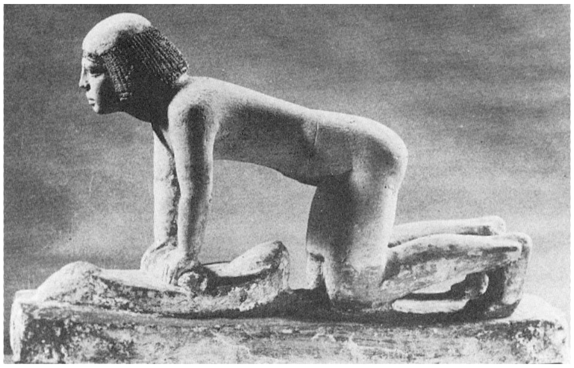
Period	Dates (cal BC)
Chalcolithic	Late 6th millennium to 3600
Early Bronze I (EBI)	3600 to 3000
Late Bronze Age (LBA)	1500 to1200
Iron Age I (IAI)	1200 to 1000
Iron Age II (IAII)	1000 to 540

(Philip and Williams-Thorpe 2001:11; Bunimovitz 1995:320; Herr 1997:117f).

Finally, it is necessary to define the terms used to refer to ground stone artefacts. As has been discussed by Wright (1992:4), the term ‘ground stone’ refers to “tools manufactured by combinations of flaking, pecking, pounding, grinding and incising.” Grinding is therefore an important, but by no means the only, process involved in the manufacture and use of these artefacts. This is supported by the work of Hayden (1987b) and Wilke and Quintero (1996:244ff), who also report that artefacts examined from sites in Transjordan have remnant percussion scars.

A number of attempts have been made to standardise the terminology applied to ground stone artefacts, with the most comprehensive being those of Wright (1992) for most ground stone artefacts and Rowan (1998) for ground stone vessels. These will therefore be generally followed, with one main variation, which is that Wright (1992:625) reserves the term ‘quern’ for a ‘grinding slab’ where rotary motion was used for grinding. However, this conflicts with standard usage, which defines a quern as “the lower stationary element of a pair of grinding stones” (Wilke and Quintero 1996:244). This can then be subdivided by the terms ‘saddle quern’, which refers to a lower grindstone where parallel motions are used for grinding, and the term ‘rotary quern’ refers to a lower grindstone where rotary motions are used for grinding. These terms will therefore be adopted in this thesis. Wright (1992:628) defines the upper mobile stone used for grinding as a ‘handstone’, while the term ‘quern-stones’ will also be used, as a more general term to refer to both the quern and the handstone, not least as it is sometimes difficult to determine which category a broken artefact belonged to. The way in which these tools were used is illustrated by the Egyptian Old Kingdom figurine shown below.

Fig 1.1: Egyptian Old Kingdom figurine using a pair of quern-stones



From Milevski (1998:64).

Wright (1992:626) defines mortars as lower stationary stones used for pounding, where only the interior has been worked. Wright (1993:95) defines the criteria for a vessel as:

> "(1) a well-defined, uniform rim or base; (2) smooth continuous exterior wall surface; (3) consistent or gradually changing thickness of walls from rim to base; (4) fine grinding/finishing on exterior".

A number of different classification schemes have been used to further sub-divide bowls, with two of the most comprehensive being those of Rowan (1998) and Sparks (1998). The general types defined by these two typologies are remarkably consistent, especially given that Rowan (1998) examined ground stone vessels from the Pottery Neolithic (PN) to the EBI, whilst Sparks (1998) examined ground stone artefacts from the Middle Bronze Age (MBA) and LBA. The forms noted by both range from plates and shallow bowls through to pedestal bowls. However, the various sub-types are less consistent, not least due to the different forms used in the periods they studied. As has been frequently noted, this is a general problem for all ground stone artefacts and one which further inhibits their study. Unfortunately, it is outside the scope of this thesis to attempt to rectify this major problem and develop a standardised typology equally applicable to any period.

Sparks (1998) defines an intermediate 'mortar bowl', where the outside has been worked to some extent and which has a well-defined rim, base and walls, but differs from a vessel by "the presence of thicker, sometimes irregular walls and an interior profile which does not closely follow the outer contours of the vessel." Pestles are defined as upper mobile stones used for pounding through the long axis of the tool (Wright 1993:95). Wright (ibid.) defines a pounder as a tool "with battering fractures from pounding a sharp irregular edge to bluntness." She also notes that these tools are commonly manufactured from flint. Wright distinguishes pounders from hammerstones on the basis that the latter have pounding marks, but not on (formerly) sharp edges (ibid.). The other terms used to describe ground stone tools are generally self-explanatory.

The choice of basaltic rock

Another basic question which requires discussion is why basaltic rocks were often preferentially chosen for the manufacture of artefacts. Basaltic rock has been used for artefacts since the Palaeolithic (Wright 1992:287f) and, as will be discussed in Chapter 2, Weinstein-Evron et al. (1999) have demonstrated that basaltic artefacts have been transported over long distances from at least the Epipalaeolithic onwards. There are probably a number of different reasons why basaltic rock was chosen. First, mafic outcrops can be highly conspicuous, as is shown in Plate 1 of Jebel al-Dhakar in the Wadi al-Hasa (all Plates are at the end of the thesis). Even when the outcrops are not this imposing, they are still visible against the, generally lighter-coloured, surrounding rocks (Plate 2). This visibility would presumably have made people curious and encouraged them to examine the rock more closely.

In turn, this would have led them to discover its advantageous properties, which are discussed in Chapter 3. However, as the provenance studies show, these factors do not fully explain the distribution of basaltic artefacts, as the nearest potential source to the site where the artefact was found was not usually the source which was actually exploited. Two potential explanations for this anomaly are the accessibility of the potential source outcrop and the quality of the basaltic rock available at the potential source. Some outcrops, especially in Cisjordan, are very weathered (see Chapter 4) and so would probably not have been useable for manufacturing artefacts. However, even when the nearest outcrops would have been accessible and have good quality basaltic rock, they were not always exploited.

As Philip and Williams-Thorpe (2001:26f) note, there seem to be social reasons why one outcrop was chosen over another, perhaps to maintain trading links, or possibly because only certain groups were seen as legitimate manufacturers of basaltic bowls. Another, at least partial explanation, is that the bowls were some form of status symbol. Given the difficulty of working basaltic rocks, it would have taken a considerable amount of time and effort to produce the good quality bowls which are found in archaeological record and which must, therefore, have been of some value. These questions will also be considered in this thesis.

Theoretical basis

All archaeological studies are based on a theoretical understanding of the world, however implicit this understanding may be (Trigger 1989:19ff). This section will therefore explicitly state the theoretical understanding which underlies this thesis.

The two main theoretical approaches which have informed archaeological research for the last few decades have been processualism and post-processualism, which are specific versions of modernism and post-modernism, respectively. In general terms, processualism is positivistic and concerned with the search for generalising laws, whilst post-processualism is a reaction against this, with the emphasis on relativistic understanding and interpretation, especially of past thoughts and beliefs (Trigger 1989; cf. Sayer 2000:2f). Post-processualism has provided a number of important critiques of processualism, including showing that the 'rules' which operate for one society cannot be generalised for other societies. However, post-processualism replaces positivism with relativism, arguing that knowledge of past societies is socially constructed in the present, implying, or even explicitly stating, that the past is essentially unknowable. One good example of this relativism in practice is McGlade's (1999:462) assertion that "there can be no objective study of the natural environment for the very good reason that there is no 'objective' world independent of human observation".

Realism

However, an alternative position currently gaining support (especially in the other social sciences) is realism, which offers an alternative to the two extremes discussed above (Sayer 2000:2). As realism has not yet been widely acknowledged amongst archaeologists it will be discussed at greater length than would otherwise have been necessary.

Realism echoes many of the post-modern critiques of modernism, which has radically underestimated the "complexity, diversity and multiple meanings of the social world" (Sayer 2000:30). However, contrary to post-modernism, realism also argues that there is an external truth which can potentially be known, although our knowledge of it is fallible (Sayer 2000:2). Indeed, Sayer (ibid.) argues that the very fallibility of human knowledge shows that there is a world independent of human belief in it. Sayer (2000:10) makes a distinction between the objects of study (whether physical processes or social phenomena) and the rival theories and discourses about these objects. He (Sayer 2000:11) also argues that theories would not be rivals unless they were about the same objects. Therefore, McGlade's statement, above, can be seen to be false, as it confuses these two distinct dimensions of knowledge. This is supported by Trigger (1989:407f), who argues that "if subjective factors intervene at every level in the interpretation of the past, so too does archaeological evidence, which ... partially constrains and limits what it is possible to believe about the past."

Furthermore, realism argues that human action depends on pre-existing social structures, including such fundamental things as the language and economic system used (Lewis 2000:250f). This shows that the social structures cannot be reduced to the actions of individuals, but actually constrain their actions. Nonetheless, this does not imply that the social structure exists independently of individuals, who can choose to reproduce or transform the existing social structure. However, their ability to attempt this is constrained by the existing social structure, which includes the uneven distribution of resources (Lewis 2000:251f,259; Sayer 2000:13).

Realism also argues that events depend on contingent conditions, that is, there are always different potential outcomes which do not occur. For example, artefacts can usually be obtained from more sources than the ones that are actually used in any individual procurement system. Therefore, the same causal power may produce different outcomes, while different causal mechanisms may produce the same outcome (Sayer 2000:15). Such systems are termed non-linear, as there is no direct (linear) relationship between effects and causes, with the strength of a particular cause bearing no direct relationship to the extent of the eventual effect. This can seen to be the case for many systems, both natural and social (Byrne 1998:24).

Marion (1999:59) develops this using the concept of social homeostasis, defined as behaviour which drifts over a range of parameters, but keeps within self-similar boundaries. This means that social systems remain dynamically stable, which is reinforced by the interactions of the sub-systems, causing the overall social system to be resistant to change (Marion 1999:128). However, social homeostasis only maintains variables within certain ranges, while certain factors may trigger dramatic, discontinuous change, which may result either in the system radically changing and then forming a new homeostatic state, or may result in the system eventually returning to the former homeostasis, after a period of disruption (Marion 1999:59). This is known as punctuated equilibrium (Marion 1999:51), a term taken from evolutionary biology, with most change seen as sudden and dramatic, although a longer period of hidden change has usually preceded this (Marion 1999:311). Marion (1999:310) also argues that new systems are not adopted because they are in some way better, but can only be adopted when they have a network of support. Marion (ibid.) therefore concludes that “old networks, with all their commitments and interdependencies, have to be dismantled before new technologies or ideas or movements or cultures can take hold, and that is no trivial task.”

This form of change can be seen to regularly occur in archaeology, both in changes of technology and of cultures (Holladay 1995:371). Therefore, although human societies are constantly changing they generally remain within limited boundaries, whilst there is a considerable amount of inertia, both in cultural systems as a whole and also in their individual sub-systems. This implies that long-term change is not a “single, cumulative trajectory” (McGlade 1999:460), meaning that there can be significant, discontinuous changes in systems. As Greenberg (2002:4f) notes:

> “the realization that it is the nature of systems - not only social, but physical, chemical, and biological as well - to be dynamical and disjunctive releases the archaeologist (as historian or as social scientist) from the need to describe linear trajectories of social change. Diversity and unpredictable emergent properties are not only an observable characteristic of all human societies, but part of the explanation of change itself.”

Although not fully developed in this thesis (due, amongst other things, to the lack of suitable data), the understanding of realism that there is a constraining independent reality and that social systems constrain actions and are subject to punctuated equilibria is implicit throughout. This understanding will become especially important when attempting to understand the operation of procurement systems, discussed in Chapter 5.

Periods under study

The Chalcolithic and EBI periods were chosen by Philip and Williams-Thorpe (1993:51) as they represent the most sophisticated manufacture of basaltic bowls in the southern Levant. These artefacts appear to have been prestige items, but with widespread distribution, and therefore offer the potential for understanding the socio-economic contacts between groups. More artefacts from these periods were therefore analysed. Basaltic artefacts from the LBA and IA were also analysed, as they were again widely used and distributed, enabling long-term diachronic change in intra-regional, inter-group socio-economic contacts to be examined. A brief summary of each of these periods will now be given.

Chalcolithic (late 6th mil-3600 BC)

The Chalcolithic period is marked by a significant shift in the settlement patterns, from the Pottery Neolithic settlements located in the wetter coastal zone or by permanent springs, to mixed farming settlements, largely situated in the semi-arid areas of the southern Levant (Levy 1995:226). Some of these new settlements were seasonal encampments, mostly for pastoralists, although a minority were used for seasonal agriculture (Goren 1992a:47; Gilead 1995:472f). There were also some larger, permanent settlements, such as Teleilat Ghassul, Shiqmim and Grar, generally with mudbrick houses and a few public buildings (Goren 1992a:48; Gilead 1995:469; Levy 1995:229ff).

Alongside the change in settlement patterns there were also significant changes in other areas of the socio-culture. There seems to have been a growth in the population, as well as the establishment of public sanctuaries and the emergence of metallurgy, regionalism and some form of craft specialisation (Levy 1995:226; Kerner 1997b:467). It has been argued that these changes are due to the emergence of chiefdoms (cf. Levy 1995:226), but Bourke (2002:24) argues that during the Early Chalcolithic there is little evidence of social stratification, with the elites being priestly, rather than secular. The increasing diversification and intensification of agriculture enabled the later emergence of secular elites, but even in the Late Chalcolithic there is little evidence for chiefdoms as usually understood (Bourke 2002:24; 2001:151f). Bourke (2001:151f) therefore introduces the concept of group-oriented chiefdoms, whose power is based on their ability to mobilise labour from their extended kin-groups in order to produce a surplus, from which they could engage in exchange.

Furthermore, there is a large amount of evidence for regionalism during the Chalcolithic, and so it cannot be assumed that evidence for one area can be transferred to the rest of the region, especially as the regions developed at different speeds (Kerner 1997b:467f). Despite the regionalism, the various regions also shared elements of material culture across the southern Levant, with a general similarity in the architectural features (especially the house plans), as well as in the pottery and the stone artefacts (Kerner 1997b:468, Goren 1992a:52). This may be explained by the relatively common long distance contact, with many sites having, as well as basaltic artefacts, shells from the Mediterranean, the Red Sea, and the River Nile; turquoise from South Sinai; obsidian from Anatolia; copper from Faynan; and elephant ivory from Africa or north Syria (Levy 1995:233,244; Goren 1992a:62). Furthermore, bitumen was procured from the Dead Sea and has been found in sites in southern Cisjordan and Egypt (Connan et al. 1992). Both Goren (1992a:62) and Levy (1995:232) argue there is evidence for full-time specialists for a variety of materials, including ivory, copper, pottery and probably stone carving, with Levy (ibid.) arguing "stone carving or sculpture reached a level of expertise rarely seen in the later cultures of Palestine." Goren (ibid.) therefore concludes that "Chalcolithic society was based on an extensive network of prospecting and trade in raw materials, production, and the exchange of goods".

However, Bourke (2001:150) argues that this is only the case for the Late Chalcolithic (from c.4500 BC), and that there is little evidence for exchange systems during the Early Chalcolithic. Even in the Late Chalcolithic the vast majority of the exchange was intra-regional, including that of basaltic rock, although there is evidence for maritime contact with south-eastern Anatolia (Bourke 2001:150, Philip 2002:223). Bourke (ibid.) also argues that the vast majority of material was locally procured and manufactured and that the relatively small amount of material that was exchanged did not play an important role in the local economy. Although this may be the case, the exchanged artefacts probably had an important social role in the creation and maintenance of both inter-group relations and of intra-group status differences. This is supported by Philip (2001:189) who argues that the limited degree of social inequality that did exist was based on the control of symbolic artefacts, including imports and those produced by specialist craft workers. Therefore, conversely, the very rarity of these artefacts may well have had a greater socio-economic impact than otherwise, by enabling the growth of inequalities.

Early Bronze Age I (3600-3000 BC)

The end of the Chalcolithic is determined by the collapse of the Chalcolithic societies, with the breakdown of the settlement hierarchies and the return to more autonomous small villages in the EBI (Levy 1995:241). A variety of explanations has been proposed, but the result was the abandonment of the north Negev and Golan settlements and the founding of settlements in the wetter hills, plains and valleys (Ben-Tor 1992:83). Most of these settlements were small, sedentary farming villages, with the houses usually consisting of a few small rooms and a courtyard. Towards the end of the EBI, larger walled settlements start to appear, including Erani, Ai and Tell al-Fara'ah North (Ben-Tor 1992:86).

There is substantial evidence for exchange between sites in the Egyptian delta and sites in southern Cisjordan (Harrison 1993:81). Maadi, in the eastern Delta, contains the best evidence for regular contact with Cisjordan, including pottery vessels, copper ore and copper artefacts, flint tabular scrapers, and a basaltic bowl and basaltic spindle whorls. These artefacts have clear typological links with Cisjordan, which have been confirmed by a number of provenance analyses (Harrison 1993:82ff; Philip and Williams-Thorpe 2001:26), Connan et al. (1992) have also shown that Dead Sea bitumen continued to be exported to Egypt during the EBA. In the southern Cisjordan, Egyptian pottery is common, whilst sites also contain Egyptian flint, Nile mollusc shells, and catfish spikes (Ben-Tor 1992:93; Harrison 1993:87).

There is now good evidence for both an overland and a maritime procurement system from the Early EBI onwards. There are a large number of very small sites throughout northern Sinai, which have storage, cooking and baking installations and contain large quantities of both Egyptian and Levantine pottery and flint tools dating to the EBI-II, indicating an overland route (Harrison 1993:88). There is also evidence that north Levantine wood was procured by the southern Levant and Egypt, and south Levantine olive oil was procured by Egypt (Gophna and Lipschitz 1996:147). Furthermore, the ceramic industry along the Levantine coast shares many features, again indicating maritime links (Philip 2002:216). This maritime system would have allowed large quantities of material and bulkier items to be transported. However, the overland route would have had the advantage of providing smaller traders access to the foreign market, without the expense and risk entailed in a maritime venture (cf. Monroe 2000:78).

The EBI also marks the end of the Chalcolithic prestige artefacts, which are not replaced (Philip 2001:188). Philip (2001:189) argues that this is due to a shift from social inequalities being maintained through the control of symbolic artefacts, to a non-hierarchical system, where access to physical resources were important, and where communities expressed their collective power through the creation of built monuments, such as settlement walls. The significance of participating in regional exchange systems therefore diminished, leading to the disappearance of the prestige artefacts.

Instead, Philip (2001:167) argues that EBI society was organised along heterarchical lines, where there are multiple, coexisting sources of power, which have overlapping functions and transient and contingent relationships and do not have one single rank order. Different types of relationship, including cultic, kinship and procurement, are organised in different ways. This effectively prevents any one individual or group gaining a monopoly of power, as it is distributed amongst a number of groups. The relative power of these groups shifts over time, due to their competition for power (Philip 2001:168). Philip (2001:202f) also argues that this heterarchical structure can maintain specialist craft workers, without the need for the patronage by elites. This is supported by Cross (1993:65) who argues that "there is no obvious or direct connection between the restricted production of a specialist and power or control over the actions of others in other domains." This understanding therefore seems to adequately explain both the lack of elites, and the continued manufacture of specialist craft products (such as the basaltic bowls), which do not seem to have been available to everyone.

Late Bronze Age (1500-1200 BC)

The start of the LBA is marked by the collapse of the Middle Bronze Age city-states and the conquest of the southern Levant by Egypt, which maintained control of the region for most of the period (Goren 1992b:211; Strange 2001:292,315). This external control had a marked effect on the material culture of the region. In contrast to the preceding MBA, most of the settlements were unfortified and declined in both size and number (Goren 1992b:217f; Bunimovitz 1995:324). New styles of buildings and artefacts are also found at sites in the southern Levant, especially in the LBIIB, which are interpreted as Egyptian governor's residences or garrisons built to maintain the Egyptian hegemony (Goren 1992b:217f).

The main interests that Egypt had in the region were maintaining the trade routes to the north and extracting a surplus from the local population (Strange 2001:294). This intensive inter-regional and inter-empire trade meant that "the Late Bronze Age was the first truly international age in the Eastern Mediterranean and the Levant" (Strange 2001:294). Textiles and metal objects were traded, but the main exports from the southern Levant were wine and oil (Goren 1992b:247f). Stone artefacts were also imported, including alabaster jars, serpentine and calcite artefacts from Egypt, and limestone artefacts from Crete (Strange 2001:300; Sparks 2002), whilst basaltic artefacts were exported (Williams-Thorpe and Thorpe 1993). Artzy (1994) also argues that the southern Levant was an important staging post on the incense trade routes from southern Arabia, which she argues started during the LBA, not the IA. Artzy (1994:131) argues that this helps to explain the large amount of luxury items found at certain sites in the southern Levant, including Megiddo, Beth Shean and Tell es-Sa'idyeh. She (ibid.) also notes that this may help explain the Egyptian interest in the region, as incense was an important part of Egyptian culture, not least for embalming.

Monroe (2000) surveys the evidence for the extensive inter-regional procurement systems that operated during the LBA. He notes (Monroe 2000:101ff,260) that both the palace elites and private entrepreneurs imported and exported goods, and also argues that "Levantine merchants carried out most of Egypt's long-distance commerce." Furthermore, Monroe (2000:361ff) argues that the collapse of the LBA international procurement system was due to an over-reliance on prestige goods by the elites, which lead them to over-stretch their economy, leading to its instability and collapse, which also brought down the elites.

There was also a large amount of intra-regional procurement, as demonstrated by the spread of Chocolate-on-White Ware from two main production centres, in the North Jordan Valley and the Mount Hermon area (Fischer 1999). A further example is the production and distribution of gypsum imitations of Egyptian calcite bowls from a number of production centres, including Jericho, Beth Shean and Pella (Sparks 2002).

Iron Age (1200-540 BC)

The Iron Age is usually divided into IAI (1200-1000 BC) and IAII (1000-540 BC), although there is a basic continuity of material culture between the two (Holladay 1995:372). Towards the end of the LBA, Egyptian power waned in the region, leading to the slow growth in some form of national awareness (Strange 2001:315; Herr and Najjar 2001:340). This led to the growth of the 'kingdoms' of Israel, Philistia, Phoencia, Ammon, Moab and Edom (Herr 1997). The exact status of these polities (kingdoms, tribal kingdoms, tribal confederacies, etc) is currently hotly debated, although many arguments have been advanced in favour of the existence of some form of kingdom (e.g. Holladay 1995; Herr 1997; Blakely 2002). However, a proper consideration of this debate is outside the scope of this thesis, whilst the following points are generally accepted. There was a basic population continuity, with the imperial structure being replaced by a local elite. However, there were dramatic changes in the settlement patterns, with a large number of small sites being established in the Cisjordan hill regions, whilst in Transjordan there was a slow southwards spread of sedentary settlements throughout the Iron Age (Mazar 1992:285f; Herr and Najjar 2001:323). The various polities were regularly involved in struggles to expand their territory, in part to control the overland trade and access routes and so enable their elites to gain increased access to prestige goods (Holladay 1995:372). Towards the end of the IAII, at least parts of the region were conquered by the Assyrian, Egyptian and Babylonian Empires, before the conquest of the Persian Empire, bringing to an end the Iron Age (Herr 1997:117,151,154).

Mazar (1992:300) notes that one of the main differences between the LBA and IAI is the general absence of international trade during the latter period, which only started to reappear during the 11th century BC. This is indicated by the reappearance of Cypriot pottery at such sites as Megiddo and Tel Qasile, but there was much less emphasis on imported luxuries (Mazar 1992:300f; Monroe 2000:365). Only in the IAII was there a return to extensive international and inter-regional exchange, with large quantities of Cypro-Phoenicain ware found on sites in the southern Levant (Barkay 1992:325). There is good evidence for overland procurement systems operating from South Arabia which brought in incense, spices, gold and ivory. These routes passed through the southern Levant to reach the Mediterranean, and could therefore be taxed by the settlements they passed through (Holladay 1995:383; Herr 1997:140). Blakely (2002:50) argues that the tripartite pillared buildings found in Cisjordan in both the late IAI and IAII were constructed precisely to profit from these re-emerging trade routes. Silver hoards have also been found at Eshterra, Ein Gedi and Tel Miqne (Herr 1997:140,159), which Herr (1997:144ff) suggests could have been used as a means of payment for goods. During the IAII, settlements also grew in size and public and monumental architecture were built, in contrast to the IAI (Barkay 1992:329). There is also good evidence for the operation of intra-regional procurement systems, including the large-scale production of wine at Gibeon and olive oil at Tel Miqne (Herr 1997:144,151).

Holladay (1995:389) reports that in the kingdoms of Israel and Judah, the houses in the rural settlements had storage facilities for the surplus of grain, wine, oil, dried fruits and other produce. Holladay (1995:392) therefore concludes that “debts, rents, tithes, and taxes exempted, the harvests of field, vine, orchard, flocks and herds were gathered into the individual *houses*, there to remain until sold, eaten, planted, stolen, or otherwise disposed of”. This therefore implies that the state, religious authorities and private individuals all had the means to exploit this surplus by exchanging it for non-local goods.

Conclusion

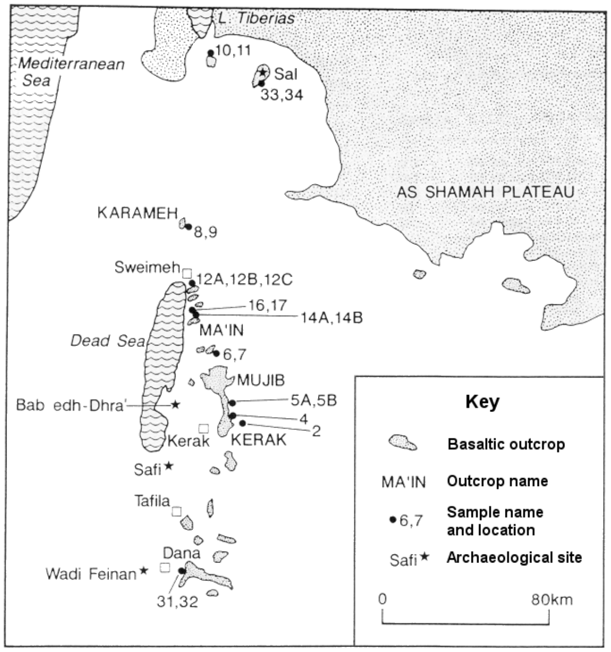
These brief summaries of the periods from which artefacts have been analysed have shown that there were significant differences in how the societies were organised and therefore, most probably, in how basaltic artefacts were manufactured and procured. However, one enduring similarity is the continued intra-regional procurement and use of basaltic artefacts.

Basis of current work

The studies of Philip and Williams-Thorpe (1993 and 2001) form the basis for this study as they were able to demonstrate that the systematic investigation of trace element geochemistry could provide meaningful data which revealed a complex web of procurement systems of basaltic-rock artefacts. These studies showed that this approach had great potential for further work, with this thesis being designed to continue and expand this work. These studies will now be briefly discussed in order to show the current state of investigation and identify those areas where further research is required.

Philip and Williams-Thorpe (1993:54) noted that previous basaltic-rock provenance studies in Transjordan had been hindered by the lack of both archaeological and geological data and so it was necessary to collect new samples. They therefore sampled 16 Chalcolithic and EBI basaltic bowls from 4 different sites in Transjordan and 21 new samples from outcrops in Transjordan (Fig 1.2). All the samples were analysed for trace and some major elements using wavelength-dispersive X-ray fluorescence (WDXRF; see Chapter 3). The analyses of the geological samples were then used to define a number of different fields, with the samples grouped by location. These fields were then used to provenance the archaeological samples (Philip and Williams-Thorpe 1993:54ff). These indicated that the majority of artefacts probably originated from the Kerak flow and showed that the artefacts from the sites in the Wadi Faynan did not come from the nearby Dana flow. The results also showed that the artefacts from Sal probably originated near the site. However, the remaining artefacts could not be definitely assigned, due to a lack of geological data and overlaps in the existing data (Philip and Williams-Thorpe 1993:59).

Fig 1.2: Samples taken by Philip and Williams-Thorpe (1993)



After Philip and Williams-Thorpe (1993:53).

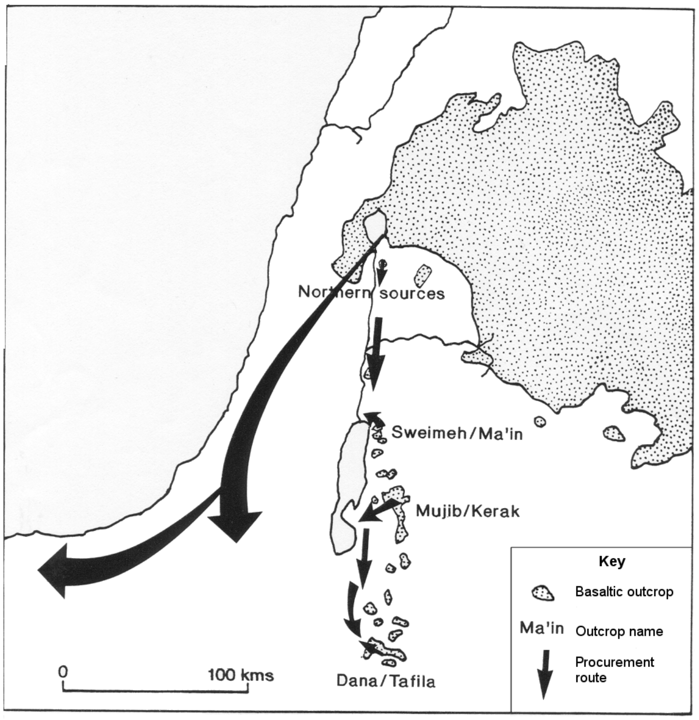
There are, however, a number of problems with this study. First, Philip and Williams-Thorpe (1993:58) present a plot of Nb against Sr, showing the geological fields and where the archaeological samples plot, and also discuss the results of a number of other element ratios. However, in the graph's caption they (ibid.) note that "provenancing is done by considering all analysed elements not only the elements shown on this graph." Although the geochemical data is presented in a table, it is not graphically summarised, making it difficult to properly evaluate their conclusions. Furthermore, too few outcrop samples were analysed to be certain that the chemical variability of the outcrops was accurately assessed (cf. Pearce 1996:82; Chapters 3 and 7). Given the overlapping or near-overlapping nature of the geological fields, none of the archaeological samples can be regarded as securely provenanced to an individual outcrop.

Philip and Williams-Thorpe (1993:61f) conclude that the most likely mechanism for the procurement of the basaltic bowls was by pastoralists bringing basalt to the sites as part of their yearly round. They furthermore suggest that this is the most likely mechanism for basaltic artefacts being procured by the sites in southern Cisjordan, as this is also the probable mechanism for the procurement of copper from the Wadi Faynan.

However, Philip and Williams-Thorpe (1993:62) also note that both these suggestions are somewhat speculative in nature and so require further work to substantiate them. They therefore expanded their previous study by collecting another 50 archaeological samples, including both bowls and grinders from both Jordan and Israel, and another 8 geological samples from the North Jordan Valley (Philip and Williams-Thorpe 2001). Of these samples, 35 of the artefacts and all the geological samples were analysed, again using XRF, and were added to the database of previous analyses. Philip and Williams-Thorpe (2001:15) report that the remaining 15 archaeological samples (30%) were too small to analyse, but argue that those analysed were "visually representative" of the assemblages.

Philip and Williams-Thorpe (2001:18) again used trace element ratios, especially Y/Zr, to provenance the archaeological samples. Using these, they were able to demonstrate that sites in southern Transjordan used the most proximal sources for grinders, but another source (probably Kerak) for bowls. They were also able to show that sites in southern Israel, and the Egyptian site of Maadi, did not obtain their basalt from the closest sources across the Dead Sea, as they had previously suggested. Instead, the basalt probably originated from the north of the region, thereby revealing a more complex picture than was originally assumed (Fig 1.3).

Fig 1.3: Routes of Chalcolithic/EBI procurement systems



After Philip and Williams-Thorpe (2001:25).

However, the study of Philip and Williams-Thorpe (2001) also has a number of limitations. As the authors concede (Philip and Williams-Thorpe 2001:27), even with the new outcrop samples there is still incomplete outcrop data, meaning that the provenance of artefacts cannot be regarded as completely secure. Furthermore, the new geological data revealed that there was greater chemical variability in individual outcrops than was revealed by the previous study. This both increased the overlaps between the outcrop fields and raises the possibility, shown to be correct by Rowan (1998; discussed in Chapter 2), that additional outcrop samples could further increase the geochemical variability. These factors therefore imply that an artefact cannot be definitely assigned to a single source. It is also important to stress that the procurement patterns determined for basalt artefacts in the studies only relate to those artefacts which have actually been analysed. Given the relatively small sample-size it is difficult to determine how the results relate to the artefacts which have not been analysed (cf. Philip and Williams-Thorpe 2001:26f). This therefore points to the need for such analyses to be conducted on a representative sample of artefacts to gain a more complete understanding of how the procurement systems operated.

Conclusion

The studies of Philip and Williams-Thorpe, despite their limitations, have demonstrated the complexity of the basaltic procurement systems of the southern Levant during the Chalcolithic and EBI. As they (Philip and Williams-Thorpe 2001:27) note, there are also a number of ways in which these studies could be expanded. They argue that a computerised database of analyses should be established to aid future research and that more geological samples are necessary to enable more accurate provenancing of basalt artefacts. They also argue that it is necessary to analyse a larger numbers of artefacts in order to assess the differences in procurement strategies, both synchronically (between different artefact types) and diachronically.

This critique of Philip and Williams-Thorpe's studies has also demonstrated that the technique of XRF cannot provide geochemical data sensitive enough to conclusively provenance the artefacts. These studies, along with those reviewed in Chapter 2, have demonstrated the complex nature of basaltic procurement systems, but have yet to fully reveal the level of complexity. Finally, although a plausible procurement mechanism has been suggested by Philip and Williams-Thorpe it has not been properly demonstrated. Philip and Williams-Thorpe (2001:27) conclude by stating that "the direction of research along such lines would allow the realisation of the full potential of basalt as an indicator of interaction between human groups." Ebeling (2001:54), in her study on cultic ground stone artefacts (discussed in Chapter 6), calls for future research on ground stone artefacts to combine iconographic and textual sources, ethnographic accounts, experimental work and scientific analysis in order to properly understand their role in past societies. It is the aim of this thesis to attempt to use these various lines of evidence to realise at least some of the potential of the analysis of basaltic artefacts.

Structure of thesis

To adequately provenance basaltic artefacts, it is necessary to have an understanding of the geology of the region and accepted geological approaches to analysing igneous rocks. To properly understand the results of the provenance study it is also necessary to have an understanding of the wider archaeological context in which the basaltic artefacts were procured. Previous provenance studies can also provide useful data and suggest different approaches. Therefore, Chapter 2 is a review of a selection of provenance studies. This is followed by a review of the relevant geological concepts (Chapter 3) and a summary of the existing geological data on mafic outcrops in the southern Levant (Chapter 4). Chapter 5 examines existing theoretical approaches to the examination of provenance studies and procurement systems, while Chapter 6 places the basaltic artefacts into their wider archaeological context. Chapter 7 discusses the creation of a database of the geochemical data and its subsequent analysis. The provenance of the artefacts is then identified as accurately as the data allows. Chapter 8 attempts to produce an understanding of how the procurement systems operated and how they related to the society in which they existed. Chapter 9 discusses what conclusions can be drawn from this analysis and what future work is required.

Chapter 2: Previous provenance studies

"Stealing from one author is plagiarism, but from many is research."
(P. Bahn Bluff your way in archaeology*, 1989:46)*

As is indicated by the opening quote, it is important to examine some of the provenance studies of stone artefacts which have already been undertaken. Before examining provenance studies of mafic artefacts in the Near East, provenance studies of Neolithic stone axes in the British Isles and of obsidian artefacts will be reviewed. The approaches and procedures undertaken by these well-established studies should provide useful information for the present study, as will an understanding of their achievements and limitations.

Therefore, only the main points and conclusions of individual papers will be discussed below, although more specific references are made where relevant throughout the thesis. It should also be noted that this review is not exhaustive, but simply presents some of the main, varied approaches taken in provenance studies. The main analytical techniques used in the studies below are examined in Chapter 3. As discussed in Chapter 1, the term 'basaltic' has been used when discussing the studies below, except in direct quotations and where it is clear that the term 'basalt' refers to the specific rock type.

Provenance studies

Neolithic axes in the British Isles

During the British Neolithic, stone axes were manufactured from a variety of igneous rocks, which were then distributed hundreds of kilometres from their source (Bradley and Edmonds 1993:18,39). These sources have been identified using petrographic analysis (the examination of the rock's minerals under a microscope; see Chapter 3), with the most important being in Cornwall, North Wales, Ulster and Cumbria (op. cit., p.39). However, Bradley and Edmonds (1993:3f) comment that although this petrographic analysis has been undertaken for about 50 years, it is only recently that this data was actually used to examine the exchange systems which produced the observed distributions of stone axes.

In an attempt to understand these processes, Bradley and Edmonds (1993:4) undertook fieldwork on the production sites in the Great Langdale, Cumbria and attempted to integrate this new data with "one of the largest bodies of data in prehistoric archaeology". The Great Langdale production sites were situated in the Cumbrian uplands, some distance from the populated lowlands (op. cit., pp.201f). Bradley and Edmonds (1993:201) were able to identify two phases of production, with a shift from a relatively informal system towards a more regularised, controlled system occurring around 3300 BC. They note (op. cit., pp.204f) that this corresponds with changes observed in both the distribution of stone axes and in other spheres of social life. After c.3300 BC the range over which stone axes were distributed contracted, suggesting that exchange had become more competitive. Artefact types traditionally manufactured from one raw material were emulated using different materials, and, in certain areas, they argue that “the products of one source area may have supplanted those of another” (Bradley and Edmonds 1993:204).

Bradley and Edmonds (1993:205f) also contend that the procurement systems of igneous stone axes during the British Neolithic were linked to social factors including communication and control. They argue that the sources used possibly became important because of their distant, difficult locations and that the material was not selected primarily for its physical, mechanical or functional properties. This is shown by the study of Bradley et al. (1992) who examined the tensile strength of the rock types used to manufacture axes. They were able to show that the choice of both quarry location and rock type only had a limited influence on these choices, with rock types with higher tensile strengths not always being preferentially chosen and with quarry locations not preferentially exploiting rock with a higher tensile strength. These observations lead Bradley et al. (1992) to argue that social factors were important in the choices concerning raw material exploitation and distribution.

Bradley and Edmonds (1993:206) also argue that the number of axes produced shows “the effectiveness of [Cumbrian] axes in social transactions was maintained over a considerable period.” They (ibid.) suggest that this is partially due to the marginal nature of the source and note that there are many questions which have not been answered, including determining how many axes were produced, what they were exchanged for, and how their value and associations changed with context. Some or all of these ideas and questions may also be useful for the understanding of basaltic-rock procurement systems in the southern Levant.

Obsidian artefacts

Obsidian is a volcanic glass, formed by the quick cooling of a magma. It is therefore durable and can be flaked to produce a cutting edge, as well as being easily recognisable. These properties made it valued as a raw material by past societies, whilst its chemical homogeneity and restricted availability from a few sources made it useful for provenancing studies. It was therefore one of the first rock types to be analysed for this purpose (Williams-Thorpe 1995:217f).

Obsidian provenancing in Europe and the Near East has revealed the existence of four generally self-contained, non-overlapping “exchange regions”, namely the Western Mediterranean, the Aegean, Central and Eastern Europe, and the Eastern Mediterranean and Near East (Williams-Thorpe 1995:235). Without provenancing, this would not have been recognised, whilst the analysis of obsidian from individual sites has frequently indicated contacts for which no other evidence exists (op. cit., p.234).

Williams-Thorpe (1995:235) argues that obsidian provenancing has been one of the success stories both of archaeometry and archaeology, as it can be successfully and routinely sourced to its original outcrops, which has indicated previously unknown contacts. However, she (op. cit., p.236) also notes that obsidian provenancing is limited by the fact that it is not routinely undertaken as part of the post-excavation analysis of sites. She (ibid.) argues that until this is the case, the full potential of provenance studies will not be fulfilled. There is the further problem that the provenancing does not indicate how or why the obsidian was procured (Williams-Thorpe 1995:235).

These points are borne out in the collections of papers edited by Shackley (1998) and Cauvin et al. (1998), which provide a useful indication of the current state of work. Shackley (1998a:1f) reports that the papers were collected to both present the most recent advances in obsidian analysis and to communicate these advances to archaeologists. A similar division is found in Cauvin et al. (1998). However, in both these collections, only a minority of papers are primarily concerned with presenting results from provenance studies. More are concerned with reporting experimental results designed to improve the efficiency of analytical techniques. In Cauvin et al. (1998), several papers are primarily concerned with presenting relevant geological data, which Renfrew (1998:5) argues is a vital preliminary step for sourcing artefacts. In Shackley (1998), several papers also present strategies designed to improve the results of provenance studies, primarily using examples from America. This shows that, despite the amount of work that has been undertaken on obsidian provenancing, improvements are still required to adequately source all the artefacts. This, of course, has implications for attempts to provenance basaltic artefacts. These papers will therefore be discussed further in Chapter 5.

In Shackley (1998), only two papers are primarily concerned with presenting results from provenance studies. Summerhayes et al. (1998) provenanced obsidian artefacts found in islands off Papua New Guinea and concluded that, although the main factor determining which source was used was proximity to the site, more distant sources were also exploited (Summerhayes et al. 1998:149ff). They speculate that this was probably due to a desire to maintain social contact with other groups (Summerhayes et al. 1998:153). However, there is little attempt to relate the provenance results to theories of exchange, and so little understanding of the behaviour of the groups involved is gained. This is recognised by Tykot (1998:78f) who notes that he was unable to properly explain how the observed distribution of artefacts related to past human behaviour, or determine which exchange mechanisms operated. He therefore calls for theoretical models to be developed, which take into account not just the procurement and movement of raw materials, but also the manufacturing process and how and why the finished artefacts were used and discarded.

Tykot (1998) used ICP-MS (inductively coupled plasma-mass spectrometry; see Chapter 3) to analyse the Neolithic sources of obsidian in the western Mediterranean, all of which are situated on islands, as well as more than 700 artefacts from France and Italy. Using this data he argues (Tykot 1998:68ff) that the distribution patterns vary spatially and temporally in ways which cannot be explained by accessibility or functionality, as, especially, on the islands themselves the higher quality sources are not preferentially used. This large database also confirms Williams-Thorpe's (1995:235) observation of a closed western Mediterranean obsidian exchange system, which Tykot (1998:69) argues must have been for social reasons.

In Cauvin et al. (1998), although eight papers are directly concerned with obsidian artefacts, the majority of these are concerned with placing the artefacts into their wider archaeological context. There is again little attempt to explain how the obsidian was procured, although Cauvin (1998a:268) and Cauvin and Chataigner (1998:349) argue that mobile pastoralists were an important procurement mechanism. Indeed, in her conclusion, Cauvin (1998b:383) argues that provenance work on obsidian has only just begun, despite 30 years of study. Like Tykot, she also argues that the important questions about the social significance of obsidian and of the people who traded it have not yet been answered. These problems will be discussed further in Chapter 5.

Another important development in the study of obsidian artefacts has been the study of the Central Anatolian sources and the identification of a number of workshops (Balkan-Atli et al. 1999). These workshops were identified as part of a multi-disciplinary study, investigating the geology and archaeology of the area, and geochemically analysing obsidian samples (Balkan-Atli et al. 1999:134f). Two of the main workshops studied are those of Kayirli and Kaletepe, both of which date to the PPNB (Binder and Balkan-Atli 2001:1). However, despite being contemporaneous and in only 2 km from one another, the obsidian artefacts found on these sites are very different in form (Binder and Balkan-Atli 2001:15), which they (ibid.) interpret as the co-existence of two different cultures.

This interpretation is strengthened as, unlike the majority of the artefact types found at Kayirli, the Kaletepe-style artefacts are not found anywhere else in Central Anatolia, but do match obsidian artefacts found in Cyprus and the Levant (Binder and Balkan-Atli 2001:15). Binder (2002:81) therefore argues that Kaletepe was visited seasonally by expeditions from the Levant. These studies show the importance of identifying and properly examining artefact workshops, which can provide information not available using other sources, whether the artefacts were produced from obsidian or basaltic rock.

Another development in obsidian provenancing is the move towards non-destructive analytical techniques, as these enable artefacts to be analysed that are too valuable to be destroyed

(Gratuze 1999:869). Hughes (1994:265ff) used XRF as a non-destructive technique and was able to show that the analysis of powders and flakes produced comparable results. He (Hughes 1994:267) used these analyses to show that the important Casa Diablo obsidian source (in California) was not homogenous, as originally thought, but consists of two chemically distinct sub-sources. Hughes (1994:263) notes that the Casa Diablo source was assumed to be homogenous on the basis of very few samples. He (Hughes 1994:269) therefore argues that his study has important implications for other obsidian provenance studies, as a large number of samples are required to identify intra-sources variability, and until these have been analysed, source homogeneity cannot be assumed. This may also have implications for the provenancing of basaltic artefacts.

Gratuze (1999:869) was also concerned with using a non-destructive technique, but argued that LA-ICP-MS (laser ablation-inductively coupled plasma-mass spectrometry; see Chapter 3) should be used, as non-destructive XRF can be limited by surface weathering or by the shape of the artefact. To demonstrate this, Gratuze (1999:877) analysed geological samples from 21 obsidian outcrops, in Anatolia and the Aegean, and 43 obsidian artefacts found on sites in Anatolia, Cyprus and the northern Levant. The results for the XRF and LA-ICP-MS were also comparable, with between 5 and 10% relative difference (op. cit., p.876).

Gratuze (1999:876) argues that the most effective method for provenancing the artefacts was using two element or element-ratio plots, especially Y/Zr against Nb/Zr and Ba against Sr. He argues that these can be used to distinguish between virtually all of the sources, although some sources do plot close together, raising the possibility that with more samples some of the source plots will overlap. Using these plots, Gratuze (1999:877) was able to show that all the artefacts originated from a small number of Anatolian sources, showing that the Cyprus-Anatolia links "are more ancient and more important than was first believed".

Gratuze (1999:877) therefore concludes that LA-ICP-MS should be the analytical technique of choice as it is fast and virtually non-destructive. He also notes that the main problem, an absence of suitable reference standards, has the potential to be quickly overcome. However, although discussed in the main text, Gratuze does not mention in the conclusion a more serious problem, which is that artefacts cannot currently be longer than 5 cm or thicker than 1.5 cm to fit in the sample cell (Gratuze 1999:870). Although he (ibid.) notes that "the use of larger cells is under study", this is currently a significant limitation and one that may not be fully resolved. This is therefore a major limitation to this analytical technique.

This brief examination of current work in two important, long established, fields of stone artefact provenancing have indicated potential directions and possible limitations that may also apply to the provenancing of basaltic artefacts. Most importantly, they have shown the need to relate the observed distributions of artefacts to social factors. Neither the physical properties of the raw material or its location determined its selection, although more remote, inaccessible locations were sometime preferred over local sources. The studies also showed that a large database of samples was required to adequately source the artefacts. With this background, previous attempts to provenance basaltic artefacts in the Near East will now be discussed in more detail.

Basaltic artefacts in the Near East

Potts (1989) examined basaltic bowls found in south Mesopotamia from the 3rd millennium BC and relied mainly on the textual inscriptions found on some of the bowls to determine their provenance. He (Potts 1989:123) notes that most stone found on southern Mesopotamian sites is imported, as only limestone is available locally. Potts (ibid.) therefore argues that an understanding of the origin of the stone is important to understand early Mesopotamian exchange, but notes that there have been few attempts at provenancing rock artefacts.

However, Potts does not attempt to undertake a provenance study as such, but rather examines the vessels which have inscriptions, as a direct way of determining their provenance. He notes (Potts 1989:124) that most of these inscriptions celebrate foreign conquests and describe the artefacts as “booty”. However, as many of the vessels do not have inscriptions, Potts (1989:142, 147f) argues that there was probably more than one mode of procurement, and suggests that gift-giving and tribute were possibly important (although this is by no means certain) and that diplomatic pressure was important, as is shown by the royal correspondence. Potts (1989:144ff) further argues that there is little evidence for the direct trade of stone vessels from their probable source in Iran to south Mesopotamia, although he acknowledges that it is possible that some vessels were traded via the Gulf.

Potts (1989:142ff) also notes that the basaltic vessels were not imported due to a shortage of stone, but were, rather, desired for aesthetic reasons, as they were made of an obviously exotic, hard, dark-coloured rock. Furthermore, he argues that the context was important, as they were objects of prestige, rather than commercially valuable. The important aspect of the booty vessels was that they had been captured from opposing elites, thereby acquiring value through their associations with a conquest, rather than being intrinsically valuable.

This study is useful as it attempts to both provenance the vessels and determine the mechanism by which they were procured. It is somewhat limited in nature, as the focus was on the inscriptions rather than locating the geological origin of the vessels, but it does provide important information on this aspect of Mesopotamian procurement. The study illustrates that procurement is not just a single event, and that artefacts may have been procured several different times by different mechanisms, before finally being deposited. Potts (1989:148) concludes:

> "During those periods for which both archaeological and textual evidence is available, a complex picture emerges in which political and diplomatic factors may be seen to have been intimately linked both to the perception of economic needs and to the means employed to satisfy them."

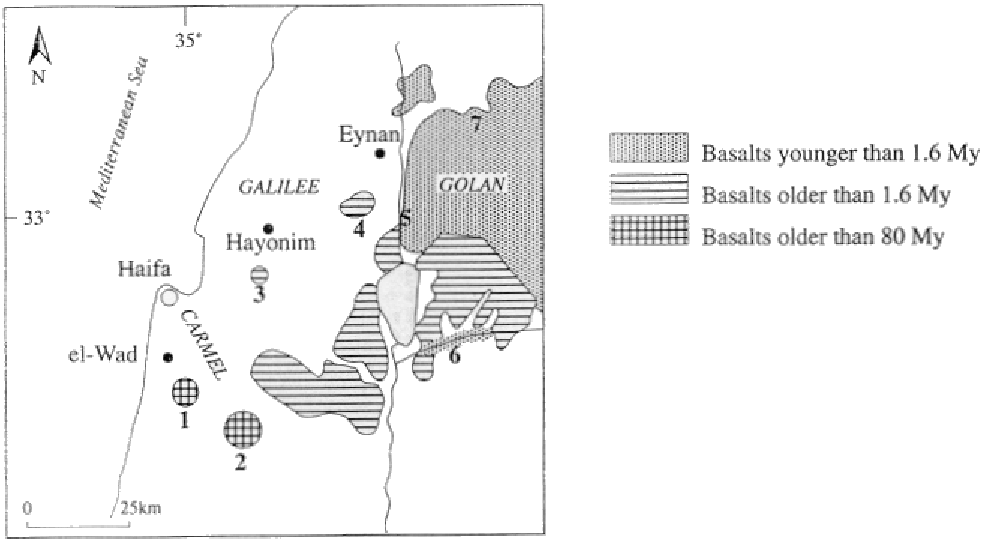
This implies that it is important not to consider economic factors in isolation, while this approach can probably be more broadly applied to different periods and regions. However, such studies are obviously limited to situations where inscriptions contain this sort of information.

Some of the first attempts to provenance basaltic artefacts in the southern Levant also used petrographic analysis. However, this met with only limited success. Amiran and Porat (1984:13f) examined a small number of artefacts and were able to rule out the southern Cisjordan outcrops, but were unable to determine whether the source was the Galilee, the Golan, or other Transjordanian outcrops. They therefore called for trace element analysis of the rocks to locate the source more precisely.

Hunt (1991:220) petrographically analysed six artefacts from Late Bronze Age Hazor, situated in the basaltic fields in the north of Israel. All the artefacts were manufactured from the same source, which was a fine-grained basalt which only contained olivine phenocrysts, unlike the local outcrops which also contained augite phenocrysts (Hunt 1991:220,225f; see Chapter 3). However, although this study was able to show that the source of the artefacts was non-local, it was not able to pinpoint its actual location. These two studies show that there are not enough variations in the mineralogy between different outcrops in the southern Levant to enable a single outcrop to be definitely identified as the source of the artefact. Furthermore, virtually all the artefacts were manufactured from aphanitic (fine-grained) basalt, making the identification of sources impossible without geochemical analysis. As will be discussed in Chapter 3, a further limitation of petrographic analysis is the large sample size required for a thin-section to be cut, limiting the number of artefacts that could be analysed using this technique.

A very different approach was taken by Weinstein-Evron et al. (1995 and 1999). In these studies, Weinstein-Evron et al. use potassium-argon (K-Ar) dating to provenance Epipalaeolithic artefacts from the southern Levant. Weinstein-Evron et al. (1995:38f) report on the K-Ar dating of 5 artefacts, and 4 geological samples from the Mount Carmel area (Fig 2.1). The basaltic rocks used to manufacture the artefacts dated from 3.7±0.2 Ma to <0.25 Ma, whilst the nearby basaltic outcrops dated from 88.0±1.8 Ma to 77.6±1.6 Ma. They note that the nearest basaltic outcrops with similar ages are those in the Galilee region, over 60 km away. However, Weinstein-Evron et al. (1995:39) argue that the nearest outcrops where rocks dating from both 3.7 Ma and 0.25 Ma can be found in a limited area are located in the Golan, approximately 80-100 km from the sites. As Weinstein-Evron et al. (1995:39f) note, this study demonstrates the existence of long-distance procurement during the Epipalaeolithic and also demonstrates that the groups ignored the basaltic rock which was locally available, in favour of the imported rock. However, they do not attempt to explain why this was the case or how the basaltic rock was procured, beyond suggesting that some form of exchange mechanism existed.

Fig 2.1: Date of Galilee and Golan basaltic outcrops



After Weinstein-Evron et al. (1999:268).

Weinstein-Evron et al. (1999:267) attempt to test their hypothesis of a manufacturing site in the Golan by K-Ar dating artefacts from two other important Natufian sites, namely those of Hayonim and Eynan (Fig 2.1; Eynan is more usually known as ‘Ain Mallaha). These sites are both situated in the Galilee area, with Hayonim situated in western Galilee, 6 km from nearest basaltic outcrop and 30 km from the major basaltic outcrops of the eastern Galilee. ‘Ain Mallaha is situated on the eastern slopes of Upper Galilee, with basaltic outcrops nearby and major outcrops found within 5 km of the site (Weinstein-Evron et al. 1999:269).

Weinstein-Evron et al. (1999:270) report that 7 basaltic artefacts from Hayonim were K-Ar dated to between 6.4±0.2 Ma and 0.5±0.6 Ma, and that 11 basaltic artefacts were K-Ar dated from ‘Ain Mallaha which dated to between 3.1±0.1 Ma and <1.0 Ma. These date ranges are therefore similar to the date ranges of the El-Wad artefacts and so they (Weinstein-Evron et al. 1999:271) conclude that the Golan was probably the source of the basaltic rock of the artefacts from all the sites studied, despite the fact that basaltic rock was available from sources closer to the sites. Weinstein-Evron et al. (1999:271f) also note that there is no evidence of on-site manufacturing and they therefore conclude that the basaltic artefacts were probably manufactured near the source and transported as completed artefacts. They therefore argue that this is possibly evidence of incipient craft specialisation, but note that the nature of the long-distance contacts and the underlying social structures have yet to be determined.

One problem with K-Ar dating is that some of the argon may be released during weathering or hydrothermal alteration, thereby giving erroneous dates (Aitken 1990:122), which Laws (1997:9) notes is a serious problem with K-Ar dates in the southern Levant. Furthermore, given the potential for differential weathering between the geological and archaeological samples it is therefore questionable whether artefacts can be provenanced using this method. This problem can be partially addressed by using argon-argon (Ar-Ar) dating, where it is possible to identify unreliable dates (Aitken 1990:122f).

However, whether K-Ar or Ar-Ar dating were used, neither would be able to demonstrate conclusively that the Golan is the source of the artefacts, as there are a number of different outcrops over a wide area with the same ages. This problem was noted by Amiran and Porat (1984:14) who commented that K-Ar ages (and by implication, Ar-Ar ages) are "capable of indicating the general source region of a given basalt vessel, but not the exact locale within that region." The technique of argon dating is therefore only of limited use in provenance studies. Weinstein-Evron et al. (1999:271) acknowledge this, but argue that:

> "detailed geochemical or petrographic studies are rare, and they are far from covering the entire range of basalt exposures in the region. Until more such data are available, and given the promising results of our provenance-determining studies based on K/Ar dating, we have chosen to expand upon our earlier work."

There is clearly a need to undertake the detailed geochemical work called for by the authors.

A number of studies have attempted to provenance basaltic artefacts from Cyprus and the Eastern Mediterranean using geochemistry. Xenophontos et al. (1988) attempted to provenance 18 LBA and Roman basaltic millstones from Cyprus. The majority of these could not originate from Cyprus itself, as there are no comparable outcrops on the island (Xenophontos et al. 1988:169). Thirty-five geological samples were therefore taken from outcrops throughout the Levant, as these were the nearest potential sources for the basaltic rock. These were analysed for major and minor elements, using atomic absorption spectrometry (AAS), and for trace elements, using XRF (Xenophontos et al. 1988:173). The authors (ibid.) report that standards were used to check the accuracy and precision of the data, although these results are not reported. The new data were combined with previous analyses of samples from both Cyprus and the Aegean (ibid.), which enabled Xenophontos et al. (1988:176) to conclude that the Levantine basaltic rocks relate to a within-plate rift, whilst the Aegean basaltic rocks relate to a plate subduction zone and therefore have different geochemical signatures, allowing the different areas to be distinguished. Xenophontos et al. (ibid.) also note that the Cypriot outcrops are older with a higher degree of alteration, again allowing them to be distinguished.

Furthermore, Xenophontos et al. (1988:178) noted that the concentrations of the major elements can be affected by weathering, whilst certain trace elements are not generally affected, and so attempted to provenance the basaltic artefacts by using plots of these trace elements (See Fig 2.2, below, for an example). These will be discussed further in Chapter 3. Using these plots Xenophontos et al. (1988:180ff) claim that the LBA artefacts originate from the Levant, as do some of the Roman artefacts, whilst the rest originate from the Aegean. They go on to claim that the Levantine artefacts were probably manufactured around the Sea of Galilee, as this is the nearest place to Cyprus were basaltic rock is available, and then were transported from the nearby major settlements (Beth Shean during the LBA, and Tell Abu Hawam during the Roman period). However, this is speculative at best, especially as Xenophontos et al. (1988:181) admit that the "chemical characteristics do not allow distinction between Syrian, Palestinian and Jordanian sources." Furthermore, they do not seek to explain why there was demand for basaltic artefacts in the LBA, whilst previous periods had used the locally available sedimentary and igneous (diabase and gabbro) rocks (Xenophontos et al. 1988:169).

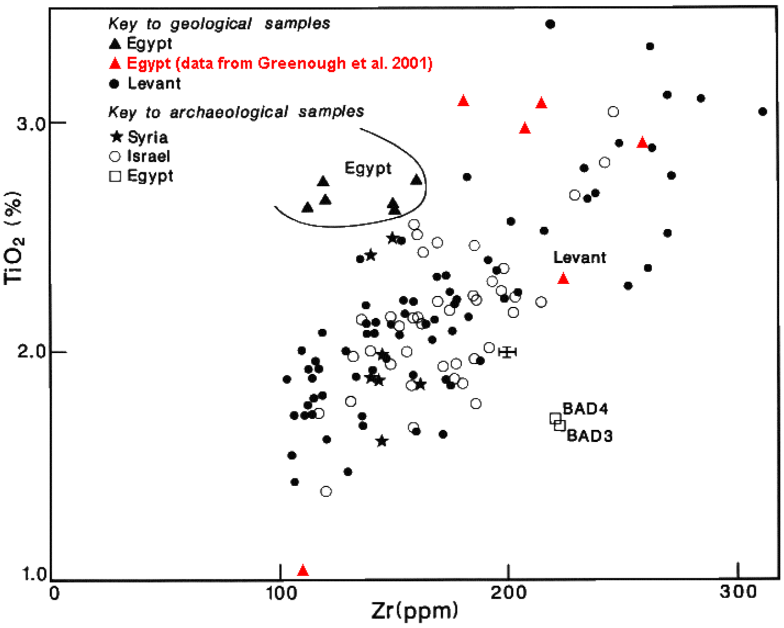
This study was expanded by Williams-Thorpe et al. (1991), who examined a further 45 LBA, Hellenistic and Roman millstones and a further 21 geological samples from the Levant, mostly from around the Sea of Galilee. The samples were analysed using XRF for both major and trace elements. Williams-Thorpe et al. (1991:37) note that other potential basaltic sources, most notably Cyprus, the Aegean and Anatolia already have a large number of geological samples, and so new samples were not analysed. However, they also note that very little work had been undertaken on characterising Egyptian basaltic outcrops.

Williams-Thorpe et al. (1991:28) divided the millstones into four main types, two of which (hopper-rubbers and rotary querns) are rarely found on Cyprus, one of which (saddle querns) was the dominant LBA type and one of which (Pompeian mills) was the dominant Roman type. Provenance of these artefacts was again attempted primarily using trace element plots. Williams-Thorpe et al. (1991:39; 1993:281) note that it is possible to distinguish volcanic arc samples (such as basaltic rock from the Aegean and Anatolia) from within-plate samples (such as basaltic rock from the Levant and Egypt) using their differing trace element ratios (discussed in Chapter 3). For the 37 artefacts analysed for trace elements, Williams-Thorpe et al. (1991:39) were able to use these ratios to determine that 6 artefacts originated from a volcanic arc source, 29 artefacts originated from a within-plate source, and 2 artefacts were from a Cypriot source. They (Williams-Thorpe et al. 1991:55) also note that there is a general correlation between the geochemical groupings and the artefact types.

Williams-Thorpe et al. (1991:45ff) then attempted to refine these broad groupings by using further trace element ratios. For the volcanic arc sources, they argued (Williams-Thorpe et al. 1991:45) that the Sr/Ba ratio provides "almost complete discrimination" between Anatolia and the Aegean, although there is still some overlap. On this plot most of the samples fall inside the Aegean field and outside the Anatolian, although one sample falls within the overlapping area. Furthermore, Williams-Thorpe et al. (1991:48) also argue that the Th/Rb plot separates many of the individual Aegean island sources. However, there is a considerable amount of overlap between the fields, as well as a number of artefacts which fall outside them, thereby suggesting there is even more variability than revealed by the available geological samples.

For the within-plate samples, Williams-Thorpe et al. (1991:49ff) first attempted to discriminate between Egypt and the Levant, by using the TiO_2/Zr ratio (Fig 2.2), on which the Egyptian samples plot in a tight cluster, whereas the Levant sources plot as a dispersed scatter. However, there are only a small number of geological samples from Egypt and some of the Levantine samples, both artefactual and geological, plot near the Egyptian samples. Therefore, when the analyses of Egyptian outcrops summarised in Greenough et al. (2001; discussed below), are plotted on this chart (shown as red triangles in Fig 2.2) it can be seen that it is considerably more difficult to discriminate between Egypt and the Levant using this ratio.

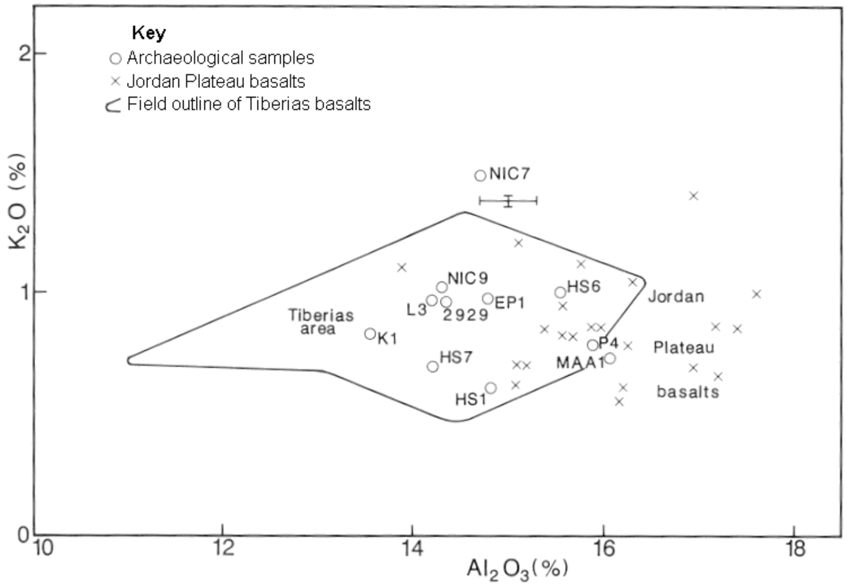
Fig 2.2: TiO_2/Zr plot for Egypt and the Levant



After Williams-Thorpe and Thorpe (1993:294).

Furthermore, Williams-Thorpe et al. (1991:51) note that the Levantine samples are very difficult to provenance more specifically. They attempted to source the artefacts using plots of Nb/Ni and TiO_2/Fe_2O_3, which show that a number of different outcrops were used to manufacture the artefacts, although not all of the artefacts plot within the known outcrop fields. Furthermore, they also note that these plots can only partially discriminate between geological sources. However, they (ibid.) argue that two of the samples were probably from North Syria, with most of the artefacts probably originating from the Jordan plateau or the Tiberias region. Williams-Thorpe et al. (ibid.) also attempt, using a plot of K_2O/Al_2O_3 (Fig 2.3), to discriminate between these two regions and argue that it is more probable that the samples originated from the Tiberias region. However, this claim is somewhat contentious, as the archaeological samples (shown as circles) lie between the main Jordanian field and Jordanian outliers (all shown as crosses), whilst the Tiberias field (shown only as an outline) is difficult to evaluate, as the geological samples which form this field are not plotted, for clarity.

Fig 2.3: K_2O/Al_2O_3 plot for the southern Levant



After Williams-Thorpe et al. (1991:54).

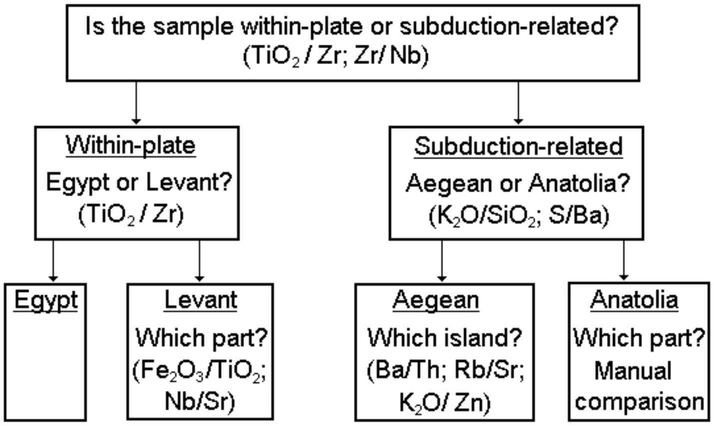
Williams-Thorpe et al. (1991:55) therefore conclude that the LBA basaltic artefacts were produced at a number of different locations, which, they argue, shows there was no centralised production. For the Pompeian-style millstones, Williams-Thorpe et al. (ibid.) note that 13 of these samples were produced from the same outcrop, probably near Tiberias, whilst 5 were produced from two sources in northern Syria. They argue that this is evidence of centralised production, which is strengthened by the fact that all the Hellenistic/Roman hopper-rubbers were produced from the same source, probably on the island of Nisyros. However, Williams-Thorpe et al. do not consider why the imports started in the LBA and why centralised production operated during the Roman period. Therefore, although this study was a useful start to the provenancing of Cypriot millstones, it was limited as it was not able to discriminate between individual outcrops and was not able to identify how or why the procurement system operated.

Williams-Thorpe and Thorpe (1993) further expanded this study by analysing, again using XRF, a further 69 millstones from the Neolithic to the Roman period, mostly from Israel and Anatolia.

These artefacts were again divided into the four broad categories used by Williams-Thorpe et al. (1991). Based on previous work, Williams-Thorpe and Thorpe (1993:281) present a flow chart which can be used to provenance the artefacts (Fig 2.4). This presents a number of different trace element ratios which allows the artefacts to be assigned to their most probable source. Again, there are problems with overlaps or very close boundaries in some of the element ratios, which may cause individual assignments to be altered with more geological samples, but the general conclusions seem to be fairly secure. Overall, Williams-Thorpe and Thorpe (1993:292) conclude that these provenance studies reveal:

> "the increasing complexity and extent of the millstone trade in the eastern Mediterranean area, from the limited traffic of the prehistoric period to complex and overlapping distributions from ten different source areas during the second half of the 1st millennium BC and in the Roman period."

Fig 2.4: Flow chart for geochemical provenancing



After Williams-Thorpe and Thorpe (1993:281).

More specifically, Williams-Thorpe and Thorpe (1993:292) conclude that there was inter-island millstone trade in the Aegean during the Neolithic, and that millstones were brought from the Levant to Cyprus during the Bronze Age. They argue (op cit., pp.292f) that the well-made, thin millstones of vesicular basalt were more highly valued than those made from the locally available rocks and also suggest that their import may have been facilitated by the intensification of metal-working and ceramic exports. They (op cit. p.293) also note that there is no evidence for specialisation or standardisation at the production sites during this period.

However, Williams-Thorpe and Thorpe (1993:293) note that between c.600 BC and the early Roman period there was a dramatic change in some parts of the Mediterranean, with Aegean millstones being transported over 800 km from their sources. Nonetheless, they (ibid.) conclude, unlike the rest of the eastern Mediterranean, that "the Levant remained self-sufficient in millstone production", both in this period and during the later Roman period (op cit. pp.293f). Williams-Thorpe and Thorpe (1993:294) also note that there was some specialisation in the southern Levant during the later Roman period, with most of the millstones exported to Cyprus being produced from a single outcrop. However, this specialisation was limited, as five outcrops were used to produce Pompeian mills and a further three were used for rotary querns, most of which were different from the sources exploited during the Bronze Age (op cit. p.296).

A similar, although considerably more limited, study was undertaken by Rowan (1998) as part of his unpublished PhD thesis. Rowan analysed 14 basaltic vessels from 11 different sites in the southern Levant and also 19 geological samples using inductively-coupled plasma atomic emission spectrometry (ICP-AES) to analyse major and trace elements, but also using Rb/Sr isotopic analysis. Unfortunately, Rowan (1998:311) did not have the ICP-AES data on the artefacts when completing his thesis, meaning that his provenance study had to rely exclusively on the Rb and Sr analysis. A further problem is that, as will be shown in Chapters 3 and 7, Rowan's data does not include some of the more useful elements for provenance studies, making it impossible to integrate with the other data-sets. Furthermore, Rowan (1998:314) admits that this database was too small to enable the definite sourcing of the artefacts, and it seems that he is more concerned with demonstrating that the provenancing technique used was valid, rather than attempting a comprehensive provenance study of the artefacts. This observation is strengthened by the uneven distribution of the 19 geological samples analysed, with all of the geological samples taken from Transjordanian locations, whilst 11 of the artefactual samples were from Cisjordanian sites, some of which were closer to the Galilee outcrops than the Transjordanian outcrops.

Despite these limitations, Rowan (1998:314) argues that the data is useful as it excludes certain flows, which he attempts to show by presenting plots of Rb/Sr and Rb against $^{87}Sr/^{86}Sr$, which show that the majority of the samples form an overlapping group, with a small number of outliers. From this Rowan (1998:315) concludes that a number of flows can be excluded from consideration when attempting to provenance the basaltic-rock artefacts. However, this is problematic, as the limited number of samples may not fully reflect the range of geochemical variability of the outcrop. This is shown in Table 2.1, which compares Rowan's geochemical data with that of Philip and Williams-Thorpe (1993:57), who present samples from the same outcrops as Rowan (discussed in Chapter 1).

Table 2.1: Comparison of geochemical data

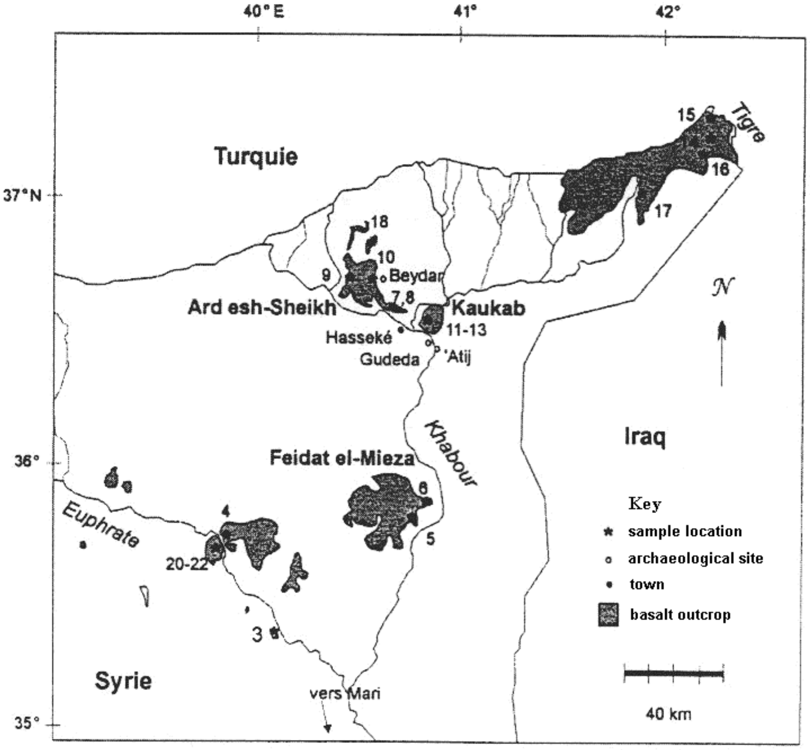
Outcrop	**Rowan (1998:312)**		**Philip and Williams-Thorpe (1993:57)**	
	Sr range (ppm)	Rb range (ppm)	Sr range (ppm)	Rb range (ppm)
Sweimah	919-952	20.9-21.6	888-1,562	6.5-12.9
Ma'in	554-824	9.9-10.4	965-1,062	22.1-29
Mujib	450-511	9.3-11.3	562-572	9.8-10.6
Kerak	500-582	6.2-11.3	580-747	8.8-20.3

(See Fig 1.2 for outcrop locations).

Table 2.1 shows that Rowan's data either overlaps with Philip and Williams-Thorpe's data or has a completely separate range. This therefore implies that the outcrops have a wider range of geochemical composition than is revealed by either set of analyses, which means that no outcrop can be eliminated as a potential source of the material for any artefact on purely geochemical grounds. It can therefore be concluded that Rowan has not demonstrated that his methods can be used to provenance artefacts, although this is mainly due to the small number of samples employed in his study and highlights the need for the analysis of a number of samples from each outcrop.

Similar work has also been undertaken in north-eastern Syria by Lease et al. (1998 and 2001), who used both petrography and geochemistry to attempt to provenance basaltic artefacts found at Tell 'Atij and Tell Gudeda in the Khabur Valley (Fig 2.5).

Fig 2.5: Basaltic rock outcrops in north-east Syria

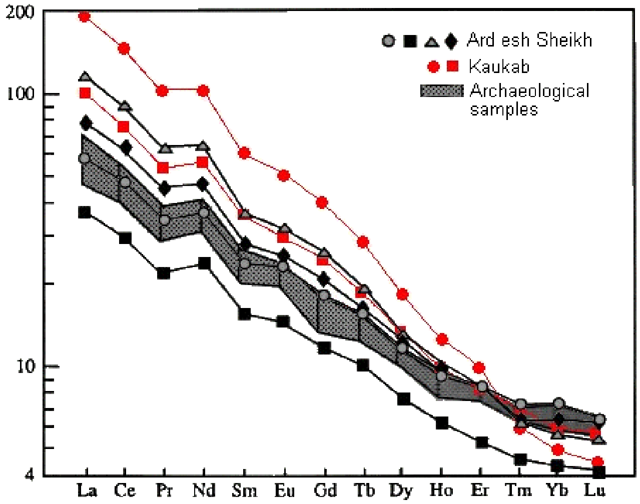


After Lease et al. (2001:229).

Lease et al. (1998 and 2001) used a variety of different methods, including microscopic examination, mineral analysis and ICP-MS (inductively coupled plasma-mass spectrometry) trace element analysis to provenance the artefacts. They concluded that most of the artefacts probably originated from the Ard esh Sheikh outcrop (approximately 30 km north-west of the sites), with a few from Feidat el-Mieza (about 50 km south of the sites), rather than the closer Kaukab outcrop (less than 5 km north of the sites).

Lease and Laurent (1998:88ff) conclude that the most useful technique was that of trace element analysis, as they note that, in principle, the distribution of these elements is unique for each outcrop. Lease et al. (1998:89; 2001:235) used rare earth element (REE) plots (Fig 2.6) and multi-element plots to match the plots of the artefacts with those of the geological samples. These plots will be further discussed in Chapter 3, but it is worth noting that (contrary to Lease et al.) it is standard geological practice to interpolate values for Pm between Nd and Sm, as this produces a smoother trend, making the data easier to examine. Nonetheless, Fig 2.6 shows that the REE abundances match those of the samples from Ard esh Sheikh and are different from those from the Kaukab outcrop. Lease and Laurent (1998:90) also recognise the importance of integrating the provenance data with the social, political and economic data of the period, although they do not attempt this. Lease et al. (2001:239) report that they are in the process of conducting similar provenance studies at other contemporary sites in the region, with the provenance of basaltic artefacts from Tell Beydar also being Ard esh Sheikh. They (ibid.) also note that it is important to investigate the level of co-operation between the different sites exploiting the same outcrop, and the level of organisation of the manufacture and exchange of the basaltic artefacts. Although this remains to be undertaken, these studies do illustrate the potential of using trace elements, analysed by ICP-MS, to successfully provenance artefacts.

Fig 2.6: REE plot of Syrian samples



After Lease and Laurent (1998:89).

The final studies that will be reviewed here are those of Mallory-Greenough et al. (1999) and Greenough et al. (2001), who attempted to provenance Egyptian basaltic artefacts. In their first study, Mallory-Greenough et al. (1999) used laser ablation microprobe-inductively coupled plasma-mass spectrometry (LAM-ICP-MS; see Chapter 3) to provenance 10 Egyptian Predynastic (3900-3000 BC) basaltic bowls, found at the sites of Abydos and Qena, near Karnak. The authors also analysed 19 basaltic outcrop samples from throughout Egypt (Fig 2.7).

In contrast, Greenough et al. (2001) analysed, using XRF and ICP-MS, the whole-rock chemistry of 24 geological samples and 9 artefacts, five 1st Dynasty bowls from Abydos and four paving stones from Giza (Fig 2.7). This approach also enabled them to use a further 96 previously published analyses of Egyptian basaltic outcrops (Greenough et al. 2001:767), thereby enabling a better characterisation of the outcrops.

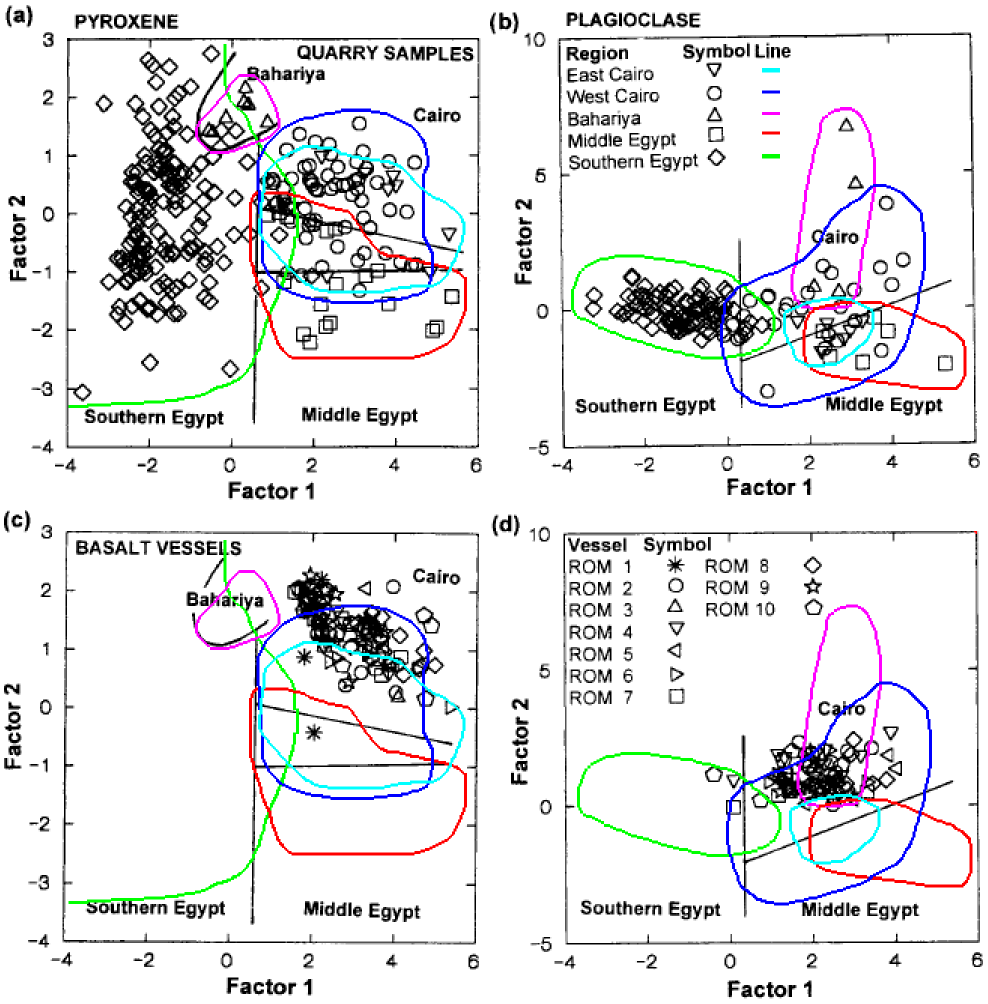
Fig 2.7: Location of Egyptian sites and outcrops

From Mallory-Greenough et al. (1999:1263).

LAM-ICP-MS allows a very small amount of sample to be analysed, meaning that individual minerals were analysed, rather than analysing the bulk rock composition (although this also is possible using this technique; see Chapter 3). Therefore, Mallory-Greenough et al. (1999:1265ff) analysed several pyroxene and plagioclase crystals (two of the most common minerals in basalt; see Chapter 3) from each sample. All the outcrop results were then plotted using multivariate statistical analysis (discussed further op. cit., pp.1269f; Fig 2.8), and regional boundaries were then drawn by hand (the black boundaries in Fig 2.8). The results from the bowls were then plotted using these boundaries, which, the authors claim, show that all the bowls originate from outcrops near Cairo, 600 km north of the sites.

However, there are a number of problems with this study. First, as Mallory-Greenough et al. (1999:1269) note, there is 14% overlap in the pyroxene and 17% overlap in the plagioclase plots between the different regions. When the published regional boundaries are compared with boundaries drawn including all the data points (the coloured boundaries in Fig 2.8), it can be seen that some of the archaeological samples plot in the overlapping areas, thereby weakening the authors' claim that the source is definitely the Cairo area. Furthermore, a number of the archaeological samples plot outside the defined geological fields. This shows that the geological samples do not fully resolve the variability of the archaeological samples, meaning that either the artefacts originate from another source, or, more probably, that the full level of variability of the outcrops has not been revealed by the samples.

Fig 2.8: Pyroxene and plagioclase plots of Egyptian data



After Mallory-Greenough et al. (1999:1269) with coloured boundaries added manually.

Furthermore, the number of outcrop samples is too small to be confident that the results are correct, irrespective of whether the archaeological samples fell within the geological fields or not. Mallory-Greenough et al. (1999:1262) claim that the Cairo outcrops are homogenous in nature, but do not attempt to demonstrate this for the other outcrops, and simply assume that this is the case. This claim is weakened by the fact that the archaeological samples which fall outside the geological fields are closest to the West Cairo field. It is therefore probable that the greater level of variability revealed by the artefacts relates to this field. Furthermore, the geological samples are unevenly distributed, with 11 being taken from Southern Egypt, 5 taken from the Cairo area, 2 from Middle Egypt and only 1 from the Bahariya Oasis. It is therefore probable that further outcrop samples could increase the observed variability of the regions and so further increase the regional overlaps, which will further obscure the actual provenance of the artefacts.

Another potential problem is that the very small archaeological samples (*c*.0·0001 g) were taken from "scuffed, or small previously damaged spots" on the bowls (Mallory-Greenough et al. 1999:1262), which raises the question of the possibility of contamination or chemical alteration of the minerals, although as samples were taken from multiple parts of the artefact this should be reduced. However, this problem could explain individual outliers, but is not discussed. It can therefore be seen that Mallory-Greenough et al. (1999) have not demonstrated that this is a useable method for securely provenancing basaltic artefacts, although Cairo does remain the most likely source, given the current data.

Finally, Greenough et al. (2001:773) note that two problems with using multivariate statistics are that they do not allow the identification of important chemical differences, while to add any new samples it is necessary to recalculate all the data. They therefore use plots of elements and element ratios, to which they add manual boundaries similar to those shown in Fig 2.8. From these they conclude that the West Cairo outcrops are the source of all of the artefacts (Greenough et al. 2001:778f). However, the manual boundaries are again problematic, again for not showing overlaps, but also for giving broader boundaries than those revealed by the analyses. As the archaeological data falls within boundaries which could have been defined by simply drawing round the data points, this would have strengthened the conclusions based on the trace element data.

Greenough et al. (2001:780) also conclude that these whole rock analyses are better for provenancing archaeological samples than the major element mineral analyses reported in Mallory-Greenough et al. (1999), although they argue that trace element mineral analyses may be better. They note that the main advantage of this approach is that only very small sample sizes are required. However, Greenough et al. (2001:781) also note that whole rock analyses are easier to obtain and easier to compare and so conclude that this type of analyses are better, if sample size is not a major consideration. This is especially the case as there appears to be little or no published data on trace element mineral analyses, thereby meaning that a great deal of work would have to be undertaken, before it would be possible to undertake provenance studies using this method (Greenough et al. (2001:780).

Greenough et al. (2001:781) briefly consider the archaeological implications of their results and argue that it is possible that the reason the West Cairo basaltic rock was the source of the artefacts was the physical properties of the rock, although they do not attempt to quantify how the physical properties vary between outcrops. Mallory-Greenough et al. (1999:1271) also go on to offer a brief discussion of the significance of their results. They argue that the results suggest that the same outcrop was used for 900 years, suggesting widespread distribution of these artefacts. However, they do not discuss how the artefacts could have been procured. Furthermore, given the small number of samples analysed, their conclusions are somewhat broad in nature, with more work required to properly assess these preliminary conclusions.

Conclusion

From this review, it can be seen that there are a number of similarities between the different provenance studies, including the usual comment that little other work has been undertaken on provenancing stone artefacts. There is also little emphasis, with the partial exception of Potts (1989) and Williams-Thorpe and Thorpe (1993), on examining the mechanism by which the artefacts were distributed, with most of the concern being on investigating from where they were imported. This is an important omission, with realist theory emphasising the need to explain the underlying structures, and not simply to identify the observed repeated regularities. Furthermore, it seems that the most useful techniques are those relying on whole-rock trace element data and element ratios, as these seem to have provided the most informative results. However, even these have not always been able to unambiguously provenance artefacts to an individual outcrop. As both Weinstein-Evron et al. (1999:271) and Lease and Laurent (1998:90) note, this is partially due to a lack of suitable data, highlighting the need for more geological samples to be analysed in the region of study.

This review also highlights the need to have an understanding of both the geology and the archaeology of the region. It also shows the importance of having a theoretical understanding of provenance studies in order to relate the results to the archaeology of the period from which the analysed artefacts originate. The succeeding chapters will therefore deal with these issues.

Chapter 3: Geological principles

"Rocks, like everything else, are subject to change and so also are our views on them."
(F. Y. Loewinson-Lessing)

As was shown in Chapter 2, to successfully provenance basaltic artefacts a good understanding of the geology and geochemistry of the outcrops in question is required, in this case those of the southern Levant. However, to properly understand and utilise this data it is first necessary to review some general geological principles.

Geological time-scale

In geology, both time and rock formations are subdivided into named and dated units (Allaby and Allaby 1999:228), very similar in nature to archaeological periods. As with archaeological periods, there are problems with determining the exact start and end dates for the periods, with the latest major change being the re-dating of the start of the Palaeozoic from 570 Ma to 544 Ma (Plummer and McGeary 1996:172). The time-scale used throughout this thesis is shown overleaf.

Plate tectonics

The Earth can be divided into three main zones, namely the crust, mantle and core (Plummer and McGeary 1996:375). The crust consists of the solid outermost surface, varying in thickness from 5 km, under the oceans, to 60 km, under the major mountain chains (Allaby and Allaby 1999:136). This is underlain by the mantle, which is mostly solid rock (called peridotite) and is approximately 2,300 km thick. It is important to note that the mantle is only solid due to the high levels of pressure, which raise the melting point of the peridotite (Allaby and Allaby 1999:332; Duff 1993:58).

Plate tectonics is now the dominant theory which unifies several different concepts, including continental drift and volcanic activity (Allaby and Allaby 1999:418). This theory divides the upper part of the Earth into two main layers, which are named the lithosphere and the asthenosphere. The lithosphere consists of the crust and the cooler outer layer of the mantle, which extends down to between 70 and 125 km. The asthenosphere consists of the hotter area of the mantle, where the rock is closer to its melting point, and extends down to about 200 km (Plummer and McGeary 1996:378).

The lithosphere is divided into separate regions, known as plates, which move independently. Plate margins are divided into three main groups, namely transform margins, where plates move past one another; convergent margins, where one plate is subducted under another; and divergent margins, where the plates move apart and new ocean crust is formed (Duff 1993:648).

Table 3.1: Geological time-scale

Eon	Era	Sub-era	Period	Epoch	Start (Ma)
Phanerozoic	Cenozoic	Quaternary	Pleistogene	Holocene	0.011
				Pleistocene	1.8
		Tertiary	Neogene	Pliocene	5
				Miocene	23
			Palaeogene	Oligocene	38
				Eocene	54
				Palaeocene	65
	Mesozoic		Cretaceous		146
			Jurassic		208
			Triassic		245
	Palaeozoic	Upper Palaeozoic	Permian		286
			Carboniferous		360
			Devonian		410
		Lower Palaeozoic	Silurian		440
			Ordovician		505
			Cambrian		544
Proterozoic					2500
Archaean					3800
Hadean					4500

After Collins and Speer (1998) and Allaby and Allaby (1999:602f).

Volcanism

Volcanic activity is generally associated with these plate margins, although within-plate volcanism is also known (Duff 1993:212ff). There are three main mechanisms which cause the mantle to melt and form magma (that is, molten rock):

1. Stretching or pulling apart of the lithosphere. This causes the hotter asthenosphere to move closer to the surface, thereby lowering the pressure and causing the peridotite to melt, forming magma. This mechanism operates at divergent plate margins and within plates, at rift valleys (including the Dead Sea rift) and the smaller, related, grabens (Duff 1993:58f; Allaby and Allaby 1999:239).
2. The introduction of large amounts of water. This occurs at convergent plate margins, where sea water is brought down with the subducted plate. This lowers the melting point of the mantle, forming magma (Duff 1993:60).

3. A mantle plume. This is a localised area of anomalously hot asthenosphere, which rises upwards, thereby forming magma. It can occur within plates, or at plate boundaries, where it may also occur in conjunction with either of the two other mechanisms, thereby creating larger amounts of magma (Duff 1993:59f).

If the magma is subsequently erupted onto the surface it is termed extrusive, whilst if it solidifies within the lithosphere it is termed intrusive. The way in which the magma is intruded or extruded leads to the formation of a number of different rock structures. Intrusive structures are classified on the basis of their size, shape, depth of formation and their relation to the country rock (the surrounding pre-existing rock). Two of the most common forms of intrusive structure are those of dykes and sills. Dykes are tabular and discordant (that is, they cut across layers of country rock), whilst sills are tabular and concordant (that is, they run parallel to layers of country rock). These structures are formed along weaknesses, typically fractures, in the country rock. Both dykes and sills vary greatly in size; their lengths can vary from metres to hundreds of kilometres, whilst their width and thickness can vary from centimetres to hundreds of metres (Duff 1993:176-182; Plummer and McGeary 1996:76f).

Less common intrusive structures, which are related to sills, are laccoliths and lopoliths. These are circular or elliptical in plan and have either arched roofing rocks and flat base rocks (laccoliths) or flat roofing rocks and arched flooring rocks (lopoliths); again they vary greatly in size. All these intrusive structures may be brought to the surface by the processes of erosion and uplift (Duff 1993:186f; Allaby and Allaby 1999:306).

The main extrusive form of magma is that of lava flows, that is, rocks which are formed from magma which flowed across the surface; they can vary greatly in size and structure. There are two main types of lava flow, namely, aa and pahoehoe flows. Pahoehoe flows are only formed from low viscosity magmas with low extrusion rates. They have relatively smooth surfaces whilst between one fifth and one half of the rock is made up of roughly spherical gas cavities, named vesicles (Duff 1993:223; Francis 1993:145,148).

Aa flows are formed by a much wider range of magma compositions, although they can also be chemically identical to pahoehoe flows. Pahoehoe flows can change into aa flows, if the rate of magma extrusion increases, but aa flows never revert to pahoehoe flows. Aa flows have a surface of jumbled, loose blocks with sharp edges. In cross-section, aa flows are usually a few metres thick and consist of an upper rubbly part and a lower massive part, containing only a small proportion of irregular vesicles. Below this, there is usually a thin layer of rubbly lava overlying the baked original ground surface (Francis 1993:145-149; Duff 1993:225f).

As lavas cool cracks or joints appear, which are usually irregular. However, in thicker flows, where the lava takes longer to cool, regular, hexagonal columns are formed. This area of the flow is termed the colonnade and is overlain by an irregularly jointed section, termed the entablature, which may also occur under the colonnade (Duff 1993:226).

Also important are pyroclastic deposits, which are formed from material which had already solidified into rock before being ejected from the volcano, due to the explosive release of gases. These deposits are known as tuff when consolidated or agglomerates when they consist mainly of large particles. (Francis 1993:12; Duff 1993:231f). Flows of these pyroclastic rocks are also known and range greatly in scale, with the resulting deposits known as ignimbrites (Allaby and Allaby 1999:278).

All magmas contain dissolved gases, which exsolve as the magma rises to the surface. If the magma is too viscous the gas cannot escape quickly enough, and so causes explosive eruptions. The viscosity of the magma is generally positively correlated with the amount of silica present (silica is discussed below). Less violently, gas may become trapped within the magma as it solidifies, leaving vesicles within the rock. Within a single flow, the top and bottom cool more quickly, trapping more gas, and so tend to be more vesicular than the centre of the flow. Vesicles can become filled or partially filled with secondary minerals, deposited by circulating water, and are then called amygdales, whilst rocks with amygdales are known as amygdaloidal (Hall 1996:28; Duff 1993:223).

However, even eruptions of low silica magma may be accompanied by violent explosions if surface water is present in the area where the magma is erupting. These eruptions are termed phreatic, unless magmatic material is ejected, usually in the form of pyroclasts, when the eruptions are termed phreatomagmatic (Duff 1993:234f; Allaby and Allaby 1999:411). If a significant amount of pyroclastic material is ejected, most of it is usually deposited close to the magma vent, forming a scoria cone (Hall 1996:46). Diatremes, volcanic vents formed by explosive action, may be associated with this activity, and are generally filled with vent breccia (angular volcanic rocks) and possibly other igneous rocks (Hall 1996:119; Allaby and Allaby 1999:157,74).

Archaeological significance

At least some of the characteristics of volcanic rock which have been discussed may be important for the manufacture of basaltic artefacts. Most of these will be considered below, but at this point it is worth noting that the type of rock structures in which the basaltic rock was found would also influence the way in which it was procured. For example, it is probable that the colonnade would be preferred as a source of rock, given its more regular, predictable fractures. Wilke and Quintero (1996:252) also argue that it is more likely that detached boulders were generally the source of rock for artefacts, rather than the outcrop itself, due to the greater effort required to detach rock from the outcrop. However, ethnoarchaeological work in

Mesoamerica shows that both the outcrop and the floodplain were used as sources of raw material (Nelson 1987:120). This is probably because rock from the outcrops will be less weathered, and therefore of better quality than already detached boulders.

Furthermore, as Wilke and Quintero (1996:252) also note, without exposed outcrops there would be no constantly renewed supply of relatively unweathered boulders. It is therefore most likely that major artefact production sites were near to relatively large outcrops, or down-stream from such outcrops, to ensure a regular supply of workable material (Wilke and Quintero 1996:245). Furthermore, Wilke and Quintero (ibid.) note that there was a high failure rate during the manufacturing process, thereby increasing the probability that primary production sites would be close to the available rock. This is supported by Nelson (1987:122) who comments that there were dense artefact scatters at both bedrock quarries and streambed collection sites. She also notes (ibid.) that the quarrying of the bedrock produced large pits in the outcrop; these may well remain visible over archaeological time-scales.

Mineral composition

As implied above, the most common element in all volcanic rocks is silicon, (which is commonly reported as silica, SiO_2), although the actual amount generally varies from 45 to 75 wt%. Most of the silicon is found as silicates, that is, substances which contain silicon as well as a variety of other elements, and are based around the silica tetrahedron (SiO_4). The composition and properties of the major rock-forming minerals are determined by how the other elements interact with this structure. Furthermore, although the mineralogy of the mantle is probably homogenous in nature, the rocks derived from the magma can be very different in mineral composition (Plummer and McGeary 1996:30f,56,378). The most important of these minerals are shown in Table 3.2.

Table 3.2: The principal rock-forming minerals

Name	Chemical composition
Olivine group	$(Mg,Fe)_2SiO_4$
Pyroxene group	SiO_3 and Fe, Mg, Al, Na, Ca
Augite	$Ca(Mg,Fe)Si_2O_6$
Amphibole group	Si_4O_{11} and Fe, Mg, Al, Na, Ca with OH and F
Mica group	$AlSi_3O_{10}$
Muscovite	$KAl_2(AlSi_3O_{10})(OH,F)_4$
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})\ (OH,F)_4$
Feldspar group	$AlSi_3O_8$
Plagioclase	$(Na,Ca)(Al)_{1-2}(Si)_{2-3}O_8$
Orthoclase	$KAlSi_3O_8$
Feldspathoid group	$Al(Si)_{1-2}(O)_{4-6}$
Nepheline	$Na_3(Na,K)(Al_4Si_4O_{16})$

(Duff 1993:48; Plummer and McGeary 1996:36; Allaby and Allaby 1999:43,367,415).

It is important to note that aluminium can sometimes substitute for one of the silicon atoms in the silica tetrahedron and that other elements can substitute for each other (shown in brackets and separated by commas) without distorting the crystal structure or significantly altering the properties of the mineral. This therefore increases the complexity of the possible chemical formulae, which means there are several different minerals within the general groups and sub-groups. For example, olivine with the formula Mg_2SiO_4 is named forsterite, whilst olivine with Fe_2SiO_4 is named fayalite. The most important of these individual minerals are given in italics. Pyroxene also has two main subdivisions, namely the orthopyroxenes and the clinopyroxenes, of which augite is one of the major individual minerals (Plummer and McGeary 1996:34; Allaby and Allaby 1999:108,380,443).

The range of different rock types, with different minerals, is explained by both the creation of magmas of different composition (primary variation) and the changes in the composition of an existing magma (secondary variation). Magmas are formed by the partial melting of the crust or mantle, and so primary variation is caused by differences in the material being melted, the degree of melting and the conditions under which melting took place (Hall 1996:220).

Secondary variation is caused by four main processes, with the first two being the most important and frequently occurring together (Hall 1996:220,280):

1. <u>Magmatic differentiation</u>. As magma solidifies over a range of temperatures, solid crystals and liquid magma occur together, while the different minerals do not all form crystals at the same time. The order of crystallisation is determined primarily by the temperature and pressure, although as a general rule, in basaltic magmas olivine crystallises first, followed by plagioclase and clinopyroxene. This therefore means that the remaining liquid is of a different composition to the crystals. The most important mechanism by which magmatic differentiation occurs is that of fractional crystallisation, which is the separation of crystals from the magma (Hall 1996:220f; Wilson 1989:73f). One of the most common methods of measuring this fractionation is the magnesium-iron ratio, usually known as the magnesium number. This is calculated either as an oxide wt% using $100[MgO/(MgO+FeO)]$ or as an atomic fraction using $100[Mg^{2+}/(Mg^{2+}+Fe^{2+})]$ (Rollinson 1993:74).
2. <u>Assimilation of country rock</u>. Magmas often either melt or chemically react with the surrounding country rock, thereby changing the chemical composition of the magma. Fragments of the surrounding rocks, which have a higher melting point than that of the magma, may be carried along by the molten rock and incorporated as inclusions when the rock cools. These inclusions are termed xenoliths (Hall 1996:220, 259).
3. <u>Zone melting</u>. The magma simultaneously crystallises and assimilates the surrounding country rock, thereby altering the composition of the magma (Hall 1996:220).
4. <u>Mixing of magmas</u>. Two separate magmas are mixed together, thereby producing a daughter magma with a different composition to the parent magmas (Hall 1996:220).

Another important factor which influences the mineral composition of the rock is the tectonic conditions under which the magma erupted. For example, a number of different basalt types have been defined, based on their tectonic setting. These are: mid-ocean ridge basalts (MORBs), which erupt at divergent plate margins; volcanic arc basalts (VABs), which erupt at convergent plate margins; and within plate basalts (WPBs) and ocean island basalts (OIBs), which erupt away from plate margins, on land or in the ocean, respectively. These differences lead to differences in the elemental composition of the resulting rocks. MORBs are generally tholeiitic basalts, and have low levels of the incompatible elements (see below for further discussion of these terms). There are also various types of MORBs including enriched and plume-type (E-MORB and P-MORB), as well as normal types (N-MORB). OIBs and WPBs have similar compositions, with higher concentrations of the incompatible elements, compared to MORBs. They also vary very widely in composition from tholeiitic basalts, through alkali basalts into nephelinites. VABs range from tholeiitic to alkali basalts, and are higher in K_2O and lower in MgO and CaO than MORBs. Transitional types of basalts can also be found (Pearce 1996:79f; Hall 1996:287f). One way of discriminating between VABs and WPBs is using the Zr/Nb ratio, with VABs having a ratio of 12 or over and WPBs usually having a ratio of between 4 and 8, although this can rise as high as 10 (Williams-Thorpe and Thorpe 1993:281).

The interaction of these various processes therefore leads to very complicated mineralogies, and so a simplified way of determining the mineralogy of the rock from chemical analyses was devised. The most commonly used calculation system is the CIPW norm, named after its originators (Cross, Iddings, Pirrson and Washington). This calculation is based on a number of simplifying assumptions, which results in a hypothetical assemblage of standard minerals, and may therefore differ substantially from the observed mineralogy, which is named the mode. The standard suite of normative minerals and their common abbreviations are shown in Table 3.3, overleaf, although no one rock can contain them all. The norm calculations are both complex and time consuming and are therefore usually calculated by computer (Rollinson 1993:52f). However, Middlemost (1989:25) has criticised many computer programs for producing "erroneous, and in some examples even bizarre, norms", showing the need to evaluate a program before its use.

Despite these limitations, the norm calculation is still useful as it enables the comparison of rocks, irrespective of their rate of cooling or water content, with the results given as the wt% norm of minerals (Rollinson 1993:52f). Currently its main use is in the classification of rock types, in conjunction with the total alkali-silica (TAS) diagram, which will be described below.

Table 3.3: Normative minerals

Mineral	Abbreviation
Quartz	*Qz*
Orthoclase	*Or*
Albite	*Ab*
Anorthite	*An*
Leucite	*Lc*
Nepheline	*Ne*
Corundum	*Co*
Acmite	*Ac*
Diopside	*Di*
Hypersthene	*Hy*
Olivine	*Ol*
Magnetite	*Mt*
Ilmenite	*Il*
Hematite	*He*
Apatite	*Ap*
Rutile	*Ru*
Perovskite	*Per*
Larnite	*Cs*

From Hall (1996:510).

Chemical composition

Although the different minerals contain differing elements in differing proportions there are only a limited number which actually form the vast majority of any igneous rock. These are therefore known as the major elements and are conventionally shown as oxides and measured as weight percent (wt%) of the total rock (Rollinson 1993:2). These elements, and the order they are conventionally presented in, are: SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5. It is important to note that iron occurs in two different oxidation states, the implications of which will be discussed below.

As well as these major elements, many of the other naturally occurring elements can be found in small quantities in the rocks, where they have been incorporated into the minerals. These are therefore termed trace elements and are usually measured as parts per million (ppm). To give some understanding of the different amounts present, 1,000 ppm by weight is the equivalent of 0.1 wt% (Rollinson 1993:2).

Within this very wide group of elements there are of course a wide variety of behaviours which affect the elemental abundances. Some trace elements are preferentially incorporated into a particular mineral, and so are termed compatible, whilst others remain in the magma, and so are termed incompatible. Degrees of compatibility of trace elements vary depending on the different minerals found in a particular magma. This means that the processes of magmatic differentiation also affect the abundances of the trace elements (Rollinson 1993:103; Hall 1996:144f). These differences may therefore aid provenance studies.

Weathering, which will be discussed more fully below, also affects different trace elements in different ways. Some trace elements are easily removed from a rock during weathering, and so are termed mobile, whilst others are very difficult to remove, and so are termed immobile. It is therefore very important to only use immobile elements when attempting to provenance artefacts, as the abundances of mobile elements will have been altered. A further problem is that absolute abundances of the elements in a rock can be altered by weathering processes, although these can be countered by using plots which use ratios of different elements, rather than using plots of absolute elemental abundance (Pearce 1996:82f).

There are also various groups of elements which behave in a similar fashion to each other. One such group is the high field strength group of elements (HFSE), which are all incompatible during mantle melting and generally immobile during weathering, and so are potentially useful for provenancing. They include the elements Y, Hf, Zr, Nb, Th and Ta (Rollinson 1993:104, 148). As shown in Chapter 2, another very important group is that of the rare earth elements (REE) or lanthanides, which have the atomic numbers 57 to 71 (Table 3.4), although promethium does not actually occur naturally (Rollinson 1993:133).

Table 3.4: The rare earth elements

Atomic number	Name	Symbol
57	Lanthanum	La
58	Cerium	Ce
59	Praseodymium	Pr
60	Neodymium	Nd
61	Promethium	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	Terbium	Tb
66	Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu

After Rollinson (1993:133).

Rollinson (1993:133) describes the REE as “the most useful of all trace elements”. This is because although they all have very similar chemical and physical properties, the differences are such that they become fractionated during petrological processes, such as magma formation. This means that they reveal a great deal of information about these processes, especially as they are generally immobile and so are not significantly affected by weathering, hydrothermal alteration, or even low-grade metamorphism (Rollinson 1993:134,137). Rollinson (1993:138) does caution that they are not totally immobile, but concludes that:

> "REE patterns, even in slightly altered rocks, can faithfully represent the original composition of the unaltered parent and a fair degree of confidence can be placed in the significance of peaks and troughs and the slope of an REE pattern."

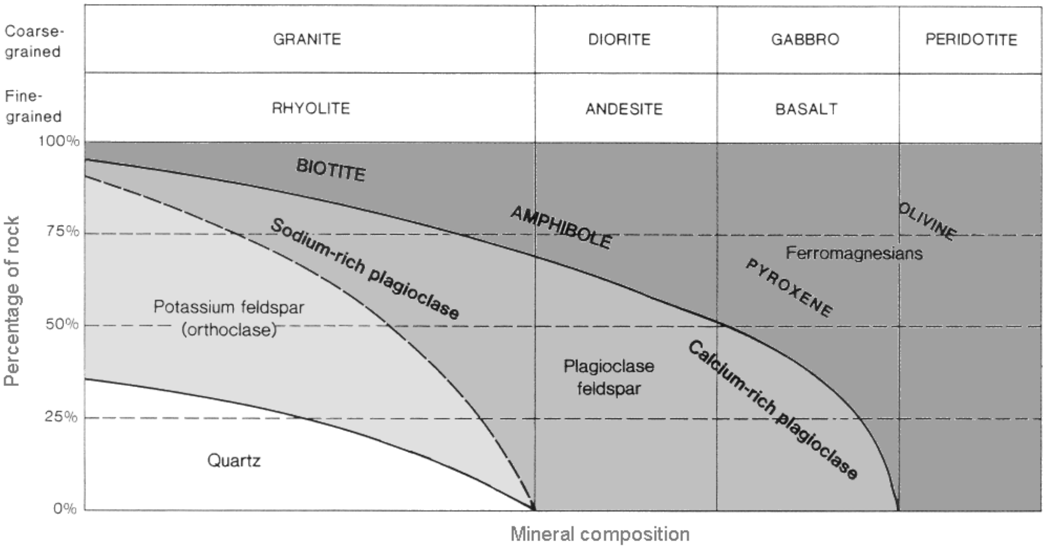
This therefore makes them potentially very useful for archaeological provenance studies. These REE patterns will be further discussed below.

Rock classification and variation diagrams

There are a number of ways in which the different rock types are classified, including on the basis of their mineralogy and on the basis of their bulk chemistry, which will be discussed below. One widely used mineralogical classification scheme uses the amount of silica which is contained within the rock. As mentioned above, this usually varies from 45 to 75 wt%. On this basis, rocks are termed basic (silica 45 to 53 wt%) intermediate (silica 53 to 66 wt%) or acid (silica greater than 66 wt%). If the silica content is less than 45 wt% then the rocks are termed ultra-basic. (Duff 1993:63f; Plummer and McGeary 1996:75f). The changing mineral content also affects the colour of the rocks (Fig 3.1), with basic rocks being darker than acid rocks. Hand specimens of rocks are therefore often classified using the terms ultramafic, mafic, intermediate and felsic, which broadly correspond to the chemical groups (Duff 1993:64).

A secondary form of classification is the grain size of the minerals, which can range from fine to coarse, with rocks of the same mineral composition having different names as the grain size changes (Plummer and McGeary 1996:74). These classification systems are illustrated below, with the names of some of the most common igneous rocks shown.

Fig 3.1: Rock classification schemes



After Plummer and McGeary (1996:75); Duff (1993:64).

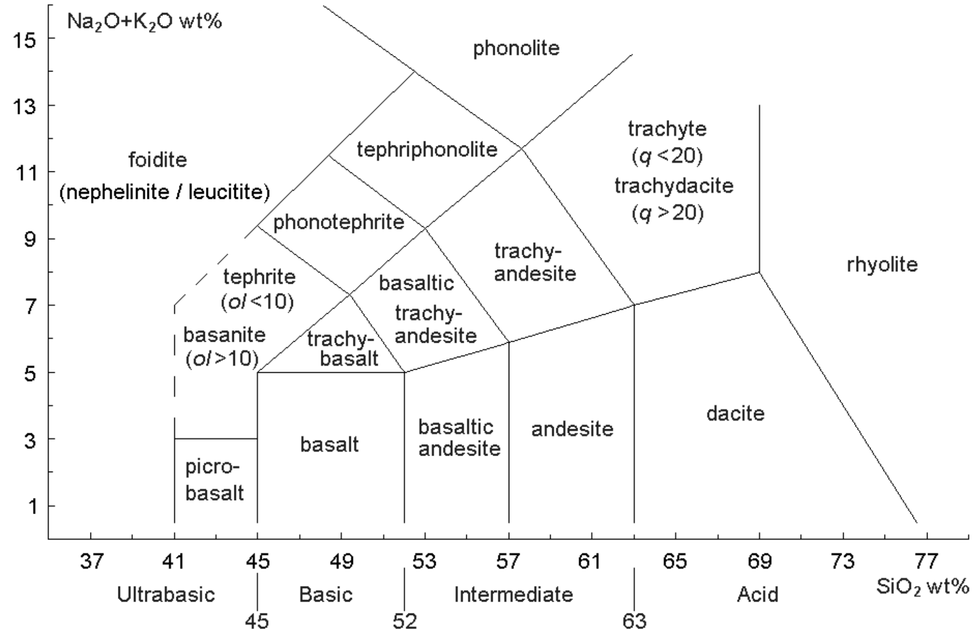
The grain size of the rock is related to the rate of cooling of the magma, with the quicker the cooling the smaller the grain size. In turn, this is related to the conditions under which the magma cooled. As mentioned above, the two main divisions are intrusive, where the magma crystallises underground, and extrusive, where the magma crystallises after being erupted onto the surface. Extrusive rocks are fine grained, due to rapid cooling. Intrusive rocks which were emplaced close to the surface are either fine-grained or medium-grained (volcanic or hypabasal). However, intrusive rocks which were emplaced deep underground cool much more slowly, allowing the crystals to grow larger, thereby leading to coarse-grained (plutonic) rocks (Plummer and McGeary 1996:74; Duff 1993:201). Hypabasal rocks are generally named after their plutonic equivalents, with the addition of the prefix 'micro', although 'dolerite' or 'diabase' are regularly used instead of 'microgabbro' (Le Maitre 2002:5).

The examination and classification of rocks using their mineralogy is termed petrography. This is undertaken by examining the rock under a microscope to identify the different minerals which make up a particular rock (Le Maitre 2002:4). A thin section is produced, which is a slice of rock cut and ground to a standard thickness of 0.03 mm. This allows light to shine through the minerals, whilst the standard thickness ensures comparability between thin sections (Gribble and Hall 1985:28; MacKenzie and Adams 1994:22). The thin sections are examined using a polarising microscope, which differs from standard microscopes in having two polarising filters. A polarizer forces light passing through it to vibrate only in a single plane, whilst the two polarizers are set at right angles to each other. The second filter can be removed, allowing the examination of the thin section in either plane-polarised light (PPL) or crossed-polarised light (XPL), aiding in the identification of the individual minerals (MacKenzie and Adams 1994:9; Gribble and Hall 1985:1). One of the important effects of XPL is that the interference colours of the minerals can be seen. This makes the minerals appear to be a variety of distinctive colours, which greatly aids their identification (MacKenzie and Adams 1994:22).

Chemical classification

However, this approach is not usually possible for most volcanic rocks, as they are too fine-grained for all the minerals to be identified. In this case the rock has to be classified on the basis of its chemical composition (Le Maitre 2002:30ff). The most widely used method to classify igneous rocks is the total alkali-silica (TAS) diagram, which plots the sum of Na_2O and K_2O against SiO_2, all given as wt% (Rollinson 1993:49). The most comprehensive discussion of this method is that of Le Maitre (2002), which contains all the recommendations of the International Union of Geological Scientists (IUGS) Subcommission on the Systematics of Igneous Rocks. As can be seen in Fig 3.2, the plot is divided into different fields, which provide the root names of the different igneous rocks.

Fig 3.2: The total alkali-silica diagram



After Le Maitre (2002:35). The subdivisions of the fields are explained below.

Le Maitre (2002:33) notes, however, that the TAS diagram is purely descriptive in nature and that rocks which have been weathered, metamorphosed, or otherwise altered should only be classified with caution, as incorrect results may be obtained. Le Maitre (2002:33f) therefore states that the diagram should only be used with analyses which have less than 2% H_2O^+ and less than 0.5% CO_2, and that analyses must be recalculated to 100% without these volatiles[1], before they are plotted on the diagram.

Furthermore, as mentioned above, the CIPW norm calculation is also required to fully use the TAS diagram, as the normative mineralogy of the rock is used to subdivide a number of the fields (Le Maitre 2002:33). However, it must be noted that there is one further problem with the norm calculation. Many geochemical analyses report the total amount of iron present as either Fe_2O_3 or as FeO, but not generally as both. This is problematic as both oxidation states are important for calculating the norm (Middlemost 1989:23f). Middlemost (ibid.) therefore suggests a number of ratios for calculating the relative proportions of the two oxides from the total iron, which vary by the groups defined by the TAS diagram (Fig 3.3). These ratios will therefore be used in this thesis where necessary.

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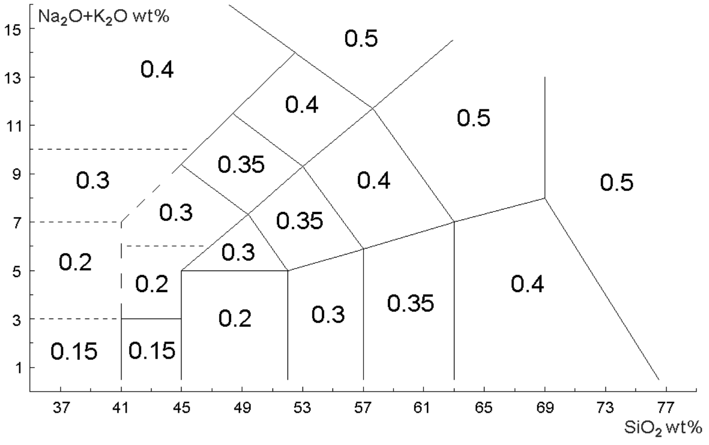
[1] H_2O^+ is defined as "water combined within the lattice of silicate minerals and released above 110°C". Water released by heating below 110°C is given as H_2O^- (Rollinson 1998:2). The total amount of volatiles are measured by heating to 1,000°C and is given as loss on ignition (LOI; ibid.).

Fig 3.3: Fe_2O_3/FeO ratios



After Middlemost (1989:24).

As is indicated on Fig 3.2, the trachyte/trachydacite field is distinguished using the function $q = 100[qz/(qz+an+ab+or)]$ (see Table 3.3 for the abbreviations). If q is less than 20 wt% then the rock is named trachyte, and if greater than 20 wt% then the rock is named trachydacite. Trachyte can be further qualified by the term peralkaline, if $(Na_2O+K_2O)/Al_2O_3$ is greater than 1. This calculation is known as the peralkaline index. The tephrite/basanite field is distinguished using the amount of normative olivine. If this is less than 10 wt% then the rock is named tephrite, and if greater than 10 wt% then the rock is named basanite (Le Maitre 2002:38).

The basalt field may be subdivided into alkali basalt, if the sample contains normative nepheline, and subalkali basalt, if it does not. If the sample contains normative hypersthene then the term tholeiitic basalt may be used (Le Maitre 2002:36,148).

The foidite field may also be subdivided, based on the most abundant feldspathoid present (see Table 3.2). The two main types are nephelinite (if nepheline is the most abundant) or leucitite (if leucite is the most abundant; Le Maitre 2002:39,32). One current problem with the TAS diagram is determining the boundary between the foidite field and the tephrite/basanite field. This is dashed on Fig 3.2, as, although tephrites and basanites fall within their defined field, some foidites also fall in this field, and are distinguished using the norm. If a rock in the tephrite/basanite field contains greater than 20 wt% normative nepheline, then the rock is classified as a nephelinite, whilst if the rock contains less than 20 wt% nepheline and if albite is present, but is less than 5 wt%, then the rock is classified as a melanephelinite (Le Maitre 2002:36).

A number of the other root rock names may also be qualified by the use of further criteria (Le Maitre 2002:35). The relative proportions of Na_2O and K_2O are used to subdivide the trachybasalt, basaltic trachyandesite and trachyandesite fields. If $(Na_2O - 2)$ is greater than the amount of K_2O present then the fields are named hawaiite, mugearite, or benmoreite, respectively. If (Na_2O – 2) is less than K_2O then the fields are named potassic trachybasalt, shoshonite, or latite. The rhyolite field may be qualified by the use of the term peralkaline, if the peralkaline index is greater than 1 (Le Maitre 2002:38).

The program used to calculate the norm and determine the TAS classification in this thesis was SINCLAS (Verma et al. 2002). SINCLAS had the advantages of being free, easy to download from the internet[2] and relatively quick and convenient to use. This is especially the case as the data are automatically recalculated to 100% without volatiles and can be imported and exported as Microsoft Excel files. SINCLAS also calculates a number of element ratios and chemical parameters, including the magnesium number, using the atomic fraction method (Verma and Torres-Alvarado 2002). The program incorporates the latest recommendations on the calculation of the norm and use of the TAS diagram, including those of Middlemost (1989) and in Le Maitre (2002) (Verma et al. 2002:712ff). Verma et al. (2002:715) also report that 73 previously published samples were used to check the accuracy of SINCLAS, following Middlemost's (1989:25) recommendations. One of Middlemost's (ibid.) recommendations was that the sum of the oxides (after adjustment for the volatiles) and the sum of the normative minerals should not differ by more than 0.001%. SINCLAS automatically calculates and reports this difference, thereby enabling the easy identification of any problems. Verma et al. (2002:713) report that the observed accuracy of SINCLAS is generally better than 0.002%. Therefore, although SINCLAS does not completely fulfil Middlemost's recommendation it is very close. Furthermore, most other programs do not have this function, making them more difficult to evaluate properly.

However, as has been noted above, there is one main problem with the TAS diagram which is that it cannot accurately classify altered igneous rocks, as the elements used are all highly mobile in nature (Pearce 1996:93). Even if this is not a problem with the geological outcrops in the southern Levant it may be a problem for basalt artefacts, especially if, as speculated (Philip and Williams-Thorpe 1993:60), the raw material for at least some of these artefacts was collected as loose blocks, possibly from wadi beds.

Variation diagrams

Another problem with the TAS diagram is that it is too broad to allow the positive identification of a source outcrop. It is also possible to plot the normative mineralogy, with the most common method outlined in Thompson (1984). However, this method will not be used in this thesis, as it suffers from the same limitations as those of the TAS diagram, and would also require the

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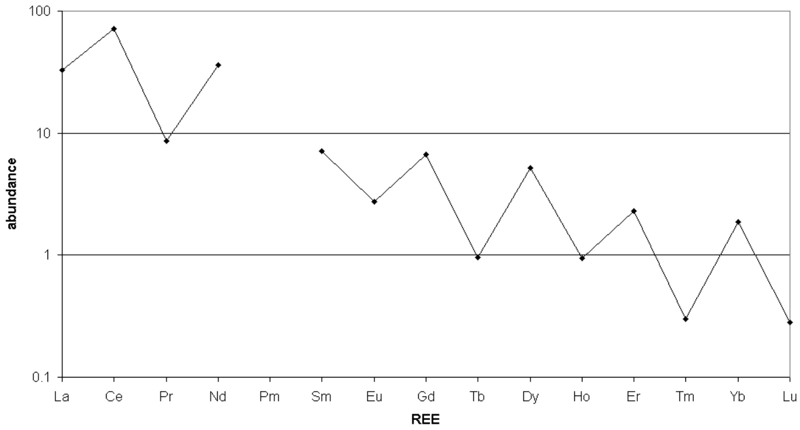
[2] Downloaded from: http://www.iamg.org/CGEditor/index.htm

re-calculation of the norm, as the diagram assumes a FeO/Fe_2O_3 ratio of 0.15 (Thompson 1984:250). A more focused, rigorous approach is therefore necessary, which may be provided by the use of variation diagrams. These are diagrams which seek to simplify the variation between individual samples to identify relationships between different rocks. They are therefore widely used in geochemical studies and usually involve plotting elements or element ratios on a bivariate or trivariate graph (Rollinson 1993:66). These are used in geochemical studies to identify certain processes involved in the formation of the rocks. However, as these diagrams show variations between samples they also have the potential to be used in archaeological provenance studies to group artefacts with their parent outcrop.

A comprehensive set of variation diagrams are discussed by Pearce (1996), which are designed to accurately assign a basalt sample to its most probable tectonic setting (Pearce 1996:106ff). These therefore have the potential to be used to provenance basaltic artefacts. However, they suffer from the major limitation that they can only be used for samples which fall within the basalt and basaltic andesite fields, as defined on the TAS diagram (Rollinson 1993:174). A further limitation for provenance studies is that if outcrops from different localities share the same eruptive setting it may not be possible to discriminate between them using these diagrams. To pre-empt the conclusions of Chapter 4, a wide variety of rock types are found in the southern Levant, whilst outcrops from different areas share a common eruptive setting. Therefore, the sequence of diagrams presented by Pearce (1996) cannot be directly applied, although some of the individual plots may be useful.

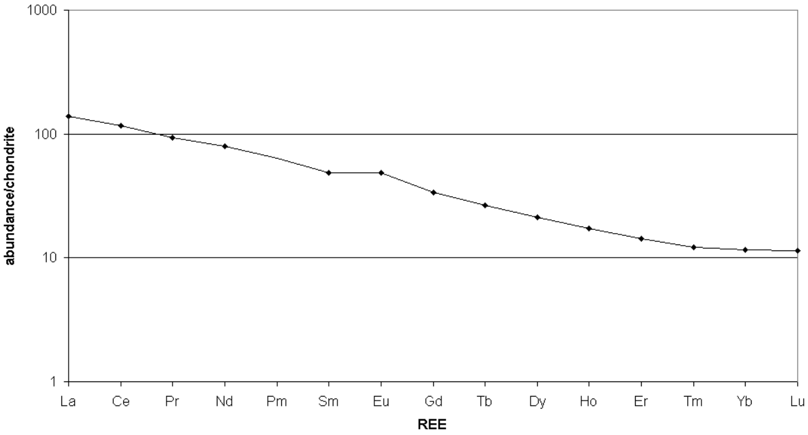
It is therefore necessary to use other variation diagrams and other plots, especially those which make use of REE data. The simplest way of presenting REE data would be a plot of the element concentrations. A logarithmic scale is routinely used, as this enables patterns to be more easily identified. An example of such a plot is shown in Fig 3.4.

Fig 3.4: REE abundance plot of sample G165



It can be seen that this plot has two main limitations. First, Pm does not occur naturally and so interrupts the general pattern. Second, the pattern forms a series of peaks and troughs. This is known as the Oddo-Harkins effect, which is due to the fact that elements with an even atomic number have a greater cosmic abundance than those with odd atomic numbers. Therefore, to make the pattern more easily interpretable, REE concentrations are normalised to an average value for the various chondritic meteorites which have been analysed[3], with the values published by McDonough and Sun (1995:228) being used throughout this thesis. The missing Pm value is then inserted by interpolating the data between Nd and Sm to produce a smoothly varying normalised pattern (Rollinson 1993:135; Allaby and Allaby 1999:378). The resulting plot is shown in Fig 3.5.

Fig 3.5: Chondrite-normalised REE abundance plot of sample G165



This plot is much easier to interpret. The overall downward trend of the chondrite-normalised abundances is clearly visible, whilst it can be clearly seen that the Eu value is anomalously high. This downward slope and europium anomaly are very common features of REE patterns of mafic rocks. The downward slope reflects the fractionation of the REE during partial melting and can be quantified by plotting La/Yb against Yb, again using a logarithmic scale and normalised data. This plot allows a simple quantification of overall REE patterns and therefore may be useful for provenancing artefacts. It is also possible to quantify the europium anomaly and the fractionation of the light (La to Sm) or heavy (Gd to Lu) REE (Rollinson 1993:137).

REE plots have also been extended to include a larger number of trace elements, including the HFSEs (high field strength elements, discussed above). The patterns of these plots can again be compared, potentially aiding provenance studies. These plots are technically known as

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[3] Chondritic meteorites are believed to represent the original cosmic elemental abundance, and so remove elemental abundance variation due solely to the Oddo-Harkins effect (Rollinson 1993:135).

chondrite-normalised multi-element diagrams, but are usually referred to as spidergrams (Rollinson 1993:142). Up to twenty elements can be used to construct a spidergram, although Rollinson (1993:147) does comment that "a condensed version of the diagram is permissible if the full range of trace elements have not been determined." This therefore increases the usefulness and flexibility of this type of plot, especially for provenancing purposes. One potential limitation is that the plots can be affected by intra-outcrop fractional crystallisation. This means that elemental abundances may vary within a single outcrop, simply due to differences in the elemental composition of individual crystals, especially phenocrysts (Rollinson 1993:138ff). Although this should not be a major problem in aphanitic basaltic outcrops, it can be avoided by using elemental ratios that are not affected by fractional crystallisation. Furthermore, if enough samples have been collected from an individual outcrop it may be possible to use any intra-outcrop variations to identify from which part of the outcrop the raw material for the artefacts originated. Therefore, these different plots and ratios, which have all been designed to show differences in the eruptive history of the rocks, may well be applicable to provenancing artefacts manufactured from these rocks.

Analytical instruments and methodologies

There are a number of analytical instruments which can measure the major and trace element concentrations in rocks, using a variety of sample preparation techniques. These all have advantages and limitations which will be briefly reviewed.

X-ray fluorescence (XRF) is probably the most widely used technique for analysing rock samples, not least as it is capable of analysing both major and trace elements. It operates by using radiation from an X-ray tube to excite X-ray emissions from the sample, which can then be measured (Fitton 1997:113,87). For the best analyses the sample needs to be ground as finely as possible before about 15g of rock is fused prior to analysis (Fitton 1997:111; P. Webb pers. com. 2001). The main limitations of this technique are the amount of sample required (which may prevent the analysis of many artefacts; cf. Chapter 1; Philip and Williams-Thorpe 2001:26) and that certain important trace elements, most notably the REE, cannot be easily analysed using XRF (Jarvis 1997:183).

Inductively coupled plasma-mass spectrometry (ICP-MS) is widely used for analysing trace elements. Samples are dissolved into solution, then nebulised (introduced) as an aerosol, where they are heated in a plasma torch. The resulting ions can then be measured (Jarvis 1997:171). The advantages of ICP-MS are that it can rapidly analyse small samples for a wide range of trace elements, including the REE. It also has very low detection limits (ppb in rock) and good precision (2 to 5% relative standard deviation) and accuracy (less than 5% deviation; Jarvis 1997:173). Furthermore, ICP-MS is the technique of choice for analysing the REE and the HFSE, making it ideal for a large number of geochemical studies (Jarvis 1997:177), and so also for provenance studies. The main disadvantage of ICP-MS is that cannot easily analyse the major elements, meaning that another technique, usually XRF, is required for their measurement. XRF also more accurately analyses the first-row transition metals, such as Cr and Ti, due to problems with the sample preparation technique and interferences with other elements (Ottley et al. in press).

There are also a number of other widely used methods. Inductively coupled plasma-atomic emission spectroscopy (ICP-AES) is similar to ICP-MS, but measures the atomic spectra of elements (Walsh 1997:41). It is also capable of measuring major elements, although not with the same ease as XRF (Walsh 1997:63). Furthermore, ICP-AES cannot measure the REE and HFS elements with the same ease and level of accuracy as ICP-MS (Walsh 1997:55ff; Jarvis p183f)

Neutron activation analysis (NAA) is also capable of analysing a wide range of trace elements, including most of the REE. It operates by irradiating the samples, which then produce gamma radiation, which can be used to determine which elements are present and in what quantities (Parry 1997:116ff). The advantage of this technique is the minimal sample preparation needed (Parry 1997:125). The main limitation of this technique is that a nuclear reactor is required to irradiate the samples, which have to be exposed for approximately 30 hours before measurement (Parry 1997:116; Rollinson 1993:12f).

There have also been a number of refinements to ICP-MS. Laser ablation ICP-MS (LA-ICP-MS) enables very small samples to be analysed, which allows the sampling of high quality, valuable or rare artefacts (Mallory-Greenough et al. 1999:1265). LA-ICP-MS also allows solid sample introduction, unlike ICP-MS, thereby greatly speeding up analyses. The elemental composition of individual minerals can also be analysed, although the main problem with this approach is the lack of geological data which can be used for comparative purposes (as discussed in Chapter 2). One further advantage of LA-ICP-MS over other microprobe techniques is the very low detection limits and rapid analysis times (Jarvis 1997:186f). However, one major problem is the small size of the analytical chamber. This means that only small artefacts can be analysed directly, whilst larger artefacts have to be sampled first, thereby removing one of the major advantages of LA-ICP-MS.

Multi-collector ICP-MS (MC-ICP-MS) can measure isotope ratios quickly and at high precision (Halliday et al. 1998). This has greatly increased the ease with which samples can be analysed and vastly reduced the cost of isotopic analysis, allowing its widespread adoption. This should permit better discrimination between outcrops and also enables one limitation of trace element analysis to be overcome, namely that as trace element abundance is controlled by mantle melting, two outcrops which are geographically distinct may be virtually indistinguishable using trace elements. However, as the isotopic composition of mantle sources are heterogeneous, even on small scales, high-precision ratio measurements are able to discriminate between the two potential sources and may even be able to discriminate between parts of a single outcrop. Again, the main problem with this technique is the current lack of geological data (at least in the southern Levant) which can be used for comparative purposes. However, as the two techniques become more widespread they will be useful for provenance studies, especially as they can be combined, allowing the measurement of isotopic ratios of very small samples (Halliday et al. 1998:932f).

Accuracy of results

To determine the overall accuracy of the measurements from any of these techniques the precision and bias of the results have to be calculated. Precision is a measure of the result's repeatability, that is, how close successive measurements of the same sample are to each other. Bias is a measure of how close the measurements are to the actual value of the sample (Gill and Ramsey 1997:8ff).

To enable the precision and bias to be measured, a standard with known elemental abundances is analysed during the analytical run. Precision is measured by determining the standard deviation between the analyses of the standard (Gill and Ramsey 1997:8). For comparative purposes, this is best expressed as the relative standard deviation (RSD), which expresses the variation from the mean as a percentage (Rollinson 1993:10). Bias is measured by determining how close the mean measured value is to the certified value of the standard, which is the average value agreed after a large number of independent measurements have been made. The percentage bias can also be calculated, which is easier to compare (Gill and Ramsey 1997:10f).

Rock properties

A further factor which requires consideration is that of the different physical properties of different rock types, as these may well affect the types of artefacts which can be manufactured (cf. Hunt 1991:36ff). The main physical properties which are important are those of hardness, density, brittleness, elasticity and surface roughness (Wright 1992:114; Hunt 1991:42). As mentioned in Chapter 1, these properties help explain why mafic rock was often preferentially selected. The different physical properties of the main rock types are summarised below:

1. <u>Flint</u> is hard, brittle and has a high compressive and low tensile strength. However, it is too smooth for grinding, without heavy roughening of the surface, although is useful for pounding (Wright 1992:114).
2. <u>Sandstone</u> is also hard and can be flaked, although not with the same precision as flint. It has a rough surface, but this is quickly smoothed by abrasion. This therefore means that the material being ground is usually contaminated to some degree by grit, and also that the surface needs to be regularly repecked to roughen the grinding surface (Wright 1992:115).

3. Limestone is much softer, and is easy to flake, although the edges are quickly dulled. It is also easily smoothed, and so cannot be used for grinding without repeated heavy repecking. However, it resists deformation by impact, and so is useful for pounding (Wright 1992:116). Wright (1992:116) also argues that limestone would be useful for vessels.
4. Mafic rock is hard, and somewhat difficult to flake. It has a lower compressive strength, but a higher tensile strength than flint, which means that it is less brittle and more resistant to deformation by impact. Mafic rock can be worked using flint and other stones, although only with some difficulty, as has been shown by the small number of experimental studies which have been undertaken (Epstein 1998:229; Hayden 1987b:16). Vesicular mafic rock has a rough, durable surface, which would be useful for grinding, especially as grit is not easily detached, meaning that the material is not contaminated to any great degree and also that the surface would not generally require repecking (Wright 1992:114f). Non-vesicular mafic rock can be broken and smoothed into thin bowl walls, making high quality vessels (Wright 1992:115). Hayden (1987b:15) also notes that non-vesicular mafic rock is harder to flake than if it were vesicular, as there are a greater number of unwanted fractures.

However, even the various mafic rock types, shown on the TAS diagram, have different physical properties, which relate to their different mineral compositions, discussed above. These different rock types do have differences in physical appearance, by which they may be broadly identified. This is especially the case if phenocrysts are present, which are larger mineral crystals set in the fine-grained matrix of the rock. Igneous rocks containing phenocrysts are termed porphyritic, whilst those without phenocrysts, which therefore cooled more quickly, are termed aphyric (Allaby and Allaby 1999:30,409). Phenocrysts may be used to attempt the initial identification of rock types, with, for example, basalt commonly containing phenocrysts of plagioclase, pyroxene and olivine (Thorpe and Brown 1985:47f).

The different mafic rock types also have different strength and fracture properties, which were probably important in the selection of rock for the manufacture of different artefact types. This is supported by the ethnoarchaeological work of Hayden (1987a:5) who argues that it is important to consider the physical and mechanical properties of the different rock types used to gain a proper understanding of why certain materials were chosen to manufacture certain artefact types. For example, basanite and nephelinite are generally both harder and more prone to unpredictable fracturing than basalt, thereby making it more likely that basalt would have been used to manufacture fine vessels. Furthermore, as discussed above, how the particular rock formed may also influence the physical properties, with, for example, rock from the colonnade part of a lava flow probably being of more use than that from the entablature. This is supported by the report of Slivka and Vavro (1996) on the modern manufacture of rock wool from mafic rocks. Slivka and Vavro (1996:149,158) report that chemically similar mafic rocks show a great deal of variability in behaviour, due almost exclusively to physical variations in the rock. Given the high degree of skill shown in the manufacture of the mafic artefacts it is very probable that these physical differences were also recognised in the past, and outcrops exploited accordingly.

These physical properties can be measured in the laboratory using a variety of techniques, with the most common being the uniaxial compressive strength test (UCS; Lockner 1995), which Gupta and Rao (2000:58) comment is a very reliable indicator of rock strength. However, the available data only includes limited information on basalt, and seems to use 'basalt' as a synonym for 'mafic' (especially the data presented by Lockner 1995). However, the limited amount of data that does exist shows that there is a wide range of variation in the strength of 'basalt' rocks. One of the main factors which causes this variation is the amount of weathering that the rocks have undergone, as is shown by the studies of Gupta and Rao (2000) and Tuğrul and Gürpiner (2001). Gupta and Rao (2000) report on the results of tests on fresh and weathered crystalline rocks, including 'basalt' from India. They conclude that weathering results in an "immediate and significant reduction" in the rock strength (Gupta and Rao 2000:258). This conclusion is also supported by Tuğrul and Gürpiner (2001), who examined the engineering properties of basalt (identified using petrography) in Turkey. Analysis of Farnoudi's (1998) data also supports this conclusion, with Spearman's correlation coefficient showing a reasonably strong (r_s= -0.75) negative correlation between the amount of weathering and the rock strength (see Appendix 1). The data are summarised in Table 3.5.

Table 3.5: Comparison of strength data for basaltic rocks

	Uniaxial compressive strength (MPa)					
	Unweathered rock			Highly weathered rock		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Farnoudi (1998)	491.94	212.50	342.92	-	-	43
Gupta and Rao (2000)	-	-	172.55	-	-	3.4
Tuğrul and Gürpiner (2001)	136.42	86.32	108.81	23.58	4.21	10

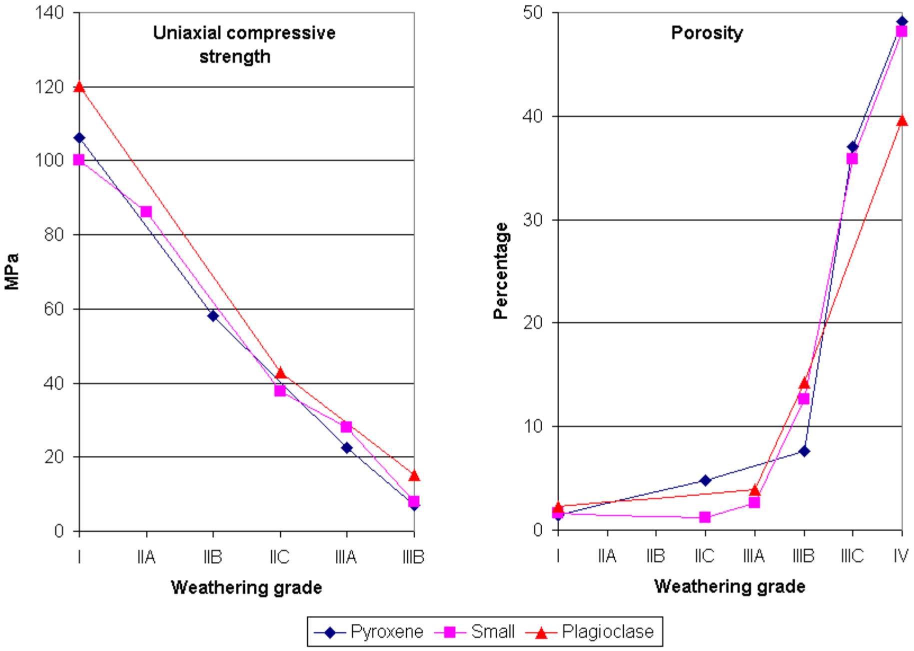
Gupta and Rao (2000:271f) also note that the mode of failure changes with the amount of weathering, which is related to the amount of microfractures and altered minerals present. Furthermore, all the studies show that porosity increases with the amount of weathering, as summarised in Table 3.6, overleaf.

Table 3.6: Comparison of porosity data for basaltic rocks

	Porosity (%)					
	Unweathered rock			Highly weathered rock		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Farnoudi (1998)	-	-	1.07	-	-	11.72
Gupta and Rao (2000)	-	-	0.66	-	-	30
Tuğrul and Gürpiner (2001)	3.49	0.39	1.79	59.15	28.75	45.63

Tables 3.5 and 3.6 show that is a great deal of variation between the measurements of the various studies, revealing the high levels of variability between similar-looking rocks. This is examined by Tuğrul and Gürpiner (2001:140) who divided the basalt samples into three groups, based on their dominant phenocrysts, which were large plagioclase phenocrysts, small (unspecified) phenocrysts and large pyroxene phenocrysts. When the measured physical properties are plotted separately for each of these groups (Fig 3.6), it can be seen that there are significant differences between these types of basalt, both in absolute measurements, and in how they react during weathering.

Fig 3.6: Properties of basalt rocks containing different phenocrysts



Data from Tuğrul and Gürpiner (2001:145).

It can be seen from Fig 3.6 that basalt with large plagioclase phenocrysts is stronger than the other two basalt groups, whilst basalt with small phenocrysts is less porous than the other basalt groups until the basalt is highly weathered, when plagioclase basalt is less porous. These differences, within a single rock type, were therefore at least potentially recognisable to manufacturers and also illustrate that the greater differences between rock types were potentially recognisable. Therefore, physical properties probably also influenced the choice of outcrop and individual rock, meaning it is important to consider both the physical properties of rocks at the level of individual outcrops and also the effects of weathering on them.

Another physical property which may be important is that of the thermal conductivity of the rocks. Clauser and Huenges (1995:108) report that for volcanic rocks porosity is the controlling factor, with higher porosity rocks having lower conductivity. This property may also have influenced the artefact types manufactured from different rock types, but again the reported rock categories are too broad to be able to draw any firm conclusions, meaning that further experimental work is again required. However, as discussed in Chapter 1, Stol (1979:85) argues that the different words used for 'basalt' in the past represent mafic rocks with different physical properties, showing that these physical properties were recognised and considered important. This is supported by the work of Tite et al. (2001), who examined the role that certain physical characteristics played in the selection of pottery vessels, and concluded that consumers were aware of at least some of these properties, with this awareness influencing their choice of vessel. Further investigation, including experiments, is therefore required to investigate the variations in all these physical properties within and between different rock types.

Weathering

As discussed above, weathering can have an important impact on the physical properties of rocks and so requires further discussion. There are two main types of weathering, namely physical weathering and chemical weathering. Physical weathering is defined as the breakdown of the rock into smaller fragments, with no chemical alteration of the rock, whilst chemical weathering involves the alteration of the rock minerals into new daughter products (Bland and Rolls 1998:85,116f).

Both of these types of weathering require consideration. As has already been discussed, physical weathering greatly affects the physical properties of the rocks in question. It also breaks down the outcrops into smaller blocks, enabling them to be more easily quarried and worked (cf. Wilke and Quintero 1996:252). Such blocks are still available near the outcrops in the southern Levant, with this availability further increasing the attractiveness of the rock for working.

However, chemical weathering is more of a cause for concern in this study, given that the chemical alteration of the rock can alter the types of minerals and the levels and proportions of elements present. This is especially important, as natural weathering and weathering after the rocks have been worked by people may take place in different ways, at varying rates. This could confound attempts to geochemically match geological outcrops with archaeological artefacts. Geological and anthropogenic weathering will therefore be considered separately.

Geological weathering

The main agent of chemical weathering is water, along with the gases dissolved in it. There are three main processes by which chemical weathering takes place, which are: the dissolution of ions and molecules; the production of new materials, such as clay minerals; and the release of unweathered materials, such as quartz. These three processes combine to form mineral products which can be very different from the parent rock both in appearance and chemically (Bland and Rolls 1998:116).

Rocks can show a variety of different responses to these weathering processes, due to a number of factors, including the length of exposure, the topography, the climatic conditions (especially the amount of precipitation) and the nature of the rocks themselves (Bland and Rolls 1998:40; Tuğrul and Gürpinar 2001:139).

Climatic conditions are important, as they greatly affect both the intensity and rate of chemical weathering. In steppe, semi-desert and desert conditions (such as those found over most of the southern Levant), the temperature is high, precipitation is low and evaporation is high, meaning that there are only low levels of chemical weathering, with the tendency being for salts, such as gypsum, to accumulate (Bland and Rolls 1998:175). Another mineral which regularly occurs in the southern Levant, due to the weathering conditions, is iddingsite (chemical formula[4]: $MgO{\cdot}Fe_2O_3{\cdot}3SiO_3{\cdot}4H_2O$), which is a reddish-brown alteration product of olivine (Philip and Williams-Thorpe 2001:14; Thrush 1968:568).

The nature of the rocks is also important as it affects the rate and intensity of the weathering which takes place. This nature depends on both the chemical properties of the rocks' minerals and also of the physical properties of the rock. Rocks are said to be anisotropic, that is, their physical properties vary spatially, due to the presence of discontinuities within them. These discontinuities (that is, breaks or fractures) are one of the major factors which influence both the chemical and physical weathering of the rock. They vary in size from faults and joints within the outcrop to microfractures within or between individual mineral grains, and greatly affect the amount of weathering by increasing the rock's surface area. This increases the permeability of the rock and therefore increases the rate at which chemical weathering takes place, as well as lowering the resistance of the rock to physical weathering (Bland and Rolls 1998:46ff).

Olivine and feldspars are particularly associated with microfractures which can cause significant increases in the permeability of the rock. Bland and Rolls (1998:45f) report that, due to capillary action, water has been observed to move at the rate of 25 mm per hour through microfractures in

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[4] The dots indicate that the different substances are incorporated together to form a solid.

basalt. This may well have significant consequences for the rates at which chemical weathering takes place. Furthermore, certain minerals, including olivine, convert to higher volume minerals when weathered, causing further extension to the microfractures, leading to further weathering.

Other important factors which affect weathering rates and intensity include the texture of the rock (that is, the relationship between the mineral grains which form the rock), the water content (both actual and potential), and the strength and elasticity of the rock. The texture of the rock affects its strength and also controls water uptake and movement through the rock. Igneous rocks have a crystalline texture, meaning that the rock consists of interlocking crystals. As discussed above, this is due to the growth of crystals during the cooling of the parent magma. This texture means that the rock is generally resistant to weathering and stress and has a low porosity, reducing the amount of weathering that can take place (Bland and Rolls 1998:41).

However, despite the differences in the rate and intensity of weathering, the main effects of chemical weathering are usually the small-scale leaching and alteration of individual grains, the development of a weathering rind and the growth of microfractures within the rock (Hunt 1991:253f; Bland and Rolls 1998:193). A weathering rind is a zone of oxidation which forms on the exposed surface of the rock and grows inwards. This is caused by oxides in solution, and is of a lighter colour than the unaltered rock (Hunt 1991:254). It has been shown that sub-surface rocks weather much more slowly than those exposed at the surface, with the weathering front taking several thousand years to move more than 30 cm down (Hunt 1991:256). Furthermore, studies in the western USA have shown that surface weathering rinds on basaltic and andesitic clasts grew at an average rate of 5 micrometres (that is, 0.005 mm) per thousand years over the past 500,000 years, although the rate tends to decrease with time (Bland and Rolls 1998:193). These rates may be broadly applicable to the southern Levant, given the general similarities in the climatic conditions between the two regions, although this is not certain. This type of research highlights the need for regionally specific investigations of weathering to be carried out.

The combined affects of physical and chemical weathering cause the rocks to become more porous, soft, friable and weakened, as the weathering continues (Gupta and Rao 2000:258). As discussed above, this is shown by the decrease in strength and the increase in porosity of the rocks. Tuğrul and Gürpinar (2001:143) have therefore proposed a system of classification to enable the amount of weathering that the rocks have undergone to be properly compared (Table 3.7). This will also enable the changes in physical and chemical properties to be quantified, and is therefore an important area requiring further study.

Table 3.7: Weathering classification

Classification	Description	Rock content	Description
I	Unweathered	Fresh rock	No sign of weathering. Grey-black colour. Hardly breakable. When hit with hammer gives clinking sound.
IIA	Faintly weathered	>90%	Grey-black colour, but colour change along primary discontinuities. Breakable along discontinuities.
IIB	Slightly weathered	70-90%	Partial colour change to light grey-purple. Angular blocks surrounded by discontinuities. More easily breakable.
IIC	Moderately weathered	50-70%	Total colour change to light grey-light brown. Easily breakable. When hit with hammer gives hollow sound. Rounded core stones.
IIIA	Highly weathered	20-50%	Light grey, red or brown colour. Rocks partially disintegrated and very easily breakable.
IIIB	Extremely weathered	10-20%	Brown colour. Rocks mostly disintegrated. Can be broken by hand.
IIIC	Completely weathered	<10%	Brown colour. Few core stones.
IV	Residual soil	Soil	Dark brown colour. Very few core stones.

After Tuğrul and Gürpinar (2001142f).

Anthropogenic weathering

From the information reviewed above, it therefore seems that the small amount of weathering that will have taken place on the geological outcrops should not significantly affect attempts to provenance mafic artefacts using geochemical techniques. The information further implies that the artefacts themselves should not have undergone significant amounts of weathering, especially as most of them will have been buried for most of the time since they were removed from the geological outcrop. However, only a small amount of work has been undertaken on the weathering of stone artefacts, with the most comprehensive review being Hunt's (1991) unpublished PhD thesis. As discussed above, most geological weathering usually only starts to be noticeable after thousands of years, rather than the usually shorter archaeological timescales (Hunt 1991:262f). He (Hunt 1991:335) therefore argues that this means that the weathering may either be not measurable or different weathering phenomena may be observed, especially as the working and movement of rock by humans needs to be taken into account.

Hunt (1991:300ff) argues that stoneworking may significantly increase the rate of weathering, as microfractures are created, which greatly increase the porosity of the immediate subsurface of the rock, thereby accelerating the weathering. He (Hunt 1991:310ff) also notes that the creation of microfractures depends on the type of stoneworking which took place, with battering, pecking and chiselling all causing microfractures, but with grinding not causing any damage to the rock. Hunt (1991:326ff) was also able to experimentally demonstrate the creation of microfractures by hammering, although he was not able to demonstrate that this increased porosity. However, given the observation, mentioned above, that microfractures in basalt can cause a rate of water migration of up to 25 mm per hour, it is probable that the creation of further microfractures by stoneworking will increase this rate and therefore increase the weathering of the rock. As Hunt (1991:322) notes, more research is needed to properly evaluate his initial findings.

Hunt (1991:343ff) then presents new evidence for the anthropogenic weathering of basalt and andesite. He examined two Levantine artefacts with weathering rinds, one from Jericho (from the PPN; c.8500 BC) and one from Hazor (from the LBA; c.1500 BC), both of which were manufactured from olivine basalt (Table 3.8).

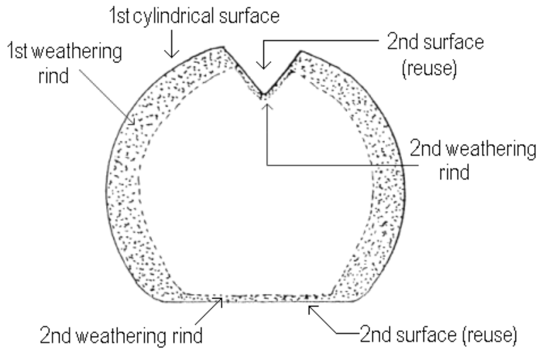
Table 3.8: Comparison of olivine basalt artefacts

Site	Period	Depth	Rock colour	Rind colour	Rind thickness
Jericho	PPN	5 m	Grey	Black	4.9 & 1.5 mm
Hazor	LBA	1-2 m	Grey	Black	0.8 mm

From Hunt (1991:343ff).

As can be seen, the Jericho artefact has two weathering rinds of differing thicknesses. This is because the artefact was originally manufactured as a conical grinding tool, before being re-worked (probably after a period of discard), by making a notch in the top and flattening the bottom surface (Fig 3.7). This led to fresh surfaces being exposed, which then began to weather (Hunt 1991:352f).

Fig 3.7: The Jericho artefact weathering rind



After Hunt (1991:353).

Table 3.8 also highlights two anomalous results which were not predicted by the previous work on geological weathering. First, the rind colour on both the artefacts is darker than the rock colour, rather than lighter, as was expected from the geological observations. Second, the first rind depth on the Jericho artefact and the Hazor rind are unexpectedly thick (Hunt 1991:351ff).

Hunt (1991:351) attempts to explain the first anomaly by arguing that the dark rinds are a characteristic of short-term weathering. Using this insight, he suggests a weathering sequence for archaeological material (Hunt 1991:414ff). This starts when stoneworking causes microfractures to form in the rock, which can be observed in freshly worked material as a white scar. Water is then incorporated into these microfractures, turning the area dark and starting the mineral alteration of the rock. This dark weathering rind eventually changes to a lighter colour than the rock, when the porosity reaches a stage where large pores outnumber the original, narrow microfractures. Although ingenious, much more work is needed to confirm this model, as Hunt acknowledges (1991:417).

To explain the anomaly of the thicker than expected weathering rinds, Hunt (1991:355ff) first notes that of more than 30 PPN tools examined from Jericho, only the one discussed above had a visible weathering rind. He therefore argues that it was the environmental conditions during use, and possibly discard, which caused the initial 3.8 mm of weathering rind, whilst only a further 1.5 mm developed after burial. However, this does not fully explain why the other artefacts do not have an observable weathering rind, unless further weathering was only able to take place after burial as a result of the initial weathering. Unfortunately, this suggestion is not discussed by Hunt.

To explain the thick weathering rind of the Hazor artefact, Hunt (1991:359) first notes that it is comparatively thicker than the Jericho artefact. Assuming a steady rate, the Hazor rind would be 2.4 mm thick after 10,500 years, as opposed to the 1.5 mm observed on the Jericho artefact after burial (although Hunt does not present these figures, thereby making his argument less clear). Hunt therefore argues that the accelerated weathering is probably due to the facts that Hazor has a considerably higher precipitation than Jericho (400 mm p.a., as opposed to 200 mm p.a.) and that the Hazor artefact was also buried closer to the surface. However, this argument rests on a number of unverified assumptions. First, it assumes that Hunt's interpretation of the creation of the weathering rind on the Jericho artefact is correct and that the artefacts would weather at a steady rate. Furthermore, it is not made clear whether other basalt artefacts from Hazor had weathering rinds, although it is more likely that they did not, given that they are not discussed. This is confirmed by this author's personal examination of a number of basaltic artefacts from Hazor, only one of which had a visible weathering rind (discussed in Chapter 7). The fact that weathering rinds only appear on a very small number of artefacts therefore requires a better explanation than the one offered by Hunt.

Given that rock weathers more quickly if exposed on the surface, rather than if buried, an alternative theory would therefore be that these artefacts were exposed on the surface for a long period of time before being buried, causing the visible weathering rinds. A way of checking this theory would be to examine small broken fragments of mafic rock in the area around Hazor for weathering rinds. However, this sort of work has not been undertaken.

Hunt (1991:409) also discusses the results of the chemical analysis of the artefacts and notes that silicon depletion was observed in the groundmass glass (thereby potentially causing erroneous analyses, if only the surface was analysed) and that biotite (where present) lost iron early in the weathering process, leading to iron staining. He (Hunt 1991:347f) notes that this iron staining was observed in some of the Jordan Valley olivine basalts, but that the Jericho and Golan material was less oxidised. Despite these observations, Hunt (1991:403) notes that analyses of the major elements show little evidence of element mobility, which, he argues, is probably due to the short-term nature of archaeological burial. Given the expected mobility of major elements during weathering, discussed above, this observation suggests that there will be no major problems with the alteration of the elemental signatures between the geological source and the artefacts. However, the work on weathering does illustrate why it is standard geological practice to remove all weathered surfaces from rock samples prior to analysis (Ramsey 1997:22). Furthermore, more work is required to verify Hunt's assertion, and to examine the degree of trace element mobility in artefacts.

Conclusion

The examination of these geological principles has shown that mafic rocks vary, due to their eruptive environment and subsequent weathering, both physically and chemically. These variations very probably influenced the selection of material used for the manufacture of mafic artefacts. Furthermore, this variation provides the potential for successfully provenancing the artefacts to their original outcrop. The next chapter will therefore examine previous geological work on mafic outcrops in the southern Levant.

Chapter 4: Outcrops of mafic rock in the southern Levant

"From stone's point of view the universe is hardly created and mountain ranges are bouncing up and down like organ-stops while continents zip backwards and forwards in general high spirits, crashing into each other from the sheer joy of momentum and getting their rocks off. It is going to be quite some time before stone notices its disfiguring little skin disease and starts to scratch, which is just as well." (T. Pratchett Equal rites*, 1987:136)*

Mafic outcrops are found throughout the southern Levant, although they are generally younger and more extensive in the north of the region. There are therefore a variety of potential sources of raw material for the manufacture of artefacts. This chapter will attempt to summarise the current state of geological knowledge of these outcrops, concentrating on the geographical location, extent and quality of exposures, and any available geochemical data. As indicated in Chapter 3 and more fully discussed in Chapter 5, it is this information which will enable artefacts to be provenanced. Changing interpretations of data will therefore not be fully discussed, nor will full details of the geological setting. Sub-surface data is also not considered, as this obviously could not have been used as a source of raw material.

There are a number of problems with attempting to synthesise the geological data on mafic outcrops in the southern Levant and in attempting to identify potential sources for artefacts. First, although there have been a number of previous attempts at synthesis, these have usually been biased towards Israel, as there is considerably less published data available for the outcrops situated in Jordan. Second, the information required to identify an outcrop as a potential source for artefacts may be difficult to obtain, as the data were not gathered for this purpose. This is especially the case when a mixture of outcrop and borehole data are used to reconstruct the geology of the area, as it is sometimes not made clear from which source specific data were derived.

Furthermore, as certain areas of the southern Levant have not been widely studied, there is an incomplete level of knowledge of the outcrops. The quality of the published data is also variable and can be partial in nature. For example, radiometric ages are frequently quoted without error limits. However, bearing in mind these caveats, a synthesis of the available data will be attempted.

Overview

Heimann (1995a:1f) divides the geological history of the southern Levant into three main stages:

1. <u>The Late Proterozoic.</u> During this stage the Pan-African orogeny (mountain-building episode) occurred, leading to tectonism and large-scale magmatism, both during and after the orogenesis. However, very few outcrops of magmatic rocks dating from this stage are found in the southern Levant, except in the south of the Sinai peninsula and in the Wadi Araba (Heimann 1995a:1f; Bogoch et al. 1993:85f).

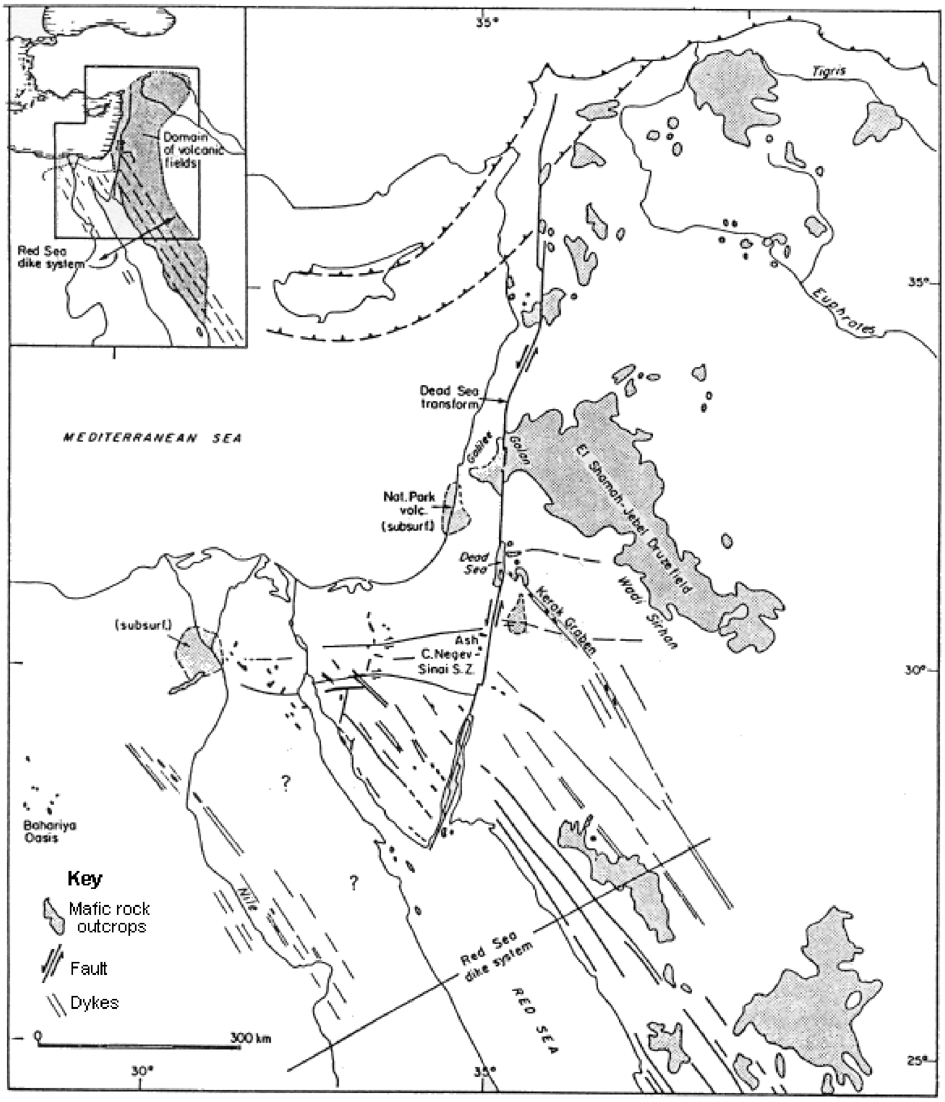
2. The Early and Middle Phanerozoic. This stage was generally characterised by sedimentation, with a limited amount of magmatism during the Mesozoic (Heimann 1995a:1f). In the Late Triassic and Early Jurassic there was a small amount of magmatism, which is only exposed in Makhtesh Ramon, a large erosional crater in southern Cisjordan (see Fig 4.3; Heimann 1995a:6; Eyal et al. 1996:31). This was followed by a more extensive period of magmatism, dating from the Late Jurassic to the Early Cretaceous (Heimann 1995a:6). During this period, magmatic activity occurred in an area extending from central Syria to the Gulf of Suez, covering an area approximately 800 by 200 km, which is known as the Levant magmatic province. The composition of the resulting rocks ranges from basanites, through alkali basalts to tholeiitic basalts, whilst the trace element and isotope signatures of all the rocks resemble those of ocean island basalts (OIBs) (Laws and Wilson 1997:460f; Garfunkel 1989:58). The magmatic activity was concentrated in three main areas, namely, the Negev, the Galilee, and around Mount Hermon (Heimann 1995a:6). Garfunkel (1989:60) therefore argues that the magmatic province was probably caused by several small, short-lived plumes.
3. The Neogene to Quaternary. This stage was characterised by extensive rifting, leading to the formation of the Dead Sea Transform and also to major volcanic activity, although the precise relationship between these two events is debated. It is during this stage that most of the mafic outcrops in the southern Levant were formed, including the Red Sea dyke system, minor outcrops on the eastern side of the Jordan Valley, and the major northern basaltic field, which covers parts of northern Jordan and the Galilee and Golan areas of Israel (Heimann 1995a:1f; Garfunkel 1989:52, 61f). During the Neogene, magmatic activity began in a vast region extending from east Africa to southern Anatolia (shown in Fig 4.1). Regionally, this is connected with the uplifting and rifting which led to the separation of the African and Arabian plates, of which the Dead Sea transform is a part (Garfunkel 1989:61). However, Garfunkel (ibid.) argues that these events are not directly related on a local scale, as volcanism often occurred hundreds of kilometres from the rifting.

   During this stage, Garfunkel (1989:61) recognises two phases of igneous activity in the southern Levant. The first phase occurred at the end of the Oligocene and in the Early Miocene, which produced intrusions of transitional to theoliitic basalts, including the Red Sea dyke system. The second, slightly later, stage produced many volcanic fields across a wide region. These consist of mildly to strongly alkaline basalts, which are more widely exposed than those of the first phase. It is this second phase which is responsible for almost all of the basaltic outcrops in the southern Levant (Garfunkel 1989:61ff). The major regional volcanic field which outcrops in the southern Levant is the North Arabian Volcanic Province, also known as the Harrat Ash Shaam (shown in

Fig 4.1). This field stretches for 500 km in a north-west direction from Saudi Arabia to Syria and covers over 46,000 km² including parts of northern Trans- and Cisjordan (Ibrahim 1996:2; Tarawneh et al. 2000:1). In Cisjordan, there are virtually no other basaltic outcrops, apart from a few small outcrops on the coastal plain and nearby foothills between Netanya and Ashdod (Garfunkel 1989:69). However, there are a number of outcrops of this age in Transjordan, south of the Harrat Ash Shaam field (Ibrahim and Saffarini 1990:318).

The geological data will now be discussed by geographical location, moving from south to north. This will enable a proper consideration of the outcrops and the available data.

Fig 4.1: Neogene to Quaternary regional magmatic activity



After Garfunkel (1989:62).

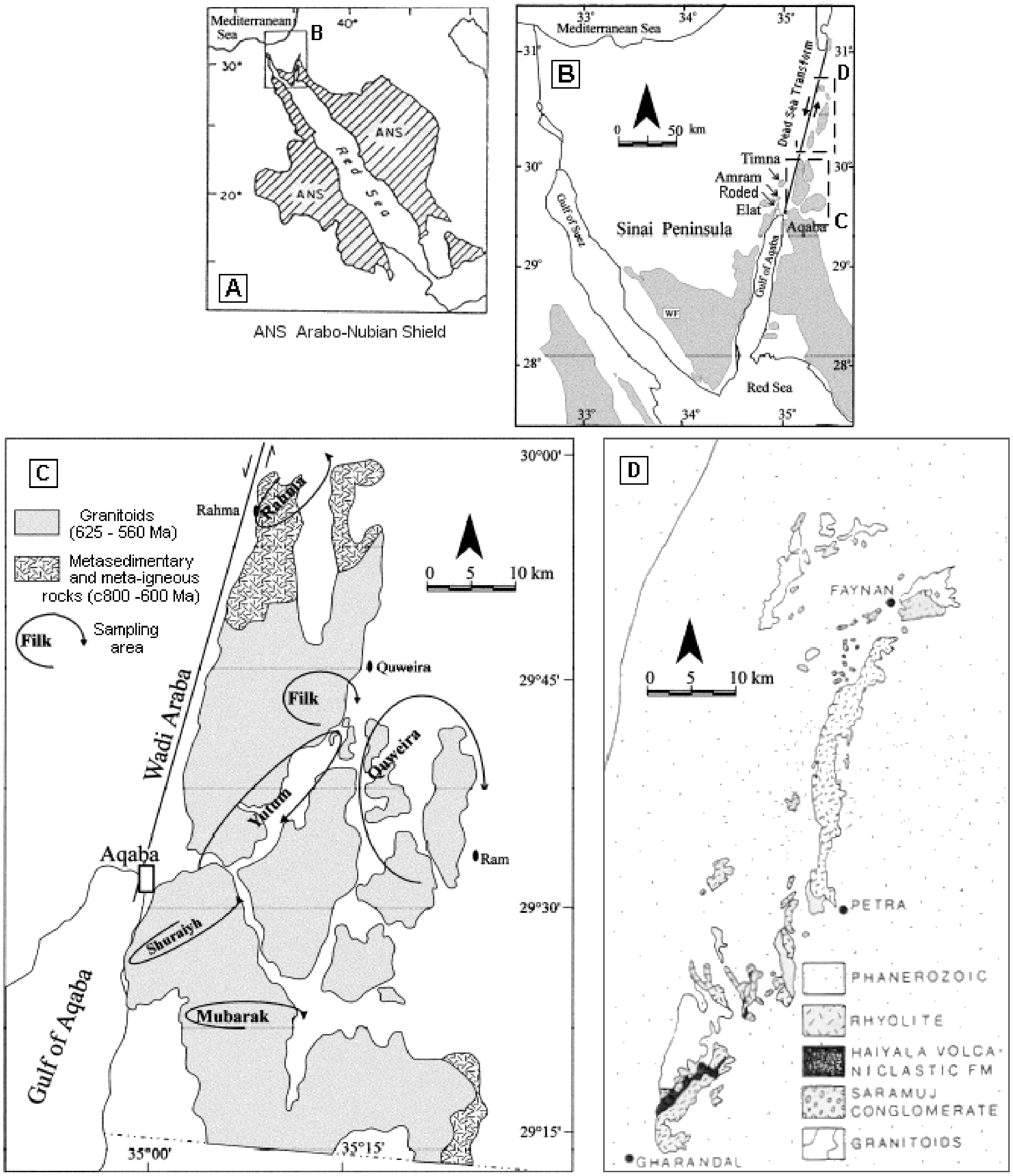
Sinai and South Transjordan

Outcrops dating from the Late Proterozoic occur in the south of the Sinai peninsula and in the Wadi Araba (the southern extent of the Dead Sea Rift), and form the northwards extent of the Arabo-Nubian Shield, which stretches down both shores of the Red Sea (Fig 4.2, overleaf). There has been little geochemical data published on these outcrops, although the main rock types are granite, syenite (the plutonic equivalent of trachyte) and diorite (Bogoch et al. 1993:85f; Abdelhamid et al. 1994:8). There are also a large number of dykes, both mafic and felsic, which were intruded between 600 and 540 Ma (Jarrar 2001:309). Abdelhamid et al. (1994:17f) report that the mafic dykes, which are composed of dacites, andesites and dolerites, are highly weathered and range in thickness from a few centimetres to more than 100 m. Jarrar (2001) reports on the major and trace element analyses of samples taken from the dykes in southern Transjordan (in the locations shown on Fig 4.2c), using ICP-OES. Jarrar (2001:314) publishes the averages of these results from the six different locations and REE data for three samples. Jarrar (2001:311) also reports that dykes from Timna and Amram (Fig 4.2b) have similar compositions to those from Transjordan. However, given their location and state of weathering, it is unlikely that they were used as a source of raw material for manufacturing artefacts.

In the modern state of Israel, approximately 90 km² of Late Proterozoic igneous rocks (mostly rhyolitic ignimbrites and diorite) are exposed, which have been dated by the K-Ar method to between c.600 and 550 Ma (Bogoch et al. 1993:85f). There are also extensive outcrops of lava flows and pyroclastics from this period exposed in the Wadi Araba, which form a 70 km long, 3 km wide belt, trending NNE-SSW, from Faynan to Gharandal (Fig 4.2d). These have been dated, using the K-Ar and Rb-Sr methods, to between 600 and 540 Ma (Jarrar et al. 1992:51ff).

Bogoch et al. (1993:86f) report on the results of a study of a mafic outcrop, exposed by a small graben (approximately 1 km by 250 m) in the Roded area of southern Cisjordan (Fig 4.2b). This outcrop consists of interbedded flows, pyroclastics and conglomerates with a total thickness of 100 m, of which the flows have a total thickness of only 15 m; similar, smaller outcrops are found nearby. Bogoch et al. (1993:87f) publish the analyses of 8 samples from the flows, with the major elements determined by ICP-AES and the trace elements by NAA. They also report that the flow samples plot as basaltic andesites and basaltic trachyandesites on the TAS diagram and are from within-plate and subduction zone settings (Bogoch et al. 1993:88f). However, using SINCLAS and the TAS diagram of Le Maitre (2002) none of the published samples plot in the basaltic andesite field, with most plotting in the basaltic trachyandesite field, whilst two fall in the trachyandesite field and one sample is classified as a tholeiitic basalt. Nonetheless, given the very limited exposures of these rocks it is unlikely that they were exploited for the manufacture of artefacts.

Fig 4.2: Sinai Peninsula and Wadi Araba



After Bogoch et al. (1993:86); Jarrar (2001:311); Jarrar et al. (1992:52).

Laws (1997:69) also reports on a small outcrop of hypabyssal alkali basalt with olivine phenocrysts, which is exposed in the erosional crater of Arif en-Naqa, in the Sinai desert, from which he only publishes one analysis. However, this outcrop is too small and isolated to be a likely source of raw material.

Jarrar et al (1992:54) report that the Wadi Araba outcrops form exposures up to 300 m thick, which consist predominately of rhyolitic lava flows, although trachybasalts and trachyandesites are also found. They also report on a 5 by 3 km exposure of fine-grained, massive, porphyritic latite near Faynan and that there are numerous dykes in the area, with their composition varying from basalt through trachyandesite to rhyolite. These outcrops are therefore a potential artefact source. Jarrar et al. (1992:56) publish a total of 73 analyses, using XRF for both major and trace elements, of which 36 are of mafic and intermediate rocks. These range in composition from basalt through to trachyte, with a small number of phonotephrite and andesite samples. They (op. cit., p.63) also note that most of the samples plot in the field of within-plate lavas, although some of the dyke samples plot in the arc lavas field. They argue that these results are consistent with a continental rift zone setting.

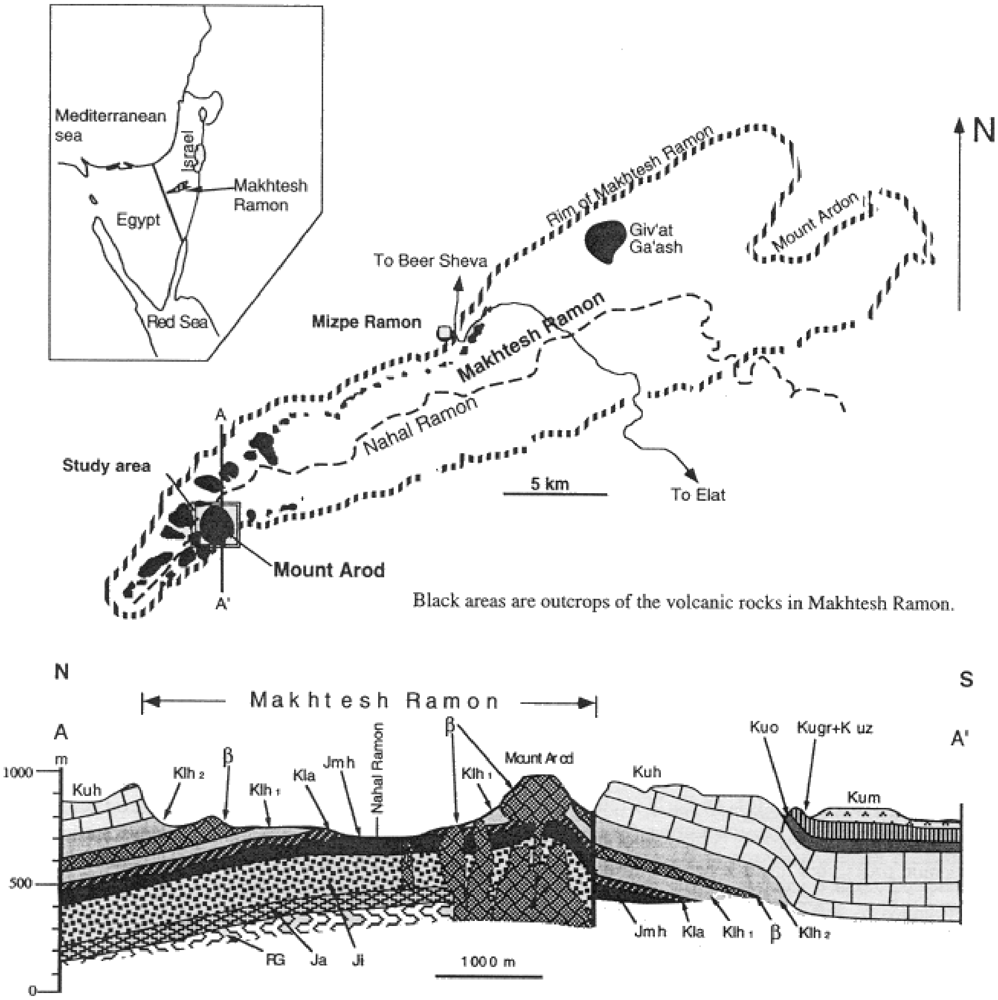
Many of the dykes in the area date from the end of the Oligocene to the Early Miocene and form the Red Sea dyke system (Fig 4.1). This stretches for several hundred kilometres, reaching as far north as the central Negev, and consists of long subalkali and tholeiitic basalt dykes (Garfunkel 1989:61; Heimann 1995a:9). These dykes have been K-Ar dated between c.25 and 20 Ma and have E-type MORB isotopic compositions (Garfunkel 1989:61; Stein and Hofmann 1992:204). However, Garfunkel (1989:61f) reports that very few outcropping dykes are found in the Negev or Sinai, making it very unlikely that they were used as a source of raw material for the manufacture of artefacts.

The Negev

Most of the magmatic rocks in the Negev, which date predominately from the Late Triassic to Early Cretaceous, are currently sub-surface in nature. The largest outcrops are found in Makhtesh Ramon (shown in Fig 4.3, overleaf), an erosional crater measuring 40 km long by 9 km wide, and surrounded by cliffs up to 250 metres high (Garfunkel 1989:56; Laws 1997:64).

Two stages of magmatism have been identified in Makhtesh Ramon. The first stage is represented by dykes, sills, a laccolith and several vents. There are a wide variety of rock types, ranging in composition from olivine-bearing basalts and trachybasalts to trachytes, possibly due to fractional crystallization (Garfunkel 1989:56ff). Garfunkel (1989:58) reports that the basalts are both alkali and sub-alkali in nature and that K-Ar and Rb-Sr dating shows that this stage formed between 145 and 125 Ma, that is, in the Early Cretaceous. Amiran and Porat (1984:14) report that in thin-section the olivine in these basalts is altered to chlorite and bowlingite, whereas in most of the outcrops of the southern Levant the olivine is altered to iddingsite. Laws (1997) reports on the analysis of four samples for major and trace elements, in addition to the six discussed below. Major outcrops of mafic rock from this stage, which have been studied in detail, include the Ramon Laccolith and Mount Arod. These will now be discussed more fully.

Fig 4.3: Makhtesh Ramon



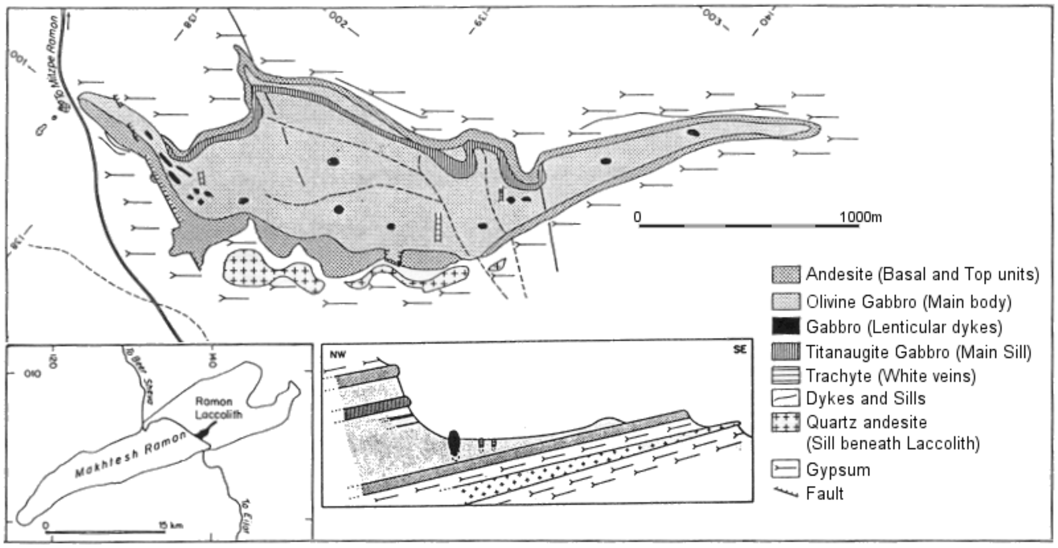
Black areas are outcrops of the volcanic rocks in Makhtesh Ramon.

After Eyal et al. (1996:32).

Eyal et al. (1996) report on Mount Arod, one of the main volcanoes in Makhtesh Ramon, which erupted during the Early Cretaceous (Fig 4.3). Mount Arod is encircled by pyroclastics, which are largely covered by a sequence of 14 lava flows, ranging from 1.3 to 6 m thick, and separated by palaeosols, 0.2 to 3.1 m thick. This formation has a total thickness of 110 m. However, the centre of the volcano is covered by a fossil lava lake (680 by 520 m), with an exposed thickness of between 70 and 125 m. In total, Mount Arod is approximately 1,500 m in diameter and up to 180 m high (Eyal et al. 1996:36f). Eyal et al. (1996:38) report that the composition of the rocks ranges from basanite to nephelinite, although they do not report any chemical analyses. Laws (1997) reports two major and trace element analyses of Mount Arod.

Rophe et al. (1989) discuss the Ramon Laccolith (Fig 4.4, overleaf), which is 3.5 km long, up to 0.8 km wide and covers an area of about 1.2 km²; it has been K-Ar dated to between 136±4 Ma and 129±4 Ma (Rophe et al. 1989:143f). Rophe et al. (1989) report that the laccolith consists of five main units, which were examined using petrography and by analysing 33 samples for the major elements (Rophe et al. 1989:144,148). Unfortunately, no trace element analyses were undertaken, but Laws (1997) reports 4 major and trace element analyses of samples from the Ramon Laccolith. The oldest unit, which forms both the basal (0.1 to 2.6 m thick) and top (up to 2 m thick) units, consists of a few black, pyroxene andesite sills, each only 0.1 to 0.3 m thick. Next oldest is the main body of the laccolith, which consists of grey-green, olivine pyroxene gabbro and is up to 90 m thick, forming the characteristic domed shape of the laccolith. Black, plagioclase-rich pyroxene gabbro is found as dykes and sills within the main body, as is the main sill, a 0.4 to 2.1 m thick black, pyroxene gabbro intrusion. The fifth unit is a network of narrow white, trachyte and microsyenite veins and dykes up to 0.2m thick.

Fig 4.4: The Ramon Laccolith



After Rophe et al. (1989:144f).

The second stage of magmatism in Makhtesh Ramon has been dated, using K-Ar and Rb-Sr, to between about 120 and 115 Ma. It is represented by up to 200 m of lava flows, which range in composition from olivine-bearing alkali basalt to nephelinite, and contain ultramafic xenoliths and xenocrysts (pre-existing crystals incorporated into the igneous rock). Laws (1997) presents the analysis of 6 samples from this stage. It is also represented by basalt outcrops at Har Arif, south of Makhtesh Ramon, and Arif en-Naqa, in Sinai (discussed above). Har Arif is a small erosional crater 15 km south of Makhtesh Ramon, in which 15 metres of olivine basalt flows are exposed, interbedded with red palaeosols. Like Arif en-Naqa, no analyses have been published (Garfunkel 1989:57f; Laws 1997:69), but it is too small and isolated an outcrop to be considered as a significant basalt source.

Laws (1997:62) also reports on a small, 250 m², alkali basalt plug found in Timna (25 km north of the Gulf of Aqaba), Ar-Ar dated to 107 Ma, which he interprets as a phreatomagmatic event.

Laws did not sample this outcrop, but, given its isolated location and the limited amount of basalt present, it is very unlikely that this outcrop would have been utilised as a raw material source, except, possibly, for the copper mining which took place nearby (Rothenberg 1990).

Furthermore, both Amiran and Porat (1984:14) and Garfunkel (1989:58) report that all these outcrops have been subject to significant erosion, with Amiran and Porat (ibid.) noting that "the basalt exposed in Makhtesh Ramon tends to fracture, and only small lumps are available." It is therefore probable that the basalt was not of a high enough quality to be manufactured into artefacts (Philip and Williams-Thorpe 1993:52f).

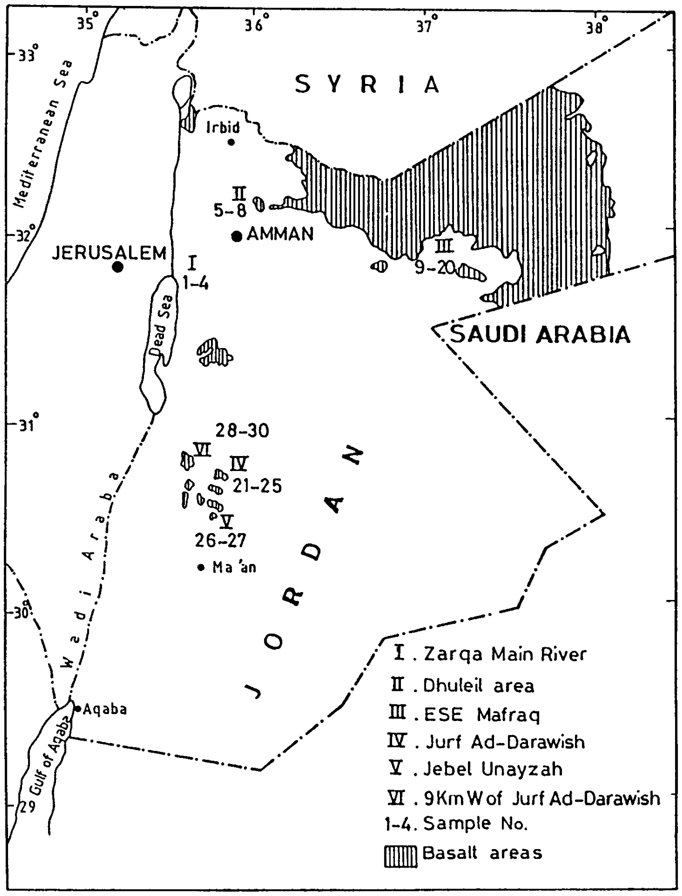
Central Transjordan and central Cisjordan

There are a number of outcrops dating from the Miocene to the Quaternary in Transjordan, south of the Harrat Ash Shaam field, which Ibrahim and Saffarini (1990:318) divide into two main groups, namely the within-rift basalts and the eastern margin basalts. The within-rift basalts consist of a number of small outcrops of basalt and tuff in the Jordan Valley. The eastern margin basalts cover 2,200 km² of southern Jordan, from Jebel Unayzah in the south to Wadi al-Mujib in the north (Fig 4.5, overleaf). Outcrops are found near Tafila and Dana and cover an area of c.28 km² to the west of Jurf ad-Darawish (Saffarini et al. 1987:198).

Saffarini et al. (1987) publish the XRF analyses of 30 samples for major and trace elements, from the 6 locations shown in Fig 4.5. When the rock types were calculated, using SINCLAS, it was apparent that the areas contain a range of rock types. The Zarqa Ma'in river samples are predominately basanite, whilst the Dhuleil area samples range from alkali basalt, through hawaiite to basanite. Both are potential sources of raw material. The south-eastern Mafraq area is predominately alkali basalt, whilst the samples from the areas south of the Dead Sea are mostly nephelinite and melanephelinite with some alkali basalt. South-eastern Mafraq was probably too remote to have been a significant source of raw material, but the outcrops south of the Dead Sea could potentially have provided raw material for artefact manufacturing.

Al-Fugha (1993) also studied samples from three outcrops south of the Dead Sea, namely Jurf ad-Darawish (Fig 4.5), Tafila and Al-Qiranah (east of Dana) (Fig 4.6, below). Al-Fugha (1993:97) notes that the principal phenocrysts found in the rocks are olivine, augite and nepheline and reports that the olivine is often partially or completely altered to iddingsite. He reports on the analysis of a number of samples, but unfortunately only for major elements and a very few minor elements. The samples were largely basanites, with some nephelinites.

Fig 4.5: Sample locations of Saffarini et al. (1987)

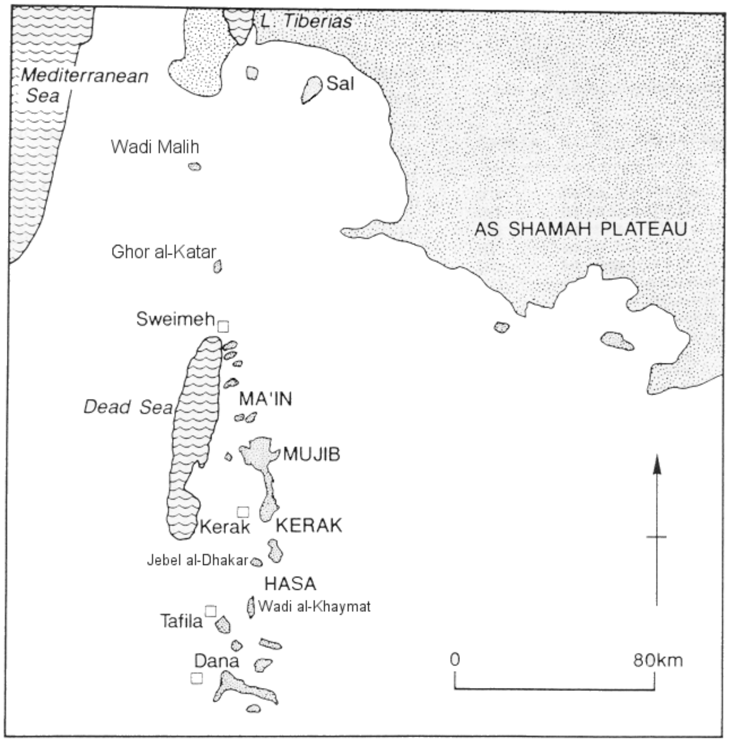


From Saffarini et al. (1987:194).

The eastern margin basalts also include the basalt outcrops of the Kerak plateau, (Fig 4.6). These outcrops have similar compositions to the other outcrops in the area (Saffarini et al. 1985) Philip and Williams-Thorpe (1993) publish 4 analyses of major and minor elements of samples from the Kerak outcrops. Ibrahim and Saffarini (1990:319) report on the analyses of 30 samples from the eastern margin basalts, using atomic absorption spectrometry (AAS). The samples were mostly analysed for major elements, with only a few trace elements analysed. Ibrahim and Saffarini (1990:323) note that the analyses show that, although most of the samples from the eastern margin basalts fall within the basanite field, there are a significant number of samples which also fall within the hawaiite and alkali basalt fields.

There have been a number of other studies examining the Transjordanian outcrops (Fig 4.6). Saffarini et al. (1985) report that one of the main within-rift basalt outcrops, Ghor al-Katar, consists of dolerite, but only present major element analyses for it. Given its location in the Jordan Valley this outcrop was potentially a source of raw material, but Wright et al. (in press, p.11) report that the outcrop was too highly eroded to have been workable. It is therefore unlikely that this outcrop was exploited. However, Philip and Williams-Thorpe (1993) report the analyses of two samples from this outcrop, enabling this theory to be tested.

Fig 4.6: Mafic rock outcrops in central and northern Transjordan



After Philip and Williams-Thorpe (1993:53); Laws (1997:137).

Shawabekeh (1998:5) notes the existence of a number of basaltic plugs by the shore of the Dead Sea, and along the wadis draining into the sea, most notably the Wadi Zarqa-Ma'in. Other important outcrops include the Sweimah outcrops, and outcrops along the Wadi Dardur, south of Sweimah. Duffield et al. (1988) publish analyses of major and minor elements, using XRF and NAA, of 3 samples, one from Sweimah and two from the Wadi Zarqa-Ma'in. Laws (1997) reports on analyses of one sample from the Wadi Dardur and one from dykes in the Wadi Himara, 1 km north of the Wadi Zarqa-Ma'in. Shawabekeh (1998:5) reports another three analyses of major and minor elements of samples from the Wadi Dardur, in addition to publishing the sample analysed by Laws (1997). These four samples are all from different rock types, namely hawaiite, tholeiitic basalt, basanite and mugearite. This shows the wide range of mafic rocks present in the eastern margin outcrops. Shawabekeh (1998:6) also publishes a further 36 analyses from two outcrops, but only of major elements. Philip and Williams-Thorpe (1993) publish a further 9 major and minor element analyses from these outcrops, which may well have been exploited, given their proximity to past settlements.

Khalil (1992:46) reports on the mafic outcrops from the Wadi al-Mujib and the nearby Wadi al-Hidan. He notes that these vary in thickness from a few metres to over 100 m, and are found on both sides of the wadi. He also reports that the basalt contains olivine phenocrysts and generally occurs in columnar jointed flows 10 to 20 m thick, which alternate with thin layers of vesicular basalt. Again, this is a potential source for raw material, with Khalil (1992) publishing averages for the Mujib and Hidan outcrops. Philip and Williams-Thorpe (1993) also publish two analyses from the Mujib outcrops.

Nasir (1990) reports on the averages of XRF analyses for major and trace elements from samples from Ma'in (8 samples) and Tafila (7 samples), which plot as basanite; samples from Kerak (4 samples) and Unayzah (5 samples), which plot as alkali basalt; and Kerak (5 samples), which plot as hawaiite.

Tarawneh (1988:29) reports that two basaltic plugs are situated in the Wadi al-Hasa. One plug, Jebel al-Dhakar, (Plate 1) is situated in the Wadi al-Hasa itself, whilst one is situated in a tributary wadi (Wadi al-Khaymat; Plate 3). In general, the rocks are porphyritic and fine grained. The lower parts of the flows are blocky and contain few vesicles, whilst the upper parts of the flows are vesicular, most of which are filled with secondary minerals. Given the past human exploitation of this, the only perennial wadi in southern Transjordan, these are potential raw material sources for artefacts, either from the outcrops themselves, or from boulders washed downstream. Unfortunately no geochemical data are given for them.

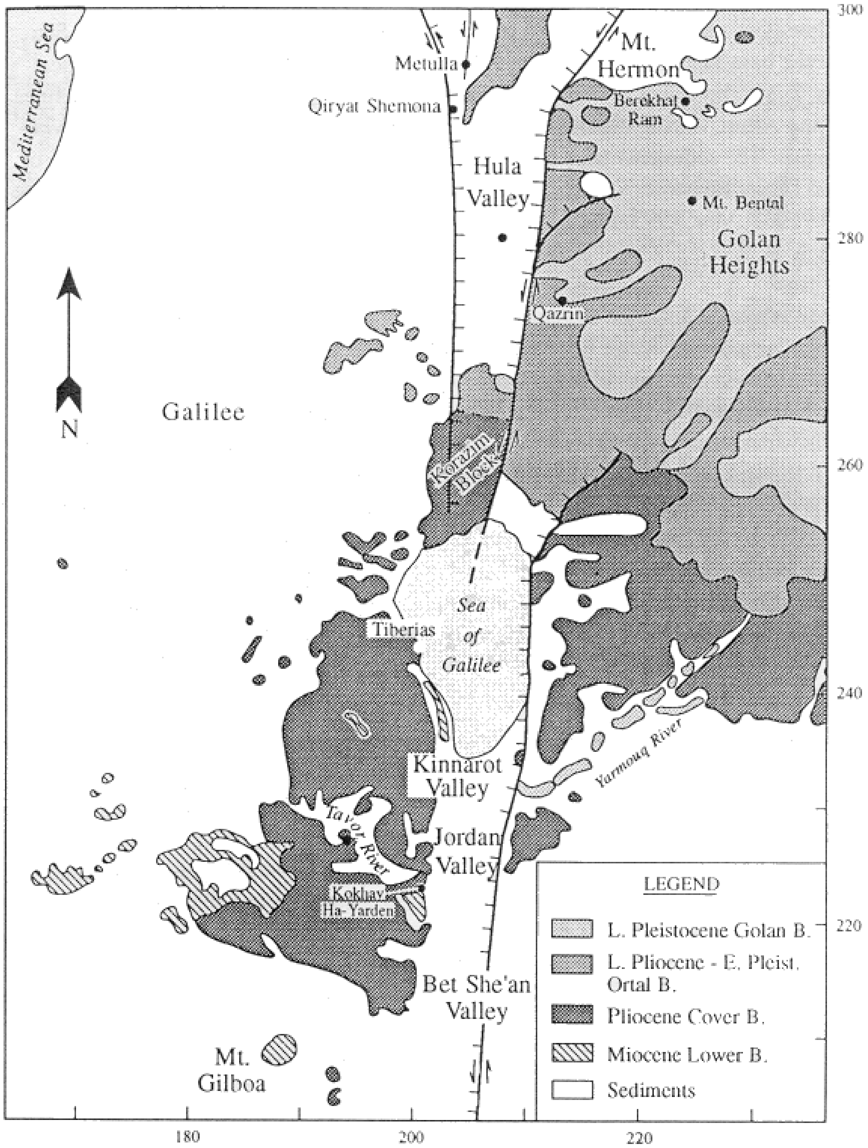
Wadi Malih and Wadi Fari'a are the two main outcrops on the Cisjordan side of the Jordan Valley, both of which only contain limited exposures of mafic rock (Laws 1997:74). Laws (1997:124) reports on two Ar-Ar dates from Wadi Malih, with the lower flow sample dating to 136±1 Ma, and the upper flow sample dating to 132±1 Ma, meaning that both flows were erupted during the Lower Cretaceous. Laws (1997) also publishes three major and trace element analyses from Wadi Malih, but does not report any from Wadi Fari'a, although as these outcrops are from the same eruptive event as the Wadi Malih outcrops, they probably have similar elemental compositions. Given the location of these outcrops, it is possible that they were sources for the manufacture of artefacts (cf. Wright et al. in press, p.7).

Williams-Thorpe (n.d.:3f) reports that there are two very small outcrops of basaltic rock on the inner coastal plain of southern Cisjordan. Yesodot is a 1m thick intrusion of strongly weathered amygdaloidal olivine basalt into marlstone and is almost certainly too small and weathered to ever have been exploited, while Hulda was an outcrop 20-30m thick, mixed with soil, which was also strongly weathered. Furthermore, when attempts were made to re-examine this outcrop in 1990, it could not be found, probably as it was completely covered by cultivation. Williams-Thorpe (ibid.) notes that this outcrop could have been used in the past, as it may have been better exposed and less weathered, but she argues that it was probably not exploited to any great extent.

Galilee and Golan

The Golan is a basaltic plateau, covering an area of 1,300 km², north-east and east of the Sea of Galilee (Heimann and Weinstein 1995:62). The Galilee is the area to the north-west and west of the Sea of Galilee (Fig 4.7). This area contains a number of separate, smaller fields, which will be discussed individually. Laws (1997) publishes 11 analyses from various outcrops in the Galilee and Golan, while Williams-Thorpe and Thorpe (1993) publish the major and trace element analyses, using XRF, of 13 samples from the Tiberias area, 5 from the southern Golan, and 1 from Berekhat Ram (Fig 4.7).

Fig 4.7: The Galilee and Golan



From Heimann (1995b:17).

Garfunkel (1989:65) argues that the volcanic activity in these areas developed in several distinct phases, during the Early to Middle Miocene, the Late Miocene, the Pliocene, and the Quaternary (these phases are shown in Fig 4.7). He also notes that the basalts often contain ultramafic xenoliths, mainly of spinel lherzolite, while their trace element and isotopic signatures resemble those of ocean island basalts.

The Samaria-Galilee field

Most of the Samaria-Galilee field (dating from the Late Triassic to Early Cretaceous) is sub-surface in nature, including the Tayasir Volcanics, which are up to 400 m of extrusive tholeiitic to alkali basalts, usually with olivine phenocrysts (Garfunkel 1989:59).

The Mount Hermon field

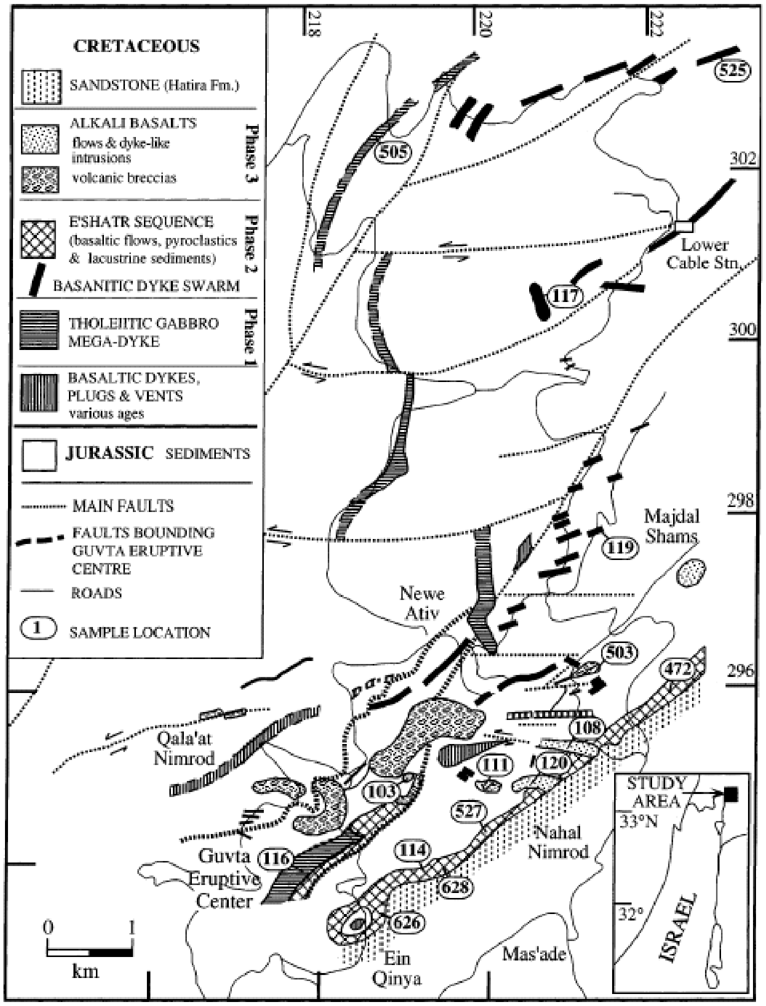
Early Cretaceous magmatism is common in the south of Mount Hermon, forming flows, dykes and intrusions (Heimann 1995b:18; Garfunkel 1989:59) (Fig 4.7 shows the location of Mount Hermon, whilst the flows are shown on Fig 4.8, overleaf). Garfunkel (1989:59) argues that this field is an eastward extension of the Samaria-Galilee field, offset by the Dead Sea transform, and has similar geochemical properties. Shimron (1995:46ff) and Wilson et al. (2000:54ff) note that there were three phases of magmatism in the Mount Hermon area (Fig 4.8):

1. A tholeiitic microgabbro (dolerite) mega-dyke, which has been dated to c.146-140 Ma.
2. The E'Shatar sequence, which is 200-400 m thick and consists of lava flows, pyroclastics and lacustrine sediments, and has been dated to c.127-120 Ma. Redetermining the rock types using SINCLAS, the samples are hawaiite, tholeiitic basalt and basanite, whilst the dyke swarm is composed of hawaiite and alkali basalt.
3. Diatreme pipes, breccia dykes and basaltic cones, which are phreatomagmatic in nature. Laws (1997:133) reports that the diatreme pipes are often highly weathered, with high clay and calcite contents. It is therefore probable that these were not used as raw material sources. This stage has been dated to c.120-115 Ma, whilst, using SINCLAS, the rock types of the samples are given mostly as alkali basalt and occasionally as basanite.

Wilson et al. (2000) published major and minor element analyses, using ICP-AES and ICP-MS, of 15 samples, representing all three phases. Laws (1997) reports a further 34 major and minor element analyses of samples from Mount Hermon. Laws (1997:96) also notes that there are a small number of very weathered outcrops on the south-western flank of Mount Hermon, but does not give any analyses for them. However, given that these outcrops are very weathered, and their proximity to larger, better quality, outcrops it is doubtful that these were exploited to any significant extent.

Both Shimron (1995:52) and Wilson et al. (2000:60) report that the trace element signatures of samples from Mount Hermon resemble ocean island basalts, except those of phase 1, which are from a different magmatic phase and were probably formed with greater partial melting than the rocks of phases 2 and 3. Laws and Wilson (1997:460f) also examine the trace element data from both Mount Hermon and the other areas of the Levant magmatic province and conclude that "there is a clearly as much variation between samples from Mt Hermon as between samples from all other areas." This conclusion therefore illustrates the importance of using as many samples as possible to ensure that the artefacts are accurately provenanced.

Fig 4.8: Mount Hermon outcrops



From Wilson et al. (2000:56).

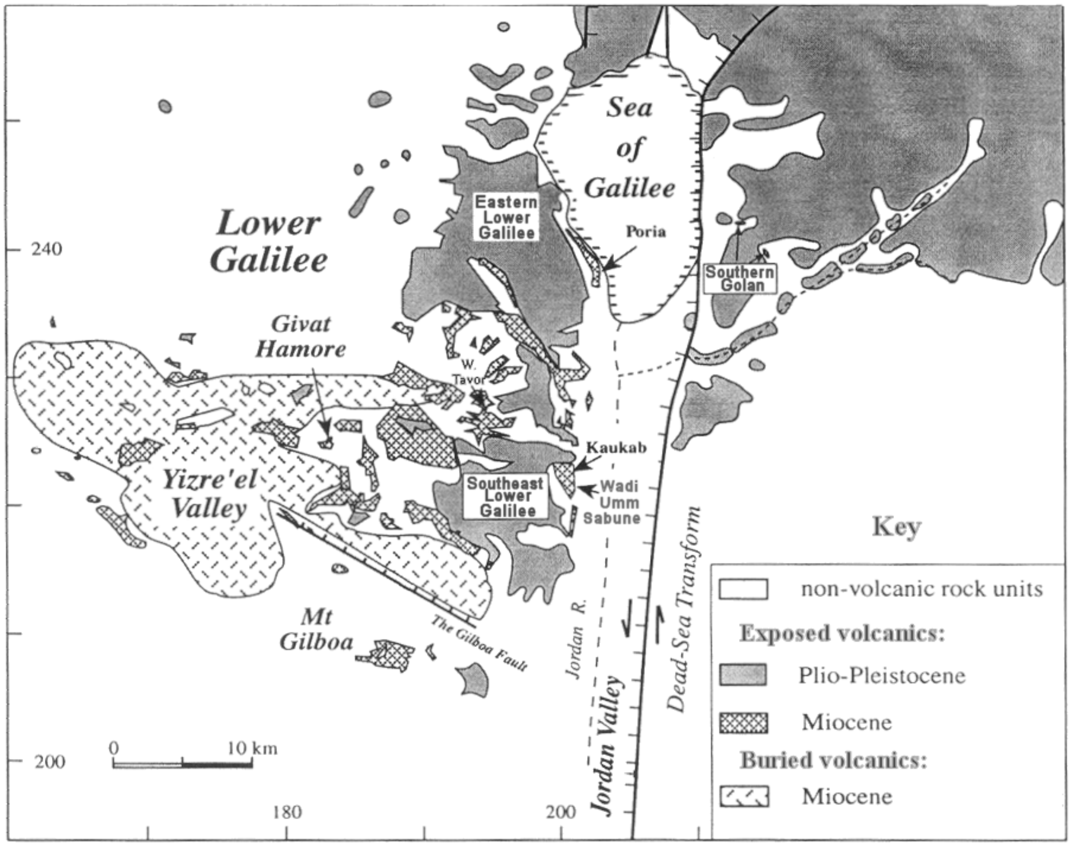
The Mount Carmel field

Garfunkel (1989:61) reports that magmatism dating to the Late Cretaceous occurred only in the Mount Carmel area, forming basalt flows and pyroclastic deposits and lasting approximately 10 Ma. This appears to be confirmed by the K-Ar dates reported by Weinstein-Evron et al. (1995:38f) of between 88.0±1.8 Ma and 77.6±1.6 Ma, although, as already noted, Laws (1997:9) reports that many south Levantine K-Ar dates are erroneous. Laws (1997:86) reports that the outcrops are largely pyroclastic in nature and basic in composition, with nine volcanic centres identified. He also notes that basalt outcrops also occur south of the Mount Carmel area, which are probably of the same age. Laws (1997) presents 4 analyses of samples from Mount Carmel which SINCLAS classifies as tholeiitic basalt, alkali basalt and basanite. Laws (1997:86) also notes that both non-vesicular and vesicular rocks are present, including in the same outcrop, but that many of the vesicular rocks have been affected by low-grade metamorphism.

Lower Basalt

In the south-east of the Galilee Basin a sequence of flows, up to c.600m thick, are found over an area of c.1,000 km². These are named the Lower Basalt and have been dated to between 17 and 8.5 Ma (Early and Middle Miocene) and have an estimated eruptive volume of 300 km³, most of which is now buried, as shown in Fig 4.9 (Garfunkel 1989:65f; Baer and Agnon 1995:23; Heimann et al. 1996:68; Weinstein 2000:868). Weinstein (2000:865) reports that the volcanic centre migrated from Poria (west of the Sea of Galilee) to the Yizreel Valley, in a south westerly direction, due to the development of an extensional basin.

Fig 4.9: Exposed and buried igneous rock in the Galilee area



After Weinstein (2000:868).

In the southern Golan there was only a minor amount of volcanism, dating to between 15 and 10 Ma, most of which is now hidden under younger flows (Garfunkel 1989:66), although the rocks are exposed in some wadi cuts (Heimann and Weinstein 1995:62).

Weinstein (2000:869f) reports on the petrographic analysis of 80 samples from Lower Basalt outcrops and the subsequent analysis of 52 samples for major and minor analysis, using XRF, NAA and ICP-MS. Petrographically, the samples had a fine-grained porphyritic texture, with 5-20% phenocrysts, mostly of olivine, which was often partly or wholly altered to iddingsite. Clinopyroxene phenocrysts and amygdales of calcite and zeolite were more rarely present. The analysed samples were selected on the basis of relative freshness, whilst the calcite and zeolite amygdales were removed (Weinstein 2000:870). This therefore raises questions about how comparable these results will be, both with analyses of other geological samples, and especially with archaeological samples.

Using SINCLAS, the samples range in composition from tholeiitic basalts to nephelinites. Furthermore, Weinstein (2000:876f) notes that the older samples from East Galilee and the Golan are alkali basalts, whilst those from the Yizreel Valley are basanites and nephelinites. The samples from Kaukab include alkali basalts, basanites, hawaiites and mugearites. Chondrite-normalised REE plots of all the samples have a positive europium anomaly, whilst the basanites and nephelinites have steeper REE slopes than the other rock types.

Intermediate Basalt

The Lower Basalt extrusion was followed by a period of reduced magmatism, although a few flows were erupted close to the Dead Sea transform, which are named the Intermediate Basalt and have been dated to between 7.5 and 5.5 Ma (Late Miocene) (Garfunkel 1989:66; Heimann et al. 1996:68).

Cover Basalt

During the Pliocene, beginning at about 4 Ma, the Dead Sea Rift started to develop. The rift is composed of a number of pull-apart basins (including the Dead Sea), separated by push-up blocks. In northern Israel there are three main basins, the Sea of Galilee, the Hula valley and the Ayun, which are separated by the Korazim Block and the Metulla High, respectively (Heimann 1995b:15).

Contemporaneously, a major new phase of volcanic activity began on both sides of the Dead Sea transform. This produced up to 200m of alkali olivine basalts, which are named the Cover Basalt (Garfunkel 1989:66ff; Heimann et al. 1996:58). This sequence is exposed in the south-east Galilee, the south and central areas of the Korazim Block, the Golan, and north-west Jordan, and has been dated to between 5.5 and 3.3 Ma (Heimann et al. 1996). However, Heimann et al. (1996:68) also note that the eruptive centres of the basalt were moving northwards with time, meaning that in any given area the maximum duration of volcanic activity was less than 1 million years.

Heimann et al. (1996:57) report that the currently exposed volume of the Cover Basalt is approximately 80 km³ in north-east Israel and 500 km³ in Jordan. However, they (Heimann et al. 1996:58) also report that individual flows are usually only 3 to 5 m thick and in many cases are separated from each other by 1 to 2 m of palaeosols. When plotted on a TAS diagram, samples from the Cover Basalt in the Golan and the Dead Sea Rift fall within the alkali-basalt field, whilst samples from the Cover Basalt in the Galilee range from alkali-basalt to basanite (Heimann et al. 1996:58).

Ilani and Peltz (1997) present a detailed study of the part of the Cover Basalt exposed near Hamadya, which is located on the western side of the northern Beth Shean valley (below Kokhav Ha-Yarden on Fig 4.7). Ilani and Peltz (1997:327f) report that in this area the exposed volcanic section is more than 190 m thick, and consists of five distinct episodes; three basaltic lava flows, alternating with two pyroclastic beds. They report that the lower flows are more than 50 m thick, with the base not exposed, and consist of sub-alkaline olivine basalt, which is vesicular in the upper part. The middle flow is 3 to 4 m thick and is a highly vesicular olivine alkali basalt, the lower part of which consists of angular fragments 0.2 to 15 mm in diameter. The upper flows are olivine alkali basalt and vary in thickness from 20 to over 100 m. Unfortunately, Ilani and Peltz only present major element analyses of the samples.

Other outcrops

Igneous rocks were also extruded in the Hula Valley, which have been dated to between 3.5 and 1.7 Ma, while in the eastern Galilee, western Golan and on the north Korazim Block there were two pulses of volcanism, dating to around 2.5 and 1.7 Ma (Garfunkel 1989:68). However, Heimann (1995c:33) reports that the south and central areas of the Korazim Block are covered by both the Cover Basalt and the Ruman Basalt, which has been dated to between 2.9 and 2.2 Ma, while the northern areas are covered by the Yarda Basalt, which has been dated to the Quaternary, between 0.9 and 0.8 Ma.

Garfunkel (1989:68) also reports that in the Quaternary (starting 1.8 Ma) volcanism only occurred to the east of the Dead Sea transform, including much of the exposed basalt in the Golan. Heimann and Weinstein (1995:62) report that the two main units are the Ortal Basalt and the Golan Basalt, which, along with the Cover Basalt (discussed above) form the Bashan Group. The Ortal Basalt is exposed in the central and northern Golan, and has been dated to between 2.9 and 1.0 Ma (the Late Pliocene and Early Pleistocene). The Golan Basalt is exposed in the north-east Golan, and has been dated to between 0.8 to 0.1 Ma.

Heimann and Weinstein (1995:62ff) report that the Cover and Ortal Basalt are only represented by basaltic flows, whilst the Ortal Basalt also includes scoria cones and tuffs. They report that for the Bashan Group basalts, the majority of the phenocrysts are usually olivine, whilst clinopyroxene phenocrysts are also common, especially in some of the younger basalts, where the majority of phenocrysts consist of clinopyroxene. Plagioclase phenocrysts also occur. Furthermore, Heimann and Weinstein (1995:64f) report that on the TAS diagram, the Cover Basalt consists mainly of alkali basalts, the Ortal Basalt consists mainly of hawaiites and the Golan Basalt consists mainly of basanites. However, there is a considerable amount of overlap in composition between the three different units.

Weinstein et al. (1994) present the results of a geochemical study of the Ortal and Golan basalts. The majority of the samples are classified as basanite or hawaiite, with a few being alkali basalt. Weinstein et al. (1994:66) note that "the chemistry of the two formations is similar, and many variation diagrams reveal overlapping ranges." They go on to argue that "clear identification" can be made using MgO, with MgO being higher than 7 wt% in the Golan Formation, and only 5 to 7 wt% in the Ortal Formation. However, although this generalisation is true for most of the analysed samples, the samples from the Kibbutz Basalt, part of the Golan Formation, have an average MgO concentration of 5.2 wt% (Weinstein et al. 1994:67). This problem is only briefly mentioned (Weinstein et al. 1994:78), but clearly implies that this method cannot be used to discriminate between the two formations. This illustrates the limitations of attempting discrimination using major elements.

There are also a group of flows which originated on the west slope of Mount Hermon and are found to the north of the Hula depression, close to the edge of the Golan shield. These flows are named the Hasbaya Basalt, and have been dated to between approximately 1.4 and 0.8 Ma (Garfunkel 1989:69). Heimann (1995b:18) also reports that Pleistocene basalts from the Golan covered the lowermost slopes of Mount Hermon.

North Jordan

As mentioned above, the major regional volcanic field which outcrops in the southern Levant is the North Arabian Volcanic Province, also known as the Harrat Ash Shaam (shown in Fig 4.1). This field stretches for 500 km in a north-west direction from Saudi Arabia to Syria and covers over 46,000 km² including over 11,000 km² of northern Jordan and parts of the Galilee and Golan areas of Israel (Ibrahim 1996:2; Tarawneh et al. 2000:1).

The exposed volcanics have been subdivided into five groups, which belong to the Harrat Ash Shaam Basaltic Super-Group (Ibrahim 1996:2). Ibrahim (1996:14) and Tarawneh et al. (2000:20) report that a wide variety of rock types are found, which comprise, in descending order of abundance, alkali basalt, nepheline-bearing basanite, hawaiite and nephelinite. The rocks also contain a large number of mafic and ultramafic xenoliths. Unfortunately no trace element analyses are provided.

Garfunkel (1989:63) argues that the Harrat Ash Shaam field is not a plateau basalt, as generally thought, but, rather, consists of a number of overlapping low shield volcanoes. He also argues that this volcanic field can be divided into two morphologically distinct parts, with the southern part being more eroded and faulted and with a well-developed drainage system, unlike the northern part of the field. He argues that this is due to the southern part being older than the north. This argument is generally supported by the recent work of Tarawneh et al. (2000).

Tarawneh et al. (2000:26,31) report that, based on K-Ar dates from 100 samples, the volcanism of the Harrat Ash Shaam Basalts can be divided into three main phases. These are:

1. The Oligocene phase (26 to 22 Ma), which is exposed in the south and central parts of the plateau.
2. The Middle to Late Miocene phase (13 to 7 Ma), which is exposed in the south-east parts of the plateau and consists of 6 different volcanic units.
3. The Late Miocene to Quaternary (6 to <0.5 Ma), which is exposed in the north-west parts of the plateau, especially the Azraq and Safawi regions, and consists of 8 different volcanic units.

Furthermore, Tarawneh et al. (2000:31) report that there are three main phases of dykes: the first (c.23 Ma) consisting of basalt with pyroxene and iddingsitised olivine phenocrysts; the second (c.9 Ma), consisting of basalt with olivine phenocrysts, some of which had been altered to iddingsite; and the third (c.1.7 Ma), consisting of basalt with fresh olivine phenocrysts. However, as already mentioned, Laws (1997:9) argues that within the southern Levant "K-Ar data rarely agree with stratigraphic ages, which suggest that where only K-Ar data are available, they should not be automatically relied upon." This point is not discussed by Tarawneh et al. (2000) and it is therefore not clear how applicable their K-Ar data are, especially given the extensive weathering of the southern part of the plateau.

Tarawneh et al. (2000:11) also note that dykes are found in most rock units, and are usually up to 20 m thick, although some are up to 100 m thick. Exceptionally, the Qitar al-Abid dyke is approximately 100 km long and varies in width from 100 to 500 m. Al-Malabeh (1994:519) also reports that, prior to the last magmatic eruption, a number of prominent scoria cones were produced, especially in the west of the field, which are still visible. Al-Malabeh (1994) publishes 20 major and trace element analyses, using ICP-AES, from two of these scoria cones, namely Jebel Aritain and Jebel Fahem situated to the west of Dhuleil (shown in Fig 4.5). He also publishes average REE data from each of these cones. Therefore, although these deposits were probably not directly used as a source of raw material, they should represent the composition of the last magmatic eruption in the Harrat Ash Shaam and will therefore be used. SINCLAS classifies all but one of the analyses as alkali basalt, with the other sample being classified as a hawaiite. Furthermore, Nasir (1990) reports the average of 10 basanite samples and the average of 6 alkali basalt samples, all analysed using XRF for both major and trace elements.

There are also a number of smaller outcrops in northern Transjordan, which are not part of the Harrat Ash Shaam. The area east of the Golan is also covered in Quaternary basalts. Two large flows are also known to have originated in this area, namely the Yarmouk flow, which flowed along the gorge of the Yarmouk River and into the Jordan Valley, and is dated at 0.8 Ma. The second flow, the Raqqad flow, is dated to 0.3 Ma and also descended into the Yarmouk River gorge, although it did not reach the Jordan Valley (Garfunkel 1989:69).

Philip and Williams-Thorpe (1993) publish two analyses of samples from the Yarmouk River and two analyses from the outcrop by Sal (Fig 4.6). Philip and Williams-Thorpe (2001) publish two further samples from the Yarmouk, and a further four from other outcrops south of the Harrat Ash Shaam.

Conclusion

Stein and Hofmann (1992) report on a geochemical study of basalts throughout Israel, dating from the Mesozoic onwards. They (op. cit., pp.199,203) note that the major and trace element compositions are generally similar in most of the basalts erupted from 200 Ma onwards, although they do report that there is a wide range of variation in the light REE. They also note that the geochemical signatures of the basalts are very similar to those of ocean island basalts. However, the exception to this observation is the samples from the Red Sea, which have different elemental patterns, being similar to MORBs. Stein and Hofmann (1992:203ff) argue that these patterns can be explained by postulating the existence of a fossil plume head at the base of the lithosphere, meaning that all basalts were derived from this source. However, during the rifting leading to the Red Sea this source was quickly depleted, thereby leading to the eruption of MORBs in this area. This has important implications for the provenancing of basalts, as it reinforces the need for analyses of the REE.

From the data discussed above, it can be seen that a large number of magmatic eruptions have occurred in the southern Levant, leading to a number of potential outcrops for the manufacture of mafic artefacts. In total, 344 analyses of geological samples (or averages of samples) were collected from the literature. The creation of a database from these samples will be discussed in Chapter 7. The current level of knowledge of these outcrops is uneven, especially for the Transjordanian outcrops, where relatively few analyses have been published, and even fewer measuring the REE and HFSE, as will also be discussed in Chapter 7. Given the strong possibility that these outcrops were the source for at least some of the basaltic artefacts (Philip and Williams-Thorpe 2001:26f), it can be seen that it is necessary to analyse more samples from these locations.

There are undoubtedly more analyses, both published and unpublished, that have been made on samples from the southern Levant, especially from Cisjordan. However, the analyses gathered represent most of the more recent analyses that have been undertaken and were available in the literature. Although not all of the outcrops can be regarded as having been completely characterised by these analyses this database is significantly larger than those used for any of the previous provenance studies discussed in Chapters 1 and 2. This should therefore enable the provenance study to undertaken on a more secure basis than was previously possible. However, to properly undertake such a study it is first necessary to review the extensive theoretical literature on the subject. This will therefore be the subject of Chapter 5.

Chapter 5: Provenance studies and procurement systems

> *"All archaeological inference about past societies ... hinges critically upon an understanding of the relationship between material and non-material aspects of culture and society: left with only remnants of the former, we seek to use them to perceive and comprehend the latter. That is the essence of the archaeological endeavor." (Dietler and Herbich 1998:233)*

The study of procurement systems is now an important aspect of the archaeological investigation of a society, due largely to the increasingly sophisticated analytical instruments and procedures now available to archaeologists (Renfrew 1975:39; Knapp and Cherry 1994:1f). This type of study generally begins when artefacts are discovered which are thought to have been manufactured from a non-local material, which has therefore been imported onto the site (Torrence 1986:3). As Dietler and Herbich argue in the opening quotation, there are two main components to such an investigation. First, the material remains need to be examined, including determining the provenance of the artefact's material. Second, the results of this study need to be related to the past human behaviour in order to reconstruct the procurement system or systems which operated. To understand these properly it is necessary to place them in the context of the society in which they were embedded. This can be done by examining both the technology and the wider socio-economic system of the society, which constrain the possibilities of how the procurement system was organised (Tite 2001:443). These individual components will now be discussed in more detail.

Provenance

Provenance studies fall within the field of geoarchaeology, which Rapp and Hill (1998:1) term the application of "earth-science disciplines and subfields to the study of the archaeological record." Rapp and Hill (1998:134) also define "provenance" as the specific geological deposit which is the origin of the artefact's material. A problem with this precise definition it that it does not take into account the possibility of material from more than one geological source being used to create a single artefact. Although this caveat is not relevant to lithic studies, it may well be the case for metals and pottery, and so requires the addition of "or deposits" to be more widely applicable. This definition will therefore be adopted in this thesis.

Rapp and Hill (1998:134f) argue that there are three major components to the process of determining the provenance of an artefact. These are:

1. The location and sampling of all geological deposits which are potential sources of the artefact's material.
2. The chemical analysis of the samples, using a technique which will provide diagnostic signatures for both the geological deposits and the artefacts.
3. The mathematical analysis of the data, using a technique which allows the artefacts to be probabilistically assigned to a source.

There are two basic assumptions in this process:

1. The artefact has not undergone any chemical or physical changes.
2. All potential source deposits are adequately represented.

If these two assumptions are not met then the study cannot be considered reliable (Rapp and Hill 1998:135). Rapp and Hill (ibid.) report that the first assumption is generally unproblematic for lithic materials and, as discussed in Chapter 3, this seems to hold true for basaltic artefacts. However, the second assumption is more problematic. The most basic problem is actually locating all the sources which may have been exploited in the past. Therefore, a necessary precursor to any archaeological provenance programme is detailed geological mapping of the resources in the area. Indeed, even in areas where it is thought that this has taken place, provenance studies may highlight the need for more detailed mapping, by indicating the existence of a previously unknown source (cf. Mallory-Greenough et al. 1999:235). Furthermore, sources which have been exploited in the past may have been worked-out, eroded, buried or removed, thereby meaning that they cannot be sampled. This will lead either to the incorrect provenance of artefacts or to artefacts which cannot be accurately provenanced, showing that not all the sources have been characterised.

Conversely, there is also the problem that sources can be sampled which were not available to the past human societies either because they have been exposed only in the recent past by activities such as mining or construction, or because they were only created in the more recent past (for example, eruptions creating new basaltic-rock outcrops). To overcome these problems Glascock et al. (1998:22) suggest that the best approach is to identify the actual ancient quarries. However, this is not always practicable, due to factors such as the potential source outcrops being so large that such surveys are not easily undertaken (cf. Mallory-Greenough et al. 1999:228). Furthermore, such identification may not even be possible, either because an ancient quarry has been destroyed, or because the form of resource acquisition used did not require quarrying, such as the collection of cobbles for stone artefacts from wadi beds. It is therefore advisable to identify and not sample potential deposits which have only been exposed or created in the recent past and then sample all other deposits, whether or not any evidence of ancient resource acquisition is present. This point is especially relevant when the form or forms of resource acquisition cannot be identified, a category which includes the present study (Philip and Williams-Thorpe 1993:61).

When taking samples from potential source deposits, Glascock et al. (1998:20ff) emphasise the need to take a number of factors into account. The physical characteristics of the raw material of the artefacts may well limit the number of potential sources. For example, obsidian can be a number of different colours, which may enable the reduction in the number of possible sources, and certain deposits may be so weathered that they would have been unusable. However, such physical indicators should be used with care and be supported by analytical evidence (Weisler and Clague 1998:109).

Shackley (1998b:83) argues that it is important to have an explicit sampling strategy, and that samples need to be gathered in explicitly scientific ways for the results to be both reliable and valid. Shackley (1998b:97ff) also argues that such a strategy is relatively easy to design and presents a general framework. First, it is necessary to conduct a thorough background search on the geological literature of the area under consideration, to gain a proper understanding of the current level of knowledge on the area. Next, samples should be taken from the whole of the potential source area, using transects, and then at least ten of these samples should be selected for analysis. If there is a wide level of variability in the elemental concentrations of these samples, more of the samples should then be analysed, to properly characterise the source's variability. Shackley argues that this approach enables the level of source variability to be accurately identified and should prevent artefacts from being erroneously provenanced.

However, the main problem with the second half of this approach is its high cost in terms of both time and money. To reduce this the background search may well include geochemical analyses which can be incorporated into the provenance study. Gaps in the data can therefore be identified and only these outcrops sampled. It may also be possible to undertake joint projects with geologists, thereby spreading the cost and work.

Furthermore, even if the artefact has not been altered and all outcrops are represented, each of the three major components in provenancing also have their own individual problems, which can also impact on the reliability of the study. This is shown by Glascock et al. (1998:20,22) in their review of obsidian provenancing studies, who note that most of the problems with these studies arose from a combination of inadequate sampling, poor chemical analysis and inadequate mathematical analysis. These problems will therefore be considered below.

First, as the geological deposit increases in size the trace-element fingerprint can become more variable, meaning it is necessary to collect more samples to accurately characterise the deposit. This increases both the difficulty of the sample collection process and the probability that the fingerprints of different sources will overlap, thereby increasing the difficulty of accurately identifying the provenance of individual artefacts (Rapp and Hill 1998:136).

This problem therefore also impacts on the choice of both the chemical and mathematical analytical techniques, as the level of accuracy required is dependant on how diffuse the trace-element fingerprints of the sources are. If the analytical technique is not accurate enough then, again, the fingerprints of different sources will overlap, reducing the effectiveness of the provenance study. This problem may also be overcome by using a combination of techniques, including calculating element ratios and measuring isotope ratios (see Chapter 3; Rapp and Hill 1998:136ff).

Both Knapp and Cherry (1994:34) and Glascock et al. (1998:24ff) argue that multivariate statistics (usually calculated on computers) can enable the identification of patterns in the data which are not immediately apparent, with Glascock et al. (1998:24ff) arguing that they have increased the scope and effectiveness of mathematical analysis in provenance studies. Knapp and Cherry (1994:34) argue that the chief role of statistical techniques in provenance studies is to divide samples into discrete groups in which internal variation is minimised and external variation is maximised. They note there are two main types of provenance problem which can be solved by the application of multivariate statistics. If there are no known sources, cluster analysis can be used to group samples into clusters. More usually, if sources are known and have been characterised, discriminant analysis can be used to attribute samples to these sources. However, Shackley (1998b:98) argues that that it is important to report data in a manner easy to interpret and that multivariate statistics should not be used alone, but in conjunction with simple graphical plots, as multivariate statistics are capable of giving spurious results. For example, when discriminant analysis is used, individual samples are *always* classified into a group, even if they are not close to one (Baxter 1994:202), which can lead to artefacts being incorrectly provenanced. Problems with multivariate statistics were also reported by Greenough et al. (2001:773; cf. Chapter 2), leading them to argue that the use of element and element ratio plots were more appropriate for provenance studies.

Furthermore, mathematical analysis of the data cannot correct basic inadequacies in the data, as Rapp and Hill (1998:152) argue: “if potential source deposits are inadequately sampled, or there are errors in the analyses, no amount of statistical power will correct for these faults.”

Both Shackley (1998b:98f) and Knapp and Cherry (1994:35f) argue that the data generated should be freely available for other researchers to use, by setting up a database of the analyses, to which new data may be added by other researchers. Knapp and Cherry note that this is necessary to provide a more comprehensive picture than is possible by a single study, given the limitations of time and money. Knowledge therefore needs to be cumulative in nature otherwise “we are destined to argue endlessly about the alleged relative merits of isolated and non-comparable data sets” (Knapp and Cherry 1994:36). However, as they acknowledge, this increases the difficulties of provenance analysis, as all the problems discussed above will have impacted on the different studies in a variety of ways. There are also problems with inter-laboratory variation in analytical accuracy, which therefore call into question the validity of any comparison using data from two or more laboratories or by two or more analytical techniques. Both Knapp and Cherry (ibid.) and Weisler and Clague (1998:124f) suggest that these problems can be overcome by the publication of the measurement standards and the levels of precision and accuracy achieved in the analysis, along with the inter-laboratory analysis of a number of samples. However, these suggestions are very rarely followed, thereby making it very difficult to properly evaluate and use the results from different laboratories.

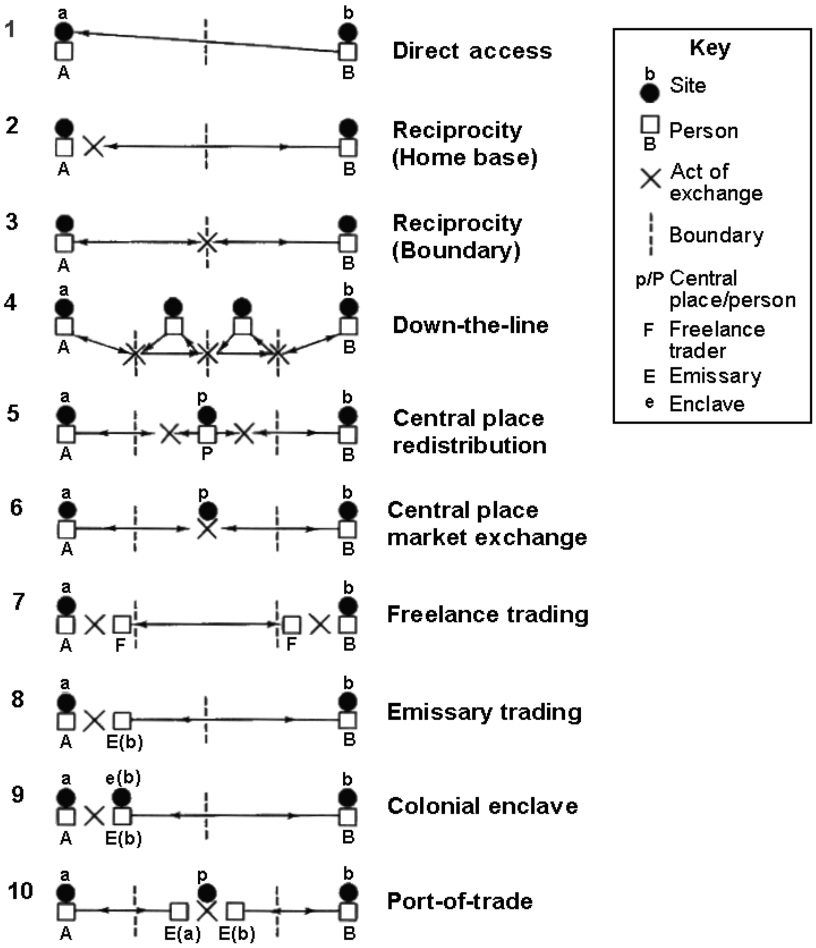
Procurement

However, even if the provenance study is completely successful, it still does not explain how the origin of the artefact's material relates to the artefact's find-spot. To explain this relationship it is necessary to relate the distribution of the material remains to past human behaviour, which involves the reconstruction of past procurement systems. Moreover, the links between the material remains and past human behaviour are complex and poorly understood, making the attempt difficult (Dietler and Herbich 1998:234). It is also possible for different mechanisms of procurement to operate, even concurrently, making the attempt even more difficult to successfully undertake (Torrence 1986:4; Knapp and Cherry 1994:3). Indeed, this is the reason that the neutral term 'procurement' is used in this thesis, which implies the acquisition of goods or services by a single group; rather than either the term 'exchange', which implies the transfer of goods or services in two directions; or 'trade' which is usually taken to imply some form of organised and competitive mechanism, generally involving the use of money (Torrence 1986:2). Nonetheless, it is important to note that the word 'exchange' is regularly used in the archaeological literature, as it is usually, sometimes implicitly, assumed that goods or services would travel in two directions, although this is not generally demonstrated.

Furthermore, 'procurement' incorporates both the indirect and direct acquisition of goods and services, whilst 'exchange' only includes the former. Indeed, Perlès (1992:116) argues that there is no unambiguous way of discriminating between direct and indirect procurement. Problems with determining the mechanism by which procurement operated are illustrated by DeBoer (2001), who reports that gambling was an important mechanism of procurement amongst the North American tribes for certain categories of goods, especially shells, but also including valuables. This therefore raises the possibility that gambling could have been an important means of procurement amongst other cultures and also highlights the problem of equating 'exchange' with 'procurement'. However, most of the investigation into procurement systems has assumed that exchange (including gift exchange) was the mechanism of procurement, rather than also considering such mechanisms as direct acquisition, gambling, theft, the payment of tribute or looting (cf. Potts 1989, discussed in Chapter 2). However, Perlès (1992:116f) also argues that direct procurement would probably have been rare, given the complex know-how needed to extract and transport the raw material and the need to appease groups situated around the raw material's source, as well as ethnographic data showing that most forms of procurement is usually indirect.

Renfrew (1975) discusses 10 major modes of procurement, of which one was direct access, with the other nine being various forms of exchange (shown in Fig 5.1). Renfrew (1975:40f) argues that these modes could potentially be differentiated using variations in the spatial distribution of artefacts. He (Renfrew 1975:46f) divides long distance exchange into two areas, the "supply zone", and the "contact zone". In the supply zone modes 1-3 operate and there is only a gradual fall-off in the quantities of artefacts at sites further from the source. In the contact zone Renfrew (ibid.) argues that the fall-off in artefacts is generally exponential, with modes 4-10 operating. Mode 4 is an aggregate of modes 2, 3, or both, whilst modes 5 and 6 distort the fall-off curve by having larger quantities of artefacts at the central place (Renfrew 1975:47f). Modes 7-10 also distort the fall-off curve in different ways, giving potentially distinctive patterns of artefact distribution.

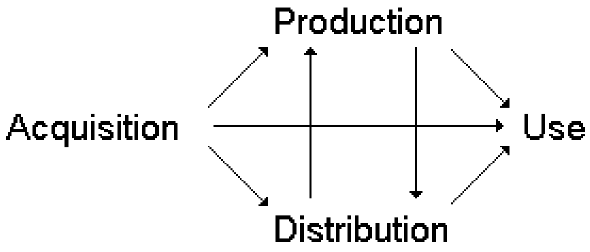
Fig 5.1: Modes of exchange



After Renfrew (1975:42).

These different modes of exchange therefore have the potential to be archaeologically identified, but, as Renfrew acknowledges, there are a number of problems with the spatial analysis of artefacts. The most fundamental problem is that the quantitative data required is not always available, which is the case for basaltic artefacts in the southern Levant (see Chapter 6). Furthermore, both Renfrew (1975:41) and Torrence (1986:5) argue that a major problem with identifying past procurement systems is that they are not directly associated with any material remains, therefore making their identification more difficult. As Renfrew (1975:40) notes, for artefacts to be recovered archaeologically they must have left the procurement system, thereby at least potentially distorting the patterns of procurement and use. Torrence (1986:5) therefore presents a basic model of a general system of actions affecting an artefact (Fig 5.2).

Fig 5.2: Actions affecting an artefact



After Torrence (1986:5).

Although, as Torrence (1986:5f) admits, this is a very simplistic model, it does have heuristic value in enabling procurement to be placed in a wider, interrelated, context. It illustrates that behaviour in one sphere affects, and is affected by, behaviour in the others and so shows that the processes of exchange may be deduced from the other processes. However, she (Torrence 1986:10) also argues that this understanding is not generally utilised in exchange studies, thereby leading to a concentration on certain aspects of the interactions, whilst ignoring the overall system. This is supported by Knapp and Cherry (1994:1) who note that only a few recent studies have shifted their attention from being exclusively on exchange systems towards a more general consideration of production (implicitly including acquisition), distribution and use. The point is also demonstrated by more recent work; for example, as discussed in Chapter 2, the papers in Cauvin et al. (1998) and Shackley (1998) are generally concerned with discussing advances in techniques and their current problems.

Both Tykot (1998) and Green (1998) conclude that obsidian distribution patterns, in the Mediterranean and the Pacific respectively, vary spatially and temporally in ways which cannot be explained by accessibility or technological considerations, showing that "exchange networks were structured more by social than simple economic and distance considerations" (Green

1998:230). Moreover, Cauvin and Chataigner (1998:349) argue that obsidian exchange cannot be understood in isolation, but only as a part of the long distance exchange of a number of materials, including seashells, malachite and basaltic rock. Although, unfortunately, they do not properly support this assertion, or develop a model of exchange, the suggestion that the exchange of different types of material is interlinked is potentially important, as it implies that the patterns of exchange of one type of material can only be understood when the whole of the exchange system is examined. Perlès (1992:119) concurs and argues that all materials in circulation should be considered to properly understand the procurement systems which operated synchronically. However, this can only be attempted once reliable provenance studies of the various individual materials have been successfully undertaken.

Both Torrence (1986:7ff) and Knapp and Cherry (1994:2ff) argue that it is important to investigate the basic assumptions behind exchange studies by critically examining the relationships between the archaeological and analytical data and behavioural interpretation. Knapp and Cherry (1994:15) criticise most science-based archaeological studies as regarding questions of technology and theory as somewhat peripheral, despite (as discussed above) these being the very factors which transform a provenance analysis into a study of procurement systems. Knapp and Cherry (1994:16,25f) also argue that the study of technology is very important, as it is a manifestation of deliberate human action, which only gains meaning from society, and plays a key role in the development of both the individual and society.

This point is supported by Cauvin (1998a), in her review of the models used to explain the exchange of obsidian in the eastern Mediterranean. She concludes (Cauvin 1998a:267f) that it is impossible to determine the circulation of obsidian without a good knowledge of the socio-economic conditions which were present in the society. This conclusion seems to be applicable to procurement studies in general, whilst Knapp and Cherry (1994:16) note that only very limited attempts have been made to rectify these problems, and with only very limited success. They attribute this to the lack of an overall research design which makes clear the relationship between data, analysis and interpretation and the bridging arguments between them.

Furthermore, this understanding has still not occurred despite advances in both the understanding of basic intra-group exchange (Winterhalder 1997) and the more general advances in the understanding of complex societies (Stein 1998). The evolutionary ecological models which Winterhalder (1997) examines are generally focused on hunter-gatherer societies, while Winterhalder (1997:136) notes that exchange has received little attention from evolutionary ecologists and no formal models have yet been developed.

Stein (1998) reviews the recent research on complex societies and notes (Stein 1998:23) that local exchange systems "have received surprisingly little attention in the bulk of recent research, despite their importance for understanding the economic and political organization of complex societies." He also notes that the two exceptions to this are prestige-goods economies and world systems theory. However, he also reports that these approaches have had their validity and usefulness called into question in reconstructing systems of exchange (Stein 1998:23ff).

Anthropological theories

There have been, however, recent developments in the anthropological understanding of the economy and exchange systems, which may be applicable to the archaeological investigation of procurement. However, there is one important caveat to this approach. Humphrey and Hugh-Jones (1992:1) argue that it is impossible to provide a universal model for any mode of exchange, as this removes the all-important social context within which it functioned. Therefore, the theories discussed below may provide a framework for the understanding and examination of exchange, but will certainly not provide a basic, universal, list of criteria which must be met before a particular mode of exchange can be said to be present (cf. Cauvin 1998a:268). Furthermore, even when an understanding of different types of exchange has been reached for ethnographic examples, there is the further problem of relating this understanding to archaeology, where all that is left is the material remains of a society, rather than the social actions and relations which anthropologists study (London 2000:2).

Narotzky (1997:3) criticises previous theoretical approaches to economic anthropology for assuming that the economy can be analysed as a separate realm, which, she claims, is not the case in non-market societies, where the economy is embedded within other social institutions. This argument is supported by Dietler and Herbich (1998:235) who argue that:

> "things are made, exchanged, used and discarded as part of human social activity. Hence, both things and techniques are embedded in and conditioned by social relations and cultural practice."

Narotzky (1997:7) therefore seeks to use a human ecology approach to counter some of these problems and so defines the economy as "social relations involved in the production and reproduction of material life, through the organised interaction of humans and nature." This definition therefore implies that it is impossible to separate the material relations of the economy from their cultural expressions and relates the economy to the production, distribution and consumption of material goods, showing that these areas are also interlinked (Narotzky 1997:7,99). Furthermore, Voutsaki (1995:7) argues that exchange is a "total social phenomenon", that is, it is related not only to the economic factors, but also to socio-political factors. This is supported by Green (1998:230), who argues that to properly understand the process of procurement it is necessary to understand the production of the artefact from the raw material, as well as its acquisition.

Narotzky (1997:9f) also notes that the human ecology approach to the economy defines the environment, usually regarded as a background factor, as the space where the exchange of energy between humans and other species takes place. However, she argues that this has to be related to social processes, as space is a "lived experience", rather than an "objective fact". This is because the perception of the surrounding environment, and therefore the available resources, is related to the knowledge and technology of the human group in question. Taking this perspective into account (which conforms with the realist understanding of social structures; cf. Chapter 1) it is now possible to examine the three main areas of the economy, namely production, distribution and consumption (Costin 1991:1).

Production

Narotzky (1997:25ff) argues that access to resources is the main factor determining the organisation of production, and can be divided into four main types. These are:

1. Free access to all groups and individuals.
2. Private property, where access rights are restricted to an individual or a group.
3. Communal access, where access rights are restricted to a specific community, usually based on kinship groups.
4. State property, where the state controls access rights.

Even within a society, the type of access can vary from resource to resource, or even between the different localities of a single resource (depending on such things as the quality and accessibility of the resource in a particular locality).

Narotzky (1997:29ff) argues that these socially-created types of access affect how the labour of a society is organised, which is also a social creation and is sustained by the ideology of the society. One very important way in which labour is organised is through the creation of specialists (Costin 1991:3), which will therefore be discussed below. Archaeologically, these types of access and production may be distinguishable by the distribution and the range of variability of artefacts. Furthermore, the technology of production is also open to archaeological investigation and so will also be discussed below.

Distribution

Narotzky (1997:42) also argues that this social organisation of access and production inevitably affects the type of distribution that takes place. This is also shown, although in less detailed terms, in Torrence's (1986:5) model (Fig 5.2, above), which includes both direct and indirect procurement, represented by the paths from acquisition to use. As shown by Renfrew (1975), a number of different types of distribution can be defined, including gift-giving, barter and trade. These will now be discussed in more detail.

Narotzky (1997:43ff) defines gift-giving as based on reciprocity, that is, obligations are created between people to give, receive and return gifts, with both the equivalence of value of the gifts (as defined by those involved) and the time elapsed between the receipt and giving of a gift, being important factors. Reciprocity therefore both creates and sustains social bonds, with Narotzky (1997:45ff) noting that Sahlins' understanding of reciprocity shows that, as the social ties between the individuals become looser, so the material, rather than the social, value of the gift becomes more important. Indeed, outside the closest kin relations, where the social obligation is generally to aid individuals (with the expectation being that aid will be provided to the gift-giver when necessary), reciprocity and barter tend to blur (Narotzky 1997:45ff; Humphrey and Hugh-Jones 1992:2f).

The Kula cycle is one of the classic anthropological examples of a complex gift exchange network, although it is only the most elaborate form of a system of gift exchange found throughout the region (Lewis 1985:199,203). Two different types of shell jewellery are exchanged between islands, creating and maintaining relations with these external groups, which enables the exchange of other goods to be more easily undertaken (Lewis 1985:200f). Kula valuables then move down the political scale, passed from elite to sub-elite (Lewis 1985:202). Furthermore, Lewis (1985:204) notes that an individual's intra-group prestige and power can be enhanced by successful external relations.

Humphrey and Hugh-Jones (1992:4ff) argue that barter is an important mode of exchange, which enables the transfer of different types of goods between groups, and also creates and maintains social relations. They also note that barter can operate simultaneously within a society with other forms of exchange, including gift-giving and redistribution, at different levels and with different goods. Barter operates when two parties are interested in exchanging goods that they possess for goods that the other party possesses. However, as Anderlini and Sabourian (1992:78f) note, this is a relatively rare occurrence, which means that, more normally, one party has to accept the promise of goods in the future, that is, credit. This need for credit therefore necessitates the creation of social relations, with at least some level of trust required between the individual traders. Furthermore, information is also essential for successful bartering, as each trader needs to know what goods the other traders can potentially supply, and whether they can actually be trusted to deliver them (Humphrey and Hugh-Jones 1992:8ff; Anderlini and Sabourian 1992:76ff; Appadurai 1986:41). These requirements therefore usually lead to the creation of barter systems, as "goods tend to be exchanged with known people at particular times and places" (Humphrey and Hugh-Jones 1992:8). As shown by Renfrew (1975), it is this regularity which may well be archaeologically recognisable. Moreover these systems of information transfer can be provided in many different ways by different societies, including by bureaucracies, merchant groups, religious institutions, kinship networks, or even through systems such as the Kula cycle, thereby making it more difficult to identify the mechanism or mechanisms which operated in a particular society (Smith 1999:112; Lewis 1985:200f).

Humphrey and Hugh-Jones (1992:17f) therefore conclude that, whilst both gift-giving and barter create regularities in the movement of goods, they differ in that gift-giving forces individuals to accept a debt, while barter can be seen as entering into a voluntary agreement. Whether this difference is archaeologically visible is unclear, although Humphrey (1992:107) argues that in many gift systems similar items are exchanged, whereas in barter systems people want to acquire types of objects which they do not have. This implies that these differences may sometimes be archaeologically visible, by examining differences in the use and deposition contexts of widely distributed artefact categories (discussed below).

The desire to acquire different types of objects is related both to the value that one party places on the object in question and, more widely, to the processes of consumption and demand, which will be discussed below. Narotzky (1997:64) notes that the concept of value is one of the crucial problems raised in exchange studies. This is supported by Voutsaki (1995:7) who notes that there has been little discussion on the issue of value in archaeology, which, she argues, has led to modern notions of value being uncritically applied to past societies. She argues (Voutsaki 1995:8,36) that these notions are based on Marx’s understanding of value as the embodiment of labour, which implies that value is created at the moment of production. Voutsaki (1995:9) criticises this view as she notes that this is actually a vague concept when it is used to determine the value of artefacts, as it is very difficult to calculate the total amount of labour used to manufacture an artefact, leading to the subjective valuation of artefacts. Furthermore, she argues (ibid.) that the use of the concept of labour as value ignores the symbolic significance of objects, which has been shown in anthropological studies to be more important than the amount of labour used to produce the artefact.

Narotzky (1997:64f) therefore recognises two main types of value, namely use value and exchange value, and defines use value as being the adequacy of a good or a service to fulfil a need, which is therefore independent of exchange. Narotzky fails to adequately define the concept of exchange value, but Appadurai (1986:3f) argues that in exchange contexts, the value of objects is determined reciprocally by the exchange partners, with the demand for an object determining its value. However, he also argues that exchange is the source of value, as this sets the level of scarcity of the object. Exchange value can therefore be seen as being how desired the object is (both by the owner and by other people), and will therefore fluctuate more widely and noticeably than use value, although both types of value are culturally determined and therefore change both through time and between groups.

Appadurai (1986:13f) therefore defines goods with a higher exchange value than use value as commodities, that is, goods which are primarily intended for exchange, rather than use. He argues (Appadurai 1986:16) that objects are generally only commodities at certain stages during their life histories and fall into four main categories. These are:

1. Destination commodities. Objects that are produced intentionally for exchange.
2. Metamorphosed commodities. Objects intended for other purposes, which have become available for exchange.
3. Diverted commodities. Metamorphosed commodities that were originally protected from being exchanged.
4. Ex-commodities. Objects that are no longer available for exchange, either temporarily or permanently.

This understanding therefore implies that objects go through different stages in their 'life cycle' and therefore acquire a unique history which is culturally regulated, although may also be partially manipulated by individuals (Appadurai 1986:17). Both Appadurai (1986:23) and Voutsaki (1995:9; 1997:37) argue that this history of use and circulation may well increase an object's value, and may even become the most valuable aspect of it. Voutsaki (1997:37) also argues that "value is created *by* and *in the process* of exchange, and not only at the moment of production".

Narotzky (1997:42) supports this point by noting that even after goods have been acquired and used, they may not necessarily be destroyed, potentially leading to further distribution and use. This process can change both the value and the use of the object in question, and also enables objects to acquire a meaning "because they embody social relations of production and because they produce and reproduce social relations during distribution" (Narotzky 1997:43). This understanding shows that Torrence's model (Fig 5.2, above) is over-simplistic, as the relations between use, distribution, and production can be cyclic in nature. Narotzky (1997:71) therefore introduces the concept of circulation, where goods are moved along chains of transactions, covering wide areas and lasting for years. As goods move along these chains their value may change, at different times and with different people. This cycle of use and distribution, with potential changes in value, could well apply to at least certain categories of basaltic artefacts.

Another form of circulation is Chapman's (2000) concept of enchainment. Chapman (2000:28f) argues that certain objects may be regarded as inalienable, that is, they cannot be commodities, even if they are exchanged. Chapman (2000:31) summarises this as "giving-while-keeping", meaning that if inalienable goods are exchanged, they create a bond between the exchange partners, enchaining them together in a social relationship. Indeed, Chapman (2000:29) argues that the identity of the enchained individuals becomes linked by these inalienable objects. This therefore means that the history of the object becomes probably its most important aspect in these types of relationships, which Chapman (2000:32) argues probably took place within kin-group exchange, as the importance and symbolism of the object would be lost outside this context, thereby alienating the object. This is therefore another possible way in which artefacts could be exchanged, although how widespread this form of exchange was remains to be demonstrated.

Consumption

Narotzky (1997:100ff) notes that the area of consumption is rarely examined and is generally obscured by an over-simplistic understanding of it. She (Narotzky 1994:104) defines two main types of consumption, namely, productive consumption, that is, goods and services used to produce other goods or services; and personal consumption, that is, goods and services used to maintain and reproduce human life. Both Appadurai (1986:31) and Narotzky (1997:113) agree that consumption is an active social process, which is both shaped by and also shapes other social and economic processes. Furthermore, they see consumption as a focus for power relations, with the act of consumption conveying power to certain people over others.

Appadurai (1986:38f) and Sherratt and Sherratt (1991) expand this by using Sombart's understanding of trade as driven by the conspicuous consumption of luxury goods, which are defined as those goods whose principal use is social and are used to display power. Furthermore, Sombart saw material goods as an essential part of cultural structures of meaning and symbolism, which can therefore be used in the social strategies of recruitment and exclusion. This therefore implies that they are an important part of social change, with Cobb (1996:256) arguing that elites were able to manipulate the exchange of prestige goods to both gain status and mobilise labour.

Sherratt and Sherratt (1991) use this understanding to explain the Mediterranean trade during the LBA. They (Sherratt and Sherratt 1991:351ff) note that most previous attempts at explanation were based on Weber's concept of ancient trade, which emphasised supply and therefore saw trade as being essentially agrarian in nature and implied that different regions were largely self-sufficient, with inter-regional trade being on a very small scale. However, they argue that this view of trade is contradicted by the archaeological evidence, which shows that LBA exchange was consumption-orientated. Consumption-orientated models of exchange explain the incentive to trade as being the desire of a minority to acquire socially significant exotic goods. This is in contrast to production-orientated models, which emphasise increases in the scale of production, the rise of local market centres and structural differentiation (Sherratt and Sherratt 1991:354). Sherratt and Sherratt (ibid.) argue that although these may have taken place, they do not adequately explain LBA trade, in which small quantities of exotic goods were moved long distances. The importance of these exotica, and the desire of the elite minorities to acquire them, can be seen to have motivated the intensification of production and the extraction of surplus to maintain specialists who produced goods for exchange. Furthermore, this can be seen to be an expanding system, with increasing numbers of local elites becoming enmeshed in these exchange systems (Sherratt and Sherratt 1991:358). Appadurai (1986:39) also argues that there are complex links between luxury goods and other commodities and argues that "trade in luxuries may well provide an amicable, durable, and sentimental framework for the conduct of exchange in other goods and modes".

Sherratt (1998:295) extends this understanding by arguing that the expansion of this exchange system lead to local elites being able to retain most of the local raw materials and still participate in the exchange system. Furthermore, she argues that this also leads to growth in the manufacture of value-added goods for exchange, such as finished metalwork, rather than simply processing raw material for exchange (as metal ingots, for example). In turn, this leads to the manufacture of goods with a greater element of added value, such as perfumed oils, and then to the manufacture of goods whose entire value is added during manufacture, such as pottery and glass. She also argues (Sherratt 1998:295f) that these value-added products could be used by sub-elites, who (to create and maintain status) wish to participate in long distance exchange, but are prevented from participating in elite exchange, and so turn to less-controlled spheres of exchange. Furthermore, she notes that these value-added goods are susceptible to import substitution, that is, local variants of these goods are manufactured and circulated among the local sub-elites.

However, Smith (1999) comes to a very different conclusion from those discussed above. She argues (Smith 1999:109) that it was actually the demand for ordinary household goods (defined as household furnishings, containers and utensils) which stimulated exchange systems. She also notes (Smith 1999:113) that there is no clear distinction between luxury and utilitarian goods, with ethnographic studies showing that these distinctions are "highly variable and culture specific" and, furthermore, can shift over time from one category to the other. Smith (1999:117) therefore goes on to argue that goods, including ordinary goods, have a social significance and symbolise wider connections between groups. Furthermore, she argues that it is this social significance of goods which is one of the main reasons why they are exchanged, and so concludes that "the demand for ordinary goods provides an explanation for the development, success, and long-term viability of regional trade networks" (Smith 1999:109).

Although there is a conflict between these theories on how exchange systems are developed and maintained, it is important to note that Smith's general understanding of the importance and social nature of goods is broadly in agreement with those reviewed above. Furthermore, one weakness in Smith's argument is that, as she notes, there is no clear definition on what constitutes a luxury good and how these can be distinguished from ordinary goods. Indeed, Cobb (1996:256) argues that "the ownership of prestige goods does not have to be restricted to elites; these goods, in fact, may be important for daily rituals or rites of passage among the populace." This argument is further strengthened by Sherratt's distinction of goods with various levels of value added during manufacturing and her argument that these were used by sub-elites.

Using this perspective as a basis, it is therefore possible to argue that, in fact, 'ordinary' goods which were traded were in fact seen as luxury goods, by the non-elite groups within a society. This perspective removes the over-simplistic dichotomy between elites possessing luxury goods and non-elites only possessing utilitarian goods, and reveals a more complex picture, where people from at least most sectors of society may possess valued artefacts and participate in the exchange of 'luxury' goods, which are commensurate with their (socially-constructed) means and desires. This perspective therefore implies that either elite or non-elite exchange could have stimulated and sustained the other, or, indeed, both could have emerged independently, possibly even simultaneously. This will therefore need to be archaeologically investigated for each society, rather than assuming that any one model can adequately explain every society.

Conclusion

Despite this discussion presenting a framework for understanding these important issues, it is still unclear how to relate most of the insights generated by this anthropological research and archaeological theory to individual archaeological investigations. This is due to the lack of emphasis by anthropologists on the material remains created and discarded by societies and on how these material remains vary with differences in how a society is economically organised (London 2000:2). This general problem leads London (ibid.) to argue that anthropological work is not adequate for answering archaeological problems, and that archaeologists should therefore undertake ethnoarchaeological work to answer these problems. However, there have been very few ethnoarchaeological studies of ground stone tools, with the main study (Hayden 1987) focusing on the manufacture, and not the exchange, of Mesoamerican quern-stones. Furthermore, there does not appear to be any recorded evidence for the continued usage of fine stone vessels, thereby making ethnoarchaeological work impossible for this important artefact category.

Specialisation

As mentioned above, specialisation is one way in which production is organised, which Costin (1991:4) describes as:

> "a differentiated, regularized, permanent, and perhaps institutionalized production system in which producers depend on extra-household exchange relationships at least in part for their livelihood, and consumers depend on them for acquisition of goods they do not produce themselves."

Costin (1991:4f,8) argues that there are many degrees and types of specialisation, which can be described using four main parameters, although Lewis (1996:372) cautions that it is difficult to accurately distinguish the different types in the archaeological record. The four parameters are:

1. <u>Context</u>, either independent or attached. Independent specialists usually produce utilitarian goods for most or all households in a society and usually occur for economic reasons, such as profit or efficiency. They assume the risk of failure during production. Attached specialists produce high status, high value goods for elites who both control them and assume the risk of failure during production. They are created primarily for social and political reasons (Costin 1991:9,11f; Lewis 1996:359).
2. <u>Concentration</u>, from dispersed to nucleated. At a regional level, the distribution of producers can vary from being situated in every settlement to being concentrated at only one site. If nucleated, then some form of exchange system must operate for consumers to acquire the goods. Independent specialists are often nucleated to exploit efficiencies in locating production near an unevenly distributed resource. Transport is also an important factor affecting the location of producers and is affected by considerations of weight, bulk and fragility of the good and the distance between the producer and consumer (Costin 1991:9,13f).
3. <u>Scale</u>, from small, kin-based to factory. The composition of the productive unit is affected by a number of factors, with efficiency usually being the most important factor for independent specialists. If the cost per unit can be decreased by producers sharing technology or by dividing tasks among many workers then the size of the workshop may increase. As the size of the workshop increases the workers, who are initially drawn from immediate kin, start to be drawn from more distant kin and finally are drawn from non-relatives. However, if no savings can be made from increasing the size of the workshop, it will remain small (Costin 1991:9,15f).
4. <u>Intensity</u>, from casual part-time to full-time. The amount of time producers spend producing their goods is affected by a number of different factors. Full-time specialists are more efficient than part-time specialists as they are able to regularise their production, gain a better return from any necessary capital investment and have increased opportunities to enhance their skills. However, full-time specialism has a greater degree of risk associated with it and is only possible if there is both sufficient

demand for the product and sufficient resources are available to fulfil this demand, including raw materials and the ability to transport the finished product.

Independent specialists usually attempt to remain part-time producers to minimise the economic risk, although this is only possible when the technology is simple or inexpensive, as otherwise full-time specialists gain a significant competitive advantage. Part-time specialists usually try to undertake their craftwork during the agricultural low season. However, if there are problems with scheduling due either to increasing demand for the product or to increasing agricultural demands, specialists may be forced to go full-time (Costin 1991:9, 16f; Lewis 1996:368).

Cross (1993:61) argues that most attention has been focused on craft specialisation in complex societies and has largely ignored specialisation in small-scale societies. He (Cross 1993:63f) argues that this is at least partially due to the fact that this form of specialisation is part-time and maintained by interpersonal social relations, rather than the institutional, full-time specialisation of state-level societies, which are easier to recognise archaeologically. This is especially the case where the specialist work is seasonal in nature or where only a small number of items are required, for example, for elite or cultic use (Cross 1993:65). Lewis (1996:377,382) agrees and argues that both independent and attached specialists can be part-time, with full-time independent specialists only becoming common in state-level societies. He also notes that non-centralised attached specialists, producing objects for such things as the payment of tribute, were important and need to be archaeologically recognised.

Cross (1993:80) further argues that craft specialisation includes situations where no-one is prevented from manufacturing certain objects, but where there is a habitual restriction of production to a few specialists. This is due to the main advantage of craft specialisation in small-scale societies being the creation of inter-personal ties and mutual obligations, rather than economic advantages.

Costin (1991:18) notes that the archaeological identification of specialisation can be made using both direct and indirect evidence. The direct evidence for specialisation is mainly gained from the production areas and the working debris. However, as has already been discussed, this evidence is virtually non-existent for basaltic artefacts in the southern Levant, meaning that only indirect evidence can be used. The main line of indirect evidence is that of the finished artefacts themselves, with the principal indicators being those of standardisation, efficiency, skill level, and regional variation (Costin 1991:32). However, Costin (1991:33) notes that these indicators can only provide evidence on the relative degree of specialisation and rarely provide unequivocal evidence on the context, scale or intensity of the specialisation. Furthermore, Lewis (1996:380,378) argues that standardisation and efficiency may not be applicable to attached specialists, as they are required to produce unique and exotic items, and there is no competition, thereby reducing the requirement to be efficient.

Standardisation is used to detect specialisation as it is usually assumed that the amount of variability decreases with the decrease in the number of producers. However, Costin (1991:33) argues that this is not always the case and that other factors must also be considered, including whether consumers preferred a standardised product, whether any other efficient ways of producing the objects were possible, and whether standardisation made transport easier.

Efficiency is a relative measure of the amount of time, energy and raw materials used to produce each object and is often linked to competition and therefore specialisation (Costin 1991:37). However, Costin (1991:37) argues that there is no necessary link between efficiency and specialisation, as the consumer may require the elaboration of utilitarian objects for social reasons, thereby making the production less "efficient". She (Costin 1991:39) therefore argues that a better measure of specialisation may be the amount of labour required, as certain technologies only become efficient at levels of production where the quantity of objects produced is higher than the number required by the producer's household. If this is the case then it indicates the existence of specialists.

Costin (1991:40) notes that it is assumed that the level of skill increases with the level of specialisation, indicated by a decrease in number of errors made. However, she notes that measures of skill are generally subjective and there has only been a limited amount of research on this topic.

Regional variation in objects can be used to examine the level of specialisation, with the fewer variants indicating a greater degree of specialisation and fewer groups of producers (Costin 1991:41). However, Costin (1991:42) also argues that the areas of highest density of artefacts are not related to the areas of highest production, as is usually assumed, but rather to the areas of highest consumption. Whether these two areas are related depends on such things as transport and demand.

Therefore, to use any indirect evidence for specialisation it is first necessary to demonstrate why it reveals specialisation, rather than some other aspect of the organisation of production (Costin 1991:44). As Kerner (1997a:420) notes, this level of analysis has not yet been undertaken for the southern Levant.

Technology

As discussed above, it is also necessary to consider the technology of production to understand properly all the factors which go into the construction of a procurement system (Narotzky 1997:10, Tite 2001:443).

Ericson (1984:2) argues that the production of stone artefacts intended for exchange (that is, as commodities) is an important indicator of regional exchange systems, which can primarily be reconstructed using quarry sites and lithic workshops. However, he also notes that it is precisely these areas which receive little archaeological attention. That this is still the case in the southern Levant is shown by the comments of Wright (1992:78) and Peterson (1999:1), who both note that not enough attention is paid to the debitage of ground stone tools. Peterson (ibid.) also notes that ground stone tool assemblages are not adequately reported, therefore making it even harder to adequately analyse the production and exchange of this category of artefacts. A further problem with the analysis of basaltic artefact production in the southern Levant is that, as will be discussed in Chapter 6, no recognisable quarries or workshops have so far been discovered. This therefore means that Ericson's discussion cannot be used in this study due to an absence of appropriate data.

Furthermore, Epstein (1998:229) argues that any areas used for manufacturing basaltic artefacts would, over time, become indistinguishable from the natural terrain. However, an alternative explanation for the absence of recognised quarries and production sites is provided by Wilke and Quintero (1996). They (op. cit., pp.244f) cite the example of Antelope Hill Quarry, now recognised as the most intensively worked sandstone quarry known in the American Southwest, but originally only known as a rock art site, with workers walking over one kilometre of evidence of stone tool manufacture, mostly in the form of stone flakes. It is therefore at least possible that similar evidence has gone unrecognised for the manufacture of basaltic artefacts in the Near East, which may provide important information in the future.

Both the archaeological work of Wilke and Quintero (1996:245,252) and the ethnoarchaeological work of Hayden (1987b:21) demonstrate that there are two main types of primary production site, namely, bedrock quarries and stream bed sites. Bedrock quarries are where either the exposed outcrops are quarried, or where boulders that have been detached by weathering are worked (Nelson 1987:120f; Wilke and Quintero 1996:252). These sites are therefore relatively restricted in range, with a relatively dense scatter of flakes and discarded, partially finished, artefacts (Nelson 1987:122; Wilke and Quintero 1996:252f). Bedrock quarry sites are therefore potentially recognisable, as Nelson (1987:122) reports that:

> "quarrying and reducing stone blocks at the bedrock outcrop produces large pits in the bedrock and a dense scatter of discarded flakes and of misplaced, exhausted and cached tools."

Stream bed sites refer to areas where boulders which have been carried downstream and deposited are worked. These sites are therefore more extensive in nature, while the actual production areas are more dispersed (Nelson 1987:122; Wilke and Quintero (996:245,252). These sites are replenished each year by flood waters which bring down fresh boulders for working (Nelson 1987:122). This may therefore make archaeological recognition of this type of site more difficult, although Wilke and Quintero (1996:252f) show that it can be successfully undertaken.

Another way of considering technology is by examining the *chaîne opératoire* (Karlin and Julien 1994:153), which Dobres and Hoffman (1994:237) translate as 'the chain of technical operations'. This is an important concept, as it examines each of the material stages involved in an artefact's manufacture, from the initial procurement of the raw material, through manufacture, to any repairs which occurred after a period of use, and also examines the order in which actions within these stages occur (Dobres and Hoffman 1994:237; Karlin and Julien 1994:164). Karlin and Julien (1994:153) argue that the reconstruction of a *chaîne opératoire* enables the procedures which go into manufacturing an artefact to be arranged into a coherent order, allowing the identification of the techniques of production, as well as the underlying conceptual pattern. However, they (op. cit., p.154) also note that the reconstruction of *chaînes opératoires* is dependent on the amount of surviving evidence of the manufacturing process, which, as has been discussed above, is not very high for basaltic artefacts. Nonetheless, they (ibid.) do suggest that experimental archaeology may provide valuable information on the ways in which an artefact was possibly manufactured, which can then be tested against the surviving archaeological data. Unfortunately, only a small amount of such work has been undertaken on basaltic artefacts, with replication experiments being one of the things that Rowan (1998:332) specifically called for at the end of his examination of south Levantine basaltic bowls.

Furthermore, Dobres and Hoffman (1994:237) argue that attempts to recreate and analyse *chaînes opératoires* are limited, as this does not include analysis of the social context of the actions which make up the *chaîne opératoire* in question. This criticism is answered by Sillar and Tite (2000:2f), who emphasise the important role that technology plays in the construction and reproduction of social relations and also highlight the importance of technological choices which are made by societies. They (Sillar and Tite 2000:4) argue that there are a wide range of technical possibilities for reaching the desired end products, even within the constraints imposed by the overall context of the society, including technological and environmental constraints (such as available resources), the economic basis, the social and political organisation, and the belief system of the society. Furthermore, although this is only implicitly considered by Sillar and Tite, another area of cultural choice is that of the desired end product itself. The choices which Sillar and Tite (ibid.) do identify include selection from the range of possible choices of raw materials, tools, energy sources, manufacturing technique and the sequence in which these acts are linked together, that is, the exact *chaîne opératoire* which was used.

As discussed in Chapter 3 and supported by the ethnoarchaeological work of Hayden (1987b:13), the physical properties of the rocks are a very important factor influencing the technological choice of a society, but one that is not usually considered. Hayden (ibid.) argues:

> "People did not indiscriminately choose any rock type, or even any rock within a rock type, to use as a tool. … If we hope to fully understand what stone tools can tell us about past culture, it is essential to know why stones with certain properties were selected for use as tools and how those properties fit into the overall design strategy."

For example, Hunt (1991:36) notes that in most societies igneous rock is only used for a limited number of artefact types (including quern-stones), whilst some societies utilise it for a wider range of tasks, including sculpture. As well as the various physical properties, other important factors include the availability and the aesthetic appeal of the rock, that is, the value given to it by the society in question. Hunt (1991:47,56) notes that the importance of all these factors varies between societies, but argues that if availability can be shown not to be the most important criteria of selection then this is evidence of deliberate, possibly experimental, choice. Sillar and Tite (2000:9) and Hunt (1991:49) also argue that once a stone type has been selected using these criteria, most workers tend to follow the technological tradition of the society, leading to cultural continuity.

This argument corresponds closely with Bourdieu's concept of habitus, which Dietler and Herbich (1998:246) define as "a system of durable dispositions" for people within a society to act in a certain way. This therefore allows creative practice in individuals, but also sets limits and exerts pressures for individuals to act in a certain way (Narotzky 1997:175). Dietler and Herbich (1998:246) therefore argue that:

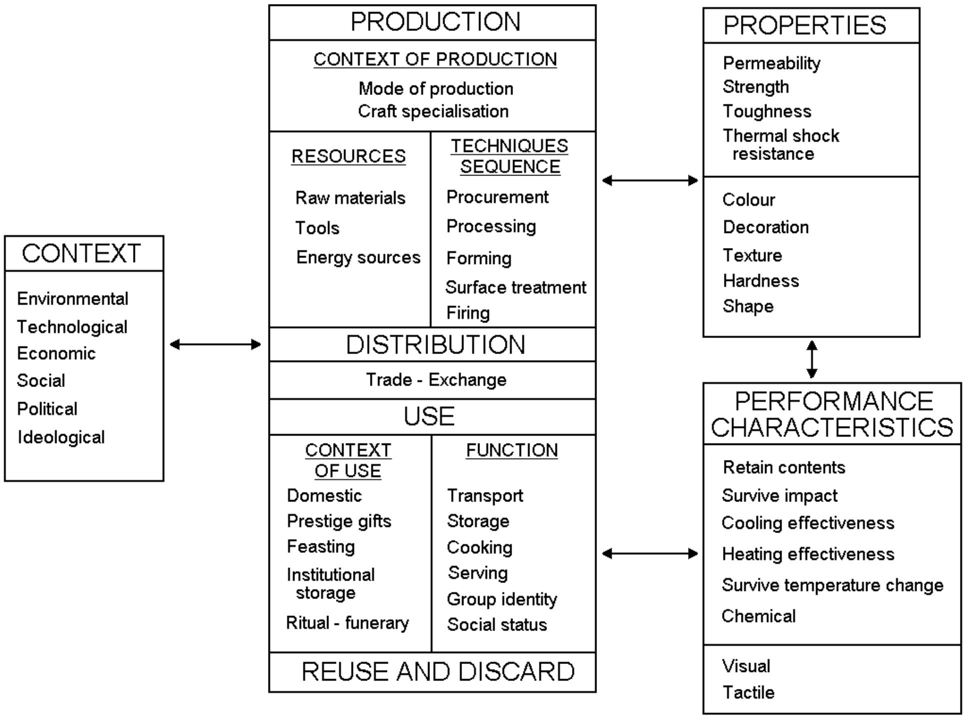
> "these dispositions of choice and perceptions of the possible in the technical domain are interwoven with similarly formed patterns of choice and perceptions in the domain of social relations and cultural categories in ways that evoke and reinforce each other such that they come to be perceived as 'natural'."

However, Dietler and Herbich (1998:247) also argue that habitus is not static, but rather alters gradually through time, due to small changes in demand and individual needs. They argue that these changes are usually unquestioningly accepted, but may occasionally lead to social structures being challenged, resulting in social conflict and the breakdown of habitus, before the restructuring of society and a new habitus, which may be based more or less closely on the previous system of habitus. This description of habitus can be explained using the realist concept of social homeostasis, discussed in Chapter 1, where social systems are generally resistant to disruption, but can occasionally radically change.

One very good example of this is the study by Harrison and Orozco Köhler (2001) of ground stone artefacts in the Iberian Peninsula. They argue (op. cit., p.124) that new artefact types were only widely adopted in a culture after they had been adopted by a small group of innovators, who were usually of relatively high status and could therefore afford to experiment. Once this small group had adopted the new technology it was then rapidly adopted throughout the rest of the society. As described, this process bears a very strong resemblance to the process discussed above and in Chapter 1. It also reveals another way in which demand and production are interlinked, as habitus operates on both the type of artefact that the manufacturer is predisposed to create and on the type of artefact which the consumer is prepared to accept.

Therefore, Sillar and Tite (2000:4ff) discuss a framework for integrating the processes and choices which affect an artefact (including individual factors within the processes) with the constraints imposed by the context and the characteristics of the material used to produce the artefact, using the example of pottery production. This is summarised as a diagram (Fig 5.3).

Fig 5.3: Interrelationships affecting technological choices



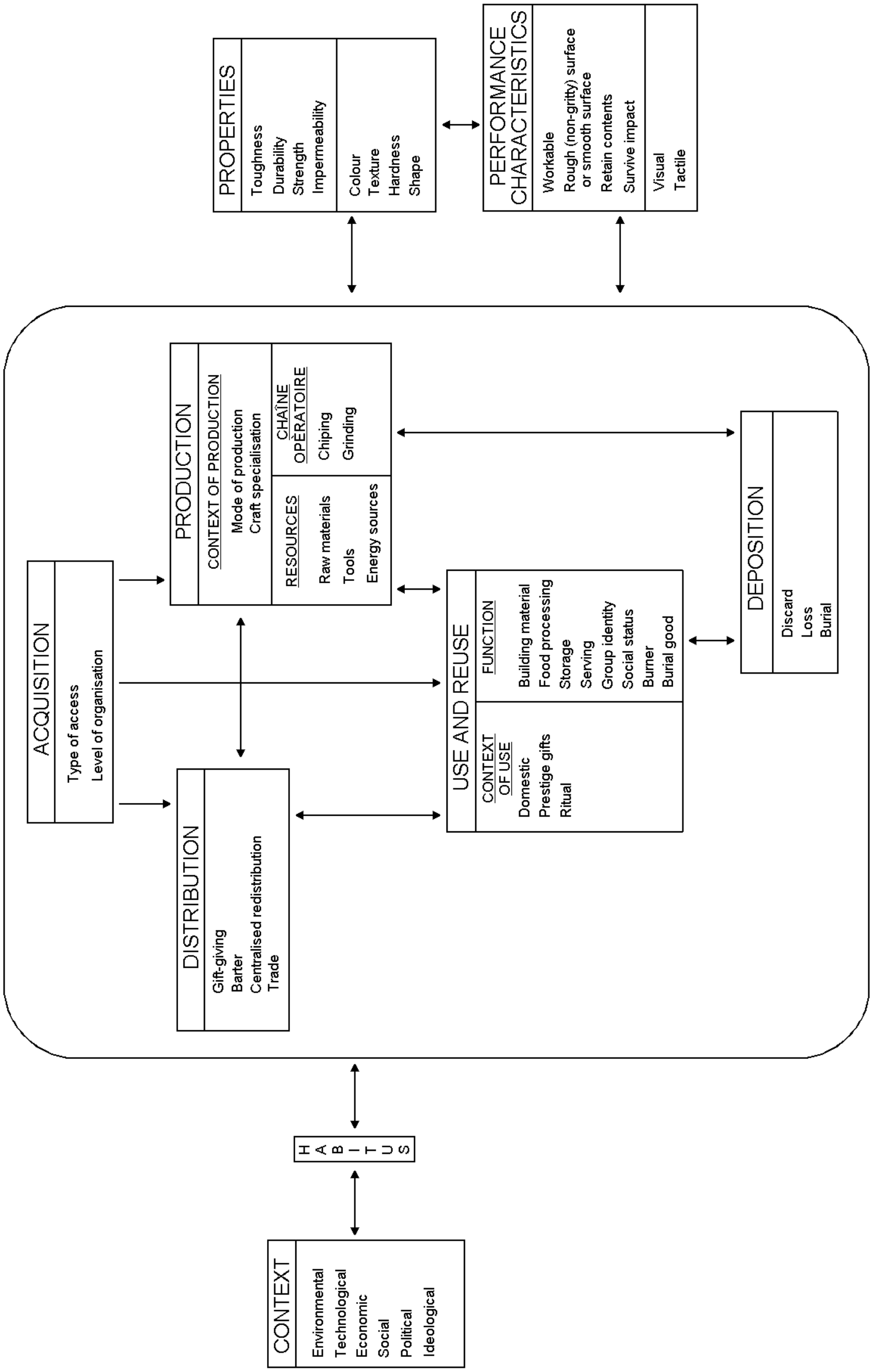
After Sillar and Tite (2000:5)

It can be seen that this diagram broadly agrees with, but expands upon, Torrence's (1986:5) diagram (Fig 5.2, above), by showing what technological choices are made during the artefact's 'life cycle' and also what factors affect these choices. However, this diagram does not show the relations between the areas in the central column, unlike Torrence's diagram. Nonetheless, it is possible to amalgamate these two diagrams (with additions suggested by the anthropological literature), into a new diagram showing both the actions and the technological choices which affect an artefact (Fig 5.4, overleaf).

This diagram retains Sillar and Tite's understanding that the technological choices which go into manufacturing an artefact are constrained by the natural and socio-cultural context and also by the characteristics of the raw material. Additionally, it shows that the context is mediated through the habitus of the society, and illustrates Hayden's (1987a:3) conclusion that "between the realms of tool use and tool discard intervenes a hazy zone of storage, caching, provisional discard, reuse, and recycling." Fig 5.4 shows that any individual artefact may pass through these different stages several times and in many different orders and combinations. Furthermore, it shows how procurement (both acquisition and distribution) is only part of an inter-related whole, while Sillar and Tite included 'Procurement' under 'Production' thereby obscuring this relationship.

Sillar and Tite's 'Reuse and Discard' category is also removed, with 'Reuse' being added to the 'Use' category, while 'Discard' becomes a sub-section of the new 'Deposition' category. This allows an understanding of how artefacts enter the archaeological record, unlike the two previous diagrams. Fig 5.4 has also been altered to reflect the production of basaltic artefacts, rather than pottery production. Most of these changes are self-explanatory, but, in the 'Performance characteristics' category, one of the sub-sections reads 'Rough (non-gritty) surface or smooth surface'. This reflects the differing uses of vesicular and non-vesicular basaltic rock, for categories such as quern-stones and bowls, respectively. Therefore, this diagram can inform the discussion of the procurement of basaltic artefacts in the southern Levant, not least by setting it in its wider context.

Fig 5.4: Actions, choices and constraints affecting a basaltic-rock artefact



Conclusion

The discussion of provenance and procurement has highlighted the strengths and weaknesses of these studies. The analytical procedures necessary for provenance have greatly improved in precision and accuracy, although care is still needed in the techniques used to source artefacts. Furthermore, recent attempts to understand the wider context of procurement have enabled a better understanding of the factors that influence these systems. However, there are still problems in relating provenance studies to the operation of past procurement systems, as the papers in both Cauvin et al. (1998) and Shackley (1998) illustrate. These problems are due both to the failure to adequately relate the anthropological theories to material remains and also to the failure to adequately collect all possible data from archaeological investigations. Hopefully, the diagram presented above may lead to a better understanding of these interrelationships and therefore lead to the required data being collected from both anthropological and archaeological investigations. In turn, this should lead to a better understanding of past procurement systems.

This discussion and the creation of Fig 5.4 has shown that past procurement systems identified by a provenance study can only be properly understood by placing them in their wider socio-cultural context. Therefore, Chapter 6 will present the relevant archaeological data, before Chapter 7 discusses the current provenance study. Chapter 8 will then attempt to examine the procurement systems revealed by this data.

Chapter 6: Basaltic artefacts and archaeological background

"Do not take a pair of millstones – not even the upper one – as a security for a debt, because that would be taking a man's livelihood as a security." Deuteronomy 24:6 (NIV)

As shown in Chapter 5, the basaltic artefacts need to be placed in their wider socio-cultural context to properly interpret the significance of any patterns which may be revealed through provenance analysis. The opening quote indicates the social significance of the millstone, frequently manufactured from basaltic rock. Their importance is emphasised in the NRSV translation which reads Deuteronomy 24:6b as: "for that would be taking *a life* in pledge" (emphasis added). This highlights the essential nature of ground stone artefacts in everyday food preparation. This chapter will discuss the manufacture, transport and use of basaltic rocks, followed by a discussion of the individual periods from which the sampled artefacts date (discussed in Chapter 7). This discussion will focus on data relevant to understanding the procurement of basaltic rocks, and will include discussions on the types of basaltic artefact which are found in the period and on the few individual sites from which the ground stone assemblage has been analysed.

Manufacture of basaltic artefacts

As discussed in Chapter 5, it has been very difficult to properly reconstruct the manufacturing process of any basaltic artefact, due to the virtual absence of any evidence for their manufacture. Epstein (1998:229) reports on a small amount of experimental work that was undertaken, which showed that basaltic rock could be worked using Chalcolithic flint tools, especially the adze, but unfortunately does not provide any more details. Hayden's (1987b:16) ethnoarchaeological study shows that another important tool, at least in Mesoamerica, was the stone pick. In the only major study of post-Neolithic Near Eastern chipped stone tool usage, Rosen (1997a:93) includes adzes, chisels and picks in the category 'celts'. He (Rosen 1997a:97) notes that the functions of any of the sub-categories of celts are not clear, but that they were probably used for a wide variety of purposes. Furthermore, apart from votive axes, chipped stone celts disappear completely at the beginning of EBI (Rosen 1997a:98). Rosen (1997a:161) argues that stone celts were completely replaced by copper tools during the EBA, probably due to the disruption in exchange networks and the fact that copper celts were easier to manufacture, especially as they could be mass produced. He also notes (Rosen 1997a:161) that no experimental work has been undertaken to determine the relative efficiency of stone and copper celts, but argues that there was probably no real gain in efficiency, and may even have been a slight decline. It was not until the widespread adoption of bronze that more efficient tools could be routinely produced (Rosen 1997a:162). This may therefore have implications for the manufacture of ground stone artefacts, which will be discussed below.

The ethnoarchaeological work of Hayden (1987b) has shown one process by which basaltic querns could be manufactured, but Wright et al. (in press, p.15) argue that the manufacture of basaltic vessels would probably be somewhat different. In conjunction with a Jordanian sculptor, they (ibid.) suggest that the process would involve a trial run using clay, followed by shaping the outside walls, hollowing out the interior (probably using drilling), shaping the rim, then the base and finally adding the decorations. It is somewhat questionable whether it would have been necessary to undertake a clay trial each time; however, the current limited state of knowledge clearly shows the need for further work, both by experimental archaeology, and through the discovery and analysis of basaltic production workshops (cf. Rowan 1998:332).

It is worth noting that Dalman (1902:9) reports that basaltic rock was still used for quern-stones in the southern Levant in the late 19th century AD, although these were rotary querns, which only came into common usage in approximately the 2nd century BC (Williams-Thorpe and Thorpe 1993:271). This observation does indicate, however, the continuing importance and usefulness of basaltic rock for quern-stones.

Transport of basaltic rock

Basaltic rock is a heavy, bulky material and is therefore difficult to transport over long distances. This is illustrated by Rowan's (1998:105ff) examination of ground stone assemblages from eight Chalcolithic and EBI sites. These sites fell into two groups, with four being within 20 km of a basaltic outcrop and four being between 90 and 110 km from the nearest outcrop. Although the nearest outcrop was not necessarily the source of the basaltic rock, this assumption is made so the relationship between distance and quantity of basaltic rock can be examined (Rowan 1998:119). If stone vessels are excluded from the analysis, there is a very sharp fall-off in the amount of basaltic rock used between the two groups of sites, although even the most distant sites had a small amount of basaltic rock (Rowan 1998:119). However, Rowan (1998:119) notes that as no sites were examined that were between 20 and 90 km this may distort this pattern somewhat.

Rowan (1998:107ff) also notes that he did not include stone vessels in his discussion, as over 90% of vessel fragments from all the sites were basaltic. This therefore highlights both the general difficulties with transporting basaltic rock, and the importance that was obviously attached to basaltic vessels during the Chalcolithic and EBI. For a more rigorous examination of the fall-off patterns of basaltic rock it would be necessary to examine more sites and also to compare the fall-off patterns of different rock types. However, this work has not been undertaken and is hampered by the lack of complete recording of ground stone assemblages at most sites.

A similar pattern was observed by Petit (2001), who examined the LBA and IA ground stone artefacts from Tel Rehov, situated just south of the Galilee outcrops, and Tell Deir ‘Alla, situated in the Jordan Valley. He reported that c.90% of the ground stone artefacts at Rehov were manufactured from basaltic rock, whilst at Deir ‘Alla during the LBA and IAI, only c.20% of artefacts were manufactured from basaltic rock, rising to c.50% during the IAII. These figures demonstrate the fall-off effect that even relatively short distances have on the artefactual assemblage.

As discussed in Chapter 2, Weinstein-Evron et al. (1999) demonstrated that basaltic rock was transported up to 100 km in the Epipalaeolithic, which must have been carried by people, given the absence of suitable domesticated animals. Malville (2001:234) reports on her ethnographic work amongst the porters of Nepal, who carry an average load of about 70 kg (with a number carrying over 100 kg) and can travel approximately 8 to 11 km per day, or 24 km a day unladen. She (ibid.) also notes that there are commercial porters who regularly make 150 km round trips, whilst the outlying villages send a number of porters annually to obtain supplies which cannot be produced locally. Malville (2001:236ff) then applies this data to the American Southwest, where there were no beasts of burden before the European conquest. She argues (Malville 2001:239f) that as the terrain of the Southwest is less rugged than Nepal the porters would have been able to walk further and faster and concludes (Malville 2001:237f) that:

> “transport of food staples and durable goods was clearly feasible in the pre-Hispanic Southwest on a regular basis over one-way distances of at least 150 km requiring estimated round-trip walking times of two weeks or less.”

This data also seems applicable to the southern Levant, and shows that the 100 km one-way distance required for basaltic procurement is well within the potential range of human porterage.

Nonetheless, in later periods basaltic rock would have been transported using animals, given the greater weights that could be carried and the longer distances that could be travelled by animals. Grigson (1993:645) reports that “pictorial and written records indicate that from the Early Bronze Age onwards donkeys were the chief means of transport all over the Near East”, with the Mari texts (dating to c.1800 BC) referring to a donkey train consisting of 3,000 animals (Grigson 1995:258). This is supported by the faunal evidence, which shows that donkeys were widespread from the 3rd millennium onwards (Grigson 1993:645). It is therefore very probable that donkey trains were the primary means by which basaltic rock was transported from at least the EBI onwards, with Bourke (2002:12) arguing that donkey trains had the greatest impact on “the sub-regional movement of bulk commodities”, presumably including basaltic artefacts.

In the LBA, donkeys were “readily available and relatively cheap”, making them “absolutely essential” for inter- and intra-regional transport (Monroe 2000:78). Dorsey (1991:15ff) argues that during the IA, if not earlier, in the southern Levant wheeled vehicles were also regularly used to transport goods. However, he also notes (Dorsey 1991:14ff) that donkeys continued to be used, not least as they were able to travel along narrow, mountainous paths not open to wheeled traffic. It is therefore very probable that donkeys continued to be used for the transport of basaltic rock, at least to move it from the outcrop to the workshop, especially as Dorsey (1991:28-38) reports that the roads were probably unpaved and that no bridges or ferries existed, with fords being the usual method for crossing rivers.

This evidence therefore raises the question of how basaltic rock was transported in the Chalcolithic period. There is some evidence from the Chalcolithic that donkeys were domesticated and used as beasts of burden. Grigson (1995:258; 1993:645) argues that domestic donkeys were probably present in the Levant during the 4th millennium, if not one or two millennia earlier, and also notes that Mesopotamian cuneiform signs of the late 4th millennium have been found which represent donkeys. Furthermore, there are small quantities of equid bones from secure contexts on a number of important Chalcolithic sites in the southern Levant, including Bir es-Safadi, Tell Abu Matar and Teleilat Ghassul, some of which have been identified as donkey, and some as horse (Grigson 1993:646ff).

Moreover, Epstein (1985:54) reports that during the Chalcolithic the first pottery figurines of laden animals were made. She argues (Epstein 1985:59) that these included the first laden donkey figurine. These are more commonly found from the EBA, including the example shown in Fig 6.1. However, Ovadia (1992:20) argues that the Chalcolithic donkey figurine is intrusive from the EBI levels and so cannot be used to support the use of the donkey during the Chalcolithic.

Fig 6.1: Pottery donkey figurine from Azor

From Epstein (1985:58).

More importantly, Epstein (1985:54f) also reports that a number of pottery figurines of laden rams have been found from Chalcolithic sites, as well as a ram figurine made out of basaltic rock (Fig 6.2), which was found at Tell Turmus, in the Huleh Valley. Ovadia (1992:24ff) therefore argues that rams were the main beasts of burden used during the Chalcolithic (and possibly earlier), especially given the supporting textual and ethnographic evidence of such usage. Therefore, it is very probable that rams were used to transport basaltic rock, before the introduction and widespread use of the donkey, whether this occurred only at the beginning of the EBI or, as is more likely, during the Late Chalcolithic (cf. Bourke 2001:117). This is also supported by the recent discovery by Quintero et al. (2002) of a major flint production area in the Jafr Basin in south-east Transjordan. This started in the Chalcolithic and continued until the EBIII, with Quintero et al. (2002:18) arguing that hundreds or thousands of tons of flint was worked and transported to settlements during this time. They (Quintero et al. 2002:45f) therefore argue that the flint was transported by donkeys and that the exploitation was probably seasonal and undertaken by pastoralists. These various lines of evidence therefore support the suggestion of Philip and Williams-Thorpe (1993:62) that pastoralists were responsible for the transportation of basaltic artefacts during the Chalcolithic and EBI.

Fig 6.2: Basaltic ram figurine from Tell Turmus

After Epstein (1985:55).

Use of basaltic rock

As discussed in Chapter 3, basaltic rock is very durable, and, if vesicular, has many advantageous properties for grinding. However, although, querns were certainly regularly used for the grinding of grain, it should not be assumed that this was their sole purpose. Wright (1992:87f) reports that the ethnographic evidence and Mesopotamian texts shows that a wide range of materials were processed using stone querns or mortars, including nuts, seeds, fruit, vegetables, herbs, spices, meat, bark, pigments, temper and clay. Furthermore, during their geochemical analyses of basaltic artefacts, Lease et al (1998:90 and 2001:235) noted that a number of querns had traces of arsenic and bismuth, unlike the outcrop samples, and had levels of antimony which were ten times higher than those of the outcrops. They conclude that this was probably due to the use of these querns in the preparation of medicines, cosmetics, dyes or even in the manufacture of alloys. This also illustrates another way in which uses of querns and mortars could potentially be examined, although unfortunately none of the southern Levantine artefacts have been analysed for these elements (cf. Appendix 7). This therefore remains a potential direction for future research.

Other potential ways of gaining a better understanding of the use of basaltic artefacts include their examination for any residues they might contain (Wright 1992:90), and the analysis of artefacts for any plant or animal lipids or proteins they may have absorbed (Evershed et al. 2001; Gernaey et al. 2001). Starch grains from certain plants have also been identified on stone tools (and can be matched to individual species; Piperno and Holst 1998). The results of such analyses may well provide some indication of how the vessels were used. However, macroscopic residues are usually only left after burning, whilst biomolecules from dry foodstuffs will not be absorbed into the rock, unless heated. Nonetheless, these sorts of analyses could constrain speculation on the potential uses of particular artefacts. Wright (1992:107f) also discusses the potential of microwear analysis for determining the functions of stone artefacts, but concludes that much more work needs to be done before this is potentially useful. She argues (Wright 1992:107) that macro-wear is currently more useful, as it enables broad distinctions to be made, such as whether a tool was used for grinding or pounding.

It is widely argued that quern-stones were not usually used to dehusk glume wheats, which include emmer, einkorn and spelt (Wright 1992:70; Hillman 1984:129,146). Instead, there is widespread ethnographic evidence for the use of wooden pestle and mortars, or the use of a wooden pestle with a stone mortar (Hillman 1984:129; Peterson 1999:6). This observation is supported by the experimental work of Meurers-Balke and Lüning (1992:356) which showed that a wooden pestle and mortar is the most efficient dehusking tool. Dalman (1902:17) also reports that wooden pestles were used with stone mortars in the southern Levant during the late 19th century AD. Egyptian, Classical Greek and Mesopotamian texts also mention wooden pestles and either stone or wooden mortars (Hillman 1984:129; Wright 1992:71). Although this usage may not be directly archaeologically visible, if stone mortars were used with wooden pestles then the discrepancy between the number of mortars and pestles could be recognisable.

However, Hillman (1984:130f) also notes that in north-west Anatolia basaltic pestles and mortars were used to dehusk rice, showing, he suggests, that this method could potentially be used to dehusk cereals. Furthermore, he reports on an experiment where a saddle-quern using a small handstone was found to be the most effective way of dehusking. This reveals a potential problem with the experiments of Meurers-Balke and Lüning (1992:346, 350), who report using the saddle-quern only with a large, 9 kg handstone, despite experimenting with three different sized wooden pestles. As they note (Meurers-Balke and Lüning 1992:360), the results of their experiments cannot be applied uncritically to all archaeological reconstructions, although the use of wooden pestles with stone or wooden mortars remains the most likely option, given their prevalence in the ethnographic, textual and archaeological records.

Another way in which the use of basaltic artefacts could be examined was demonstrated by Wright (2000), who was able to conduct an examination of the social customs of the preparation and eating of food between the Natufian and PPNB by a spatial analysis of the structures and artefacts, including ground stone tools, which were used for these purposes. This type of analysis could well be helpful for understanding how basaltic artefacts were used, and, possibly, why basaltic vessels were important. However, given the current absence of data detailed enough to undertake such analysis, especially in later periods, this is not possible.

Peterson (1999) also examined certain types of ground stone tools from Epipalaeolithic sites in the southern Levant. Using this data she was able to draw conclusions about the type and length of occupation of Epipalaeolithic sites, and so gained fresh evidence on the settlement patterns of the region (Peterson 1999:14). Furthermore, Peterson (1999:7; 2001) argues that the available evidence, including skeletal morphology, indicates that in the southern Levant grinding and other plant processing activities were primarily undertaken by women. However, Wright (2000:114f) is more cautious, arguing that although the available evidence suggests that food preparation and cooking were probably conducted by women, it is limited and ambiguous, and so cannot be considered proven. From the 2nd millennium onwards, the evidence becomes stronger, with the textual evidence including references to quern-stones being regarded as women's property and given as gifts from husbands or fathers, whilst dowries also include handstones or querns (Wright 2000:115). These examinations therefore show that a greater understanding of past societies can be gained through the proper analysis of ground stone artefacts, but only if they are properly excavated and recorded.

Another important point is that basaltic artefacts were almost certainly used for other purposes which would leave little or no direct archaeological evidence, but which may nonetheless have been important. For example, DeBoer (2001:223), in his review of the traditional gambling games of North American tribes, reports that one of the games involved bouncing a group of split canes off a quern. These games attracted varying amounts of gambling, which resulted in artefacts such as shell jewellery and other valuables being transferred between people and groups and were therefore an important procurement mechanism, despite being virtually archaeologically invisible (DeBoer 2001:216,238-244). A further example is recorded in the book of Judges (9:53; NRSV): "But a certain woman threw an upper-millstone on Abimelech's head, and crushed his skull."

More usually, Wright (1992:96) notes that broken or worn out querns were used as masonry, or for a wide variety of other purposes, with there being numerous examples of reworked artefacts. For example, Hayden (1987c:197ff) reports that broken querns are regularly used by the highland Maya to grind calcite for temper and for grinding spices. This re-use and re-working is partially due to their long use-life, with Wright (ibid.) citing a number of studies on the use-life of basaltic querns, which report ages varying from 20 to 1,000 years, while Hayden (1987c:193) estimates that the use-life for vesicular basaltic querns amongst the highland Maya is between 15 and 30 years. These great variations in estimated use-life, some of which is probably due to differences in material and usage, reveals the need for more work to properly quantify these differences and the factors involved. Furthermore, non-utilitarian stone artefacts may well have even longer use-lives. Hankey (1974:166) reports that two Egyptian-style calcite vessels found at a LBA site in Transjordan, were probably Predynastic or 1st Dynasty in date, a gap of some 1,500 years. It is entirely possible that basaltic artefacts could also have similarly long periods of use and re-use. For example, Sparks (1998) reports that one basaltic bowl found in an LBIIB (1300-1200 BC) context was most probably manufactured during the MBII (1700-1500 BC).

Chalcolithic (late 6th mil-3600 BC)

As discussed in Chapter 1, the settlement patterns of the Chalcolithic shift towards mixed farming settlements in semi-arid areas (Levy 1995:226). As well as seasonal encampments, larger, permanent settlements grew up, including Teleilat Ghassul, Shiqmim and Grar (Goren 1992a:47f; Gilead 1995:469). Other significant changes include a growth in the population, the establishment of public sanctuaries and the emergence of metallurgy, regionalism and some form of craft specialisation (Levy 1995:226; Kerner 1997b:467). Van den Brink et al. (1999:162) note that there are striking innovations in "specialised ceramic vessel manufacture, ivory carving, sophisticated metallurgical skills in copper production and the fabrication of ground-stone artefacts, especially bowls." Bourke (2002:24) argues that during the Early Chalcolithic the elites were priestly, with little evidence of social stratification. During the Late Chalcolithic, Bourke (2001:151f) argues these were replaced with group-oriented chiefdoms, whose power was based on their ability to mobilise labour from their extended kin-groups to produce a surplus, from which they could engage in exchange.

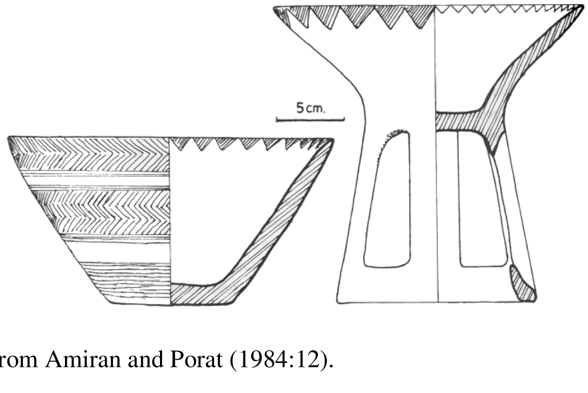
A good example of the evidence for regionalism during the Chalcolithic is Gilead's (1995:473ff) identification of two distinct, although related, cultural entities within the northern Negev. The Beersheva sites have stone foundations to buildings, copper, and ivory artefacts, but do not have the generally common pottery cornets or pigs. In contrast, the Besor-Grar sites have mudbrick foundations to buildings, stone violin-figurines, microliths and more sickle blades, pottery cornets and pigs, but few ivory or copper artefacts. Furthermore, petrographic analysis of the pottery from these sites supports this division into two groups (Gilead 1995:475).

As also discussed in Chapter 1, there are also elements of shared material culture, including stone artefacts. During the Late Chalcolithic there was widespread intra-regional exchange and even some inter-regional exchange. There is also evidence for full-time specialists, probably including stone workers, with Levy (1995:232) arguing “stone carving or sculpture reached a level of expertise rarely seen in the later cultures of Palestine.” Goren (1992a:62) therefore concludes that “Chalcolithic society was based on an extensive network of prospecting and trade in raw materials, production, and the exchange of goods”. This is clearly demonstrated by the extensive flint production in the Jafr Basin (Quintero et al. 2002), discussed above. The exchanged artefacts probably played an important role in the creation and maintenance of both inter-group relations and of intra-group status differences (cf. Philip 2001:189).

Basaltic artefacts

During the Chalcolithic, basaltic rock was used for a wide variety of stone artefacts, including millstones, axes (long, narrow blocks), hammers, hoes (rectangular, perforated stones), whetstones and loom weights (Goren 1992a:57; Bourke 2001:142). These artefact types were usually manufactured from basaltic rock only in areas close to basaltic outcrops, whilst further away stones such as limestone, flint and sandstone were used (van den Brink et al. 1999:164). Most notably, basaltic rock was used to manufacture bowls, which were usually V-shaped, with a wide, flaring rim and a flat base and were usually highly polished inside. They were often decorated with a band of hatched triangles on the inner edge of the rim, whilst the outside was sometimes decorated with parallel incised bands filled with a herringbone pattern or hatched triangles. More rarely, the bowls were also carved with a fenestrated pedestal (Fig 6.3; Amiran and Porat 1984:11f). Goren (1992a:57) describes these basaltic vessels as “a unique and outstanding product of Chalcolithic craftsmanship.” As already noted, these vessels are found on sites throughout the southern Levant, irrespective of the distance from the basaltic outcrops.

Fig 6.3: Chalcolithic basaltic vessels



From Amiran and Porat (1984:12).

Amiran and Porat (1984:12f) note that both the V-shaped and fenestrated bowls are also pottery forms, and argue that the basaltic bowls were probably imitations of these, especially as they comment that it is considerably easier to fenestrate a pottery cylinder than a basaltic one. Furthermore, they note that the fenestrated vessels develop into bowls with four legs (Fig 6.4), showing a shift in style to one easier to manufacture using basaltic rock.

Fig 6.4: Four-legged bowl

From Amiran and Porat (1984, pl. 1).

Although both basaltic bowl types are found at sites throughout the southern Levant, they are not usually found outside this region. It is notable that they are absent from the Orontes Valley just to the north of the region, despite basaltic rock being readily available and pottery V-shaped bowls being found in nearby Byblos (Philip 2002:215,218f). Furthermore, at the important coastal site of Ras Shamra in the northern Levant, stone vessels were manufactured predominately from steatite, whilst none were basaltic, except during the last quarter of the fifth millennium BC (Level IIIC; de Contenson 1992:95-123). This is described as “a period of decline and isolation” (de Contenson 1992:201), but this is with reference to northern Mesopotamia. It is therefore possible to argue that, when these links were temporarily broken, contact was made with the southern Levant (the probable source of, or inspiration for, the basaltic vessels) and that when contact with north Mesopotamia was re-established, links with the southern Levant were no longer important. This is somewhat speculative, especially as the sample size is small, but it does illustrate the potential of ground stone analysis to elucidate the changing links between past societies.

The function of the basaltic bowls remains unclear, although some non-domestic use is probable, given their association with prestigious artefacts such as ivory and the fact that they would have taken considerably longer to produce than the similar-looking pottery vessels (Goren 1992a:58). Amiran and Porat (1984:13) argue that the two vessel types had specific ritual functions, as they are frequently found together, and only these types were selected for manufacture in basaltic rock out of the much wider repertoire of pottery forms. However, they note that one problem with this argument is that basaltic vessels were not found at the important ritual site of Ein Gedi. Nonetheless, Kerner (1997b:468f) also argues that these vessels have some ritual rather than prestige function, as they are evenly distributed throughout the region.

More widely, Ebeling (2001:195) argues that certain types of ground stone vessels, mortars and stone tables, including those manufactured from basaltic rock, are associated with Chalcolithic cultic sites, showing their use in these contexts.

Conversely, Gilead (1995:320f) argues that the vessels were primarily for domestic purposes, but concedes that they may have had some role in private rituals and that their use was context-specific. Van den Brink et al. (1999:182) argue that, as these basaltic vessels are found in a variety of contexts (ritual, mortuary and domestic), they very probably had multiple meanings and multiple functions, depending on their spatial and temporal context. Therefore it is possible to argue that during the Early Chalcolithic, if the elites were also the priests, such exotic imports may well have had a dual prestige and cultic function. In the Late Chalcolithic, the prestige of these artefacts may well have been appropriated by the newly emerging 'secular' elites, whilst retaining, at least in certain contexts, something of their ritual associations. Furthermore, basaltic vessels were probably not as prestigious as rarer artefacts, including copper maceheads (Levy 1995:234), and so could potentially have been acquired by sub-elites, as described in Chapter 5. A combination of a domestic ritual or symbolic function and their availability to sub-elites may well explain the relatively widespread nature of these vessels.

Regionally, the Golan also produced zoomorphic (such as Fig 6.2) and anthropomorphic figurines (with combinations of prominent ears, eyes and nose), which usually had a bowl-shaped top (Fig 6.5) (Bourke 2001:140). Epstein (1998:230) suggests these were house idols, with offerings placed in the bowl, although this is contentious (cf. Goren 1992a:74). Unlike the vessels, the figurines were not widely distributed, and are only found in the Golan and the immediate surrounding areas of the East Galilee lowlands, the Damascus basin and northern Transjordan (Bourke 2001:140f). Both the mode of production and the meaning of these figurines remains unclear (Kerner 1997a:425).

Fig 6.5: Golan anthropomorphic figurine

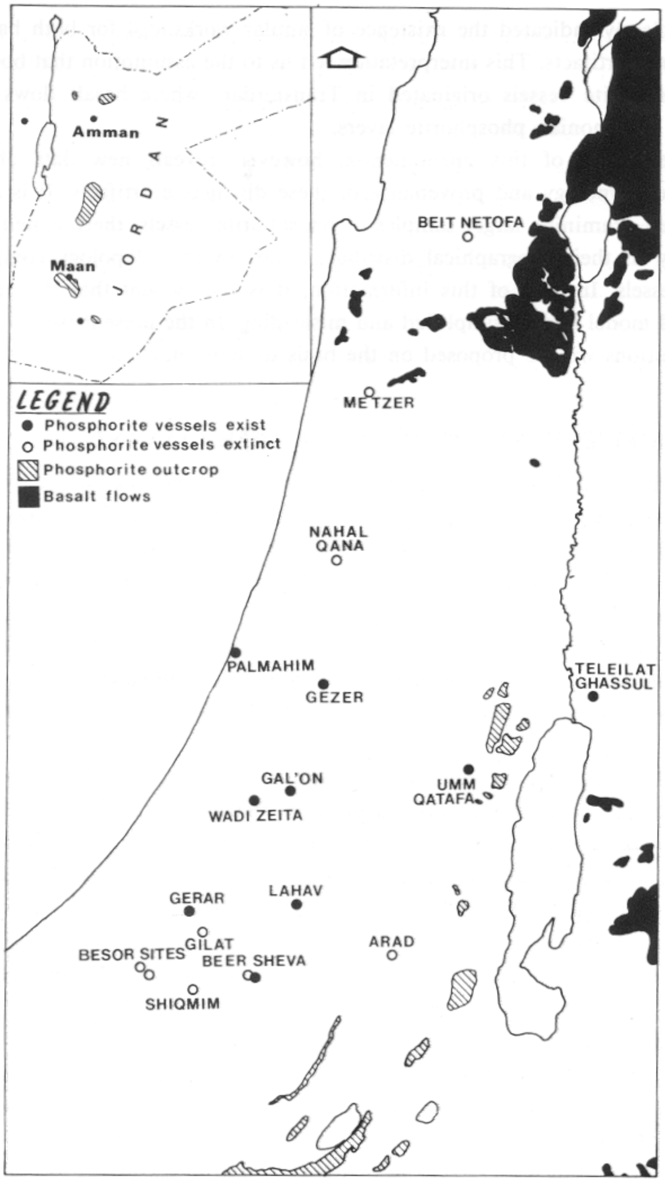
After Epstein (1998).

Another regional variation has been observed in southern Cisjordan, where basaltic artefacts are found alongside similar looking artefacts produced from the local outcrops of phosphorite (Fig 6.6, overleaf). This is a fine-grained, sedimentary rock, formed from calcium carbonate and calcium phosphate and contains fragments of fish bones (Gilead and Goren 1989:11). However, there is a "remarkable visual similarity" (Goren 1991:102) between the basaltic and phosphorite artefacts, as only the rarer dark (calcium phosphate-rich) phosphorite was chosen, whilst the phosphorite vessels were manufactured in the same style as the basaltic vessels (Gilead and Goren 1989:11; Goren 1991:109). The identified phosphorite artefacts are predominately bowls, although also include one fenestrated bowl and one loom weight (Goren 1991:108). It is worth noting that all these artefacts had previously been classified as 'basalt' (Goren 1991:107), so it is very probable that more artefacts have been misidentified. It can be seen from Fig 6.6 that the phosphorite artefacts only have a limited distribution, especially compared to the distribution of basaltic artefacts. Furthermore, at all the sites on which phosphorite artefacts have been identified there are always more basaltic artefacts than phosphorite artefacts (Goren 1991:105ff), with Rowan (1998:293f) reporting that phosphorite vessels were 12% of the 'basalt' vessel assemblage at Grar, and 6.25% of the assemblage at Teleilat Ghassul.

Gilead and Goren (1989:11f) report that it is possible to distinguish between phosphorite and basaltic artefacts in both thin section and also by using a hand lens, when the fish bones are clearly visible. Furthermore, Goren (1991:108) notes that phosphorite bowls differ from basaltic bowls as they are more crudely made, with a thicker and more irregular base and sides and only simple decorations at best. He therefore argues (Goren 1991:109) that, as phosphorite is easier to work than basaltic rock, this is evidence of less specialist manufacturing.

This limited distribution of an inferior product, which is nonetheless similar in appearance to the more widely distributed basaltic bowls may be explained by Sherratt's (1998:295f) argument, discussed in Chapter 5, that value-added goods are susceptible to import substitution. Although her arguments deal mainly with the palace-centred polities of the LBA, and so cannot be applied directly to the Chalcolithic, they may well help to explain the localised distribution of these phosphorite copies. As discussed above, spatial analysis, as well as the examination of any residues and biomolecular analysis, could indicate how these vessels were used and could therefore possibly indicate any differences in uses between basaltic and phosphorite vessels. If the hypothesis of import substitution is correct, then there should be a considerable overlap in the usage of these vessels.

Fig 6.6: Distribution of phosphorite artefacts



From Goren (1991:104).

Kerner (1997a:421) notes that it is generally assumed that some form of specialisation is necessary for the production of the stone artefacts, especially basaltic bowls. However, this understanding is hampered by the lack of knowledge on exactly how basaltic artefacts were produced (Kerner 1997a:421; van den Brink et al. 1999:166). Kerner (1997a:424) also notes that both basaltic vessels and tools are found "in literally all Chalcolithic sites", regardless of size from the Sinai desert to the Golan.

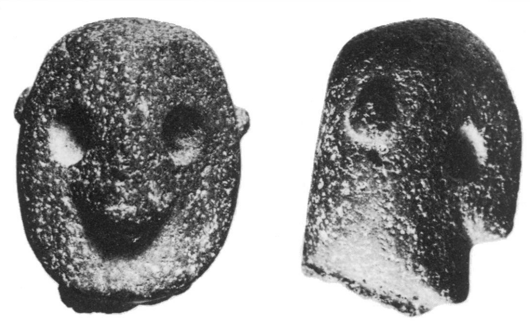
This therefore raises questions about the exact procurement mechanism which operated (cf. van den Brink et al. 1999:166), as it does not seem to be greatly affected by distance. This could be more accurately quantified if there were detailed ground stone data from a larger number of sites. However, the current situation is summarised by Wright et al. (in press, p.18) who comment that "published descriptions of Chalcolithic ground stone assemblages are generally brief and comparative figures indicating relative percentages of type are rare." This situation is also the case for the later periods under discussion, thereby greatly restricting the types of analysis that can be undertaken. However, sites where attempts have been made to analyse the ground stone artefacts will now be discussed individually, moving from south to north for Cisjordan and then Transjordan.

Shiqmim

Shiqmim is the largest Chalcolithic site in the Beersheva valley, covering 9.5 ha, and is the only Chalcolithic site in the area with a separate cemetery, which covers about 8 ha (Levy and Alon 1987:154; Levy and Alon 1993:1370). As with other sites in the area, the earliest phase of occupation was subterranean tunnels and rooms, which were replaced by an open-air village of rectilinear buildings with courtyards, pits and open areas. Some of the buildings are larger and appear to be public buildings (Levy and Alon 1987:180). However, the buildings were widely spaced and it is probable that the whole site was not occupied simultaneously, meaning that there were probably only a few hundred inhabitants (Gilead 1995:466f).

Basaltic artefacts, including vessels, were found at Shiqmim, as was a unique basaltic statuette head (Fig 6.7) (Levy and Alon 1985). This head was 3.8 cm tall, with a clear break at the neck, and has a large, prominent nose, which Levy and Alon (1985:188) note is similar to the Golan figurines, although overall it is most stylistically similar to ivory figurines found at Abu Matar and Bir es-Safadi. Levy and Golden (1996:158) attempt to explain the existence of this and other unique artefacts at Shiqmim, by arguing that a variety of Chalcolithic regional ideologies were brought together at Shiqmim into a syncretistic whole.

Fig 6.7: Shiqmim statuette head



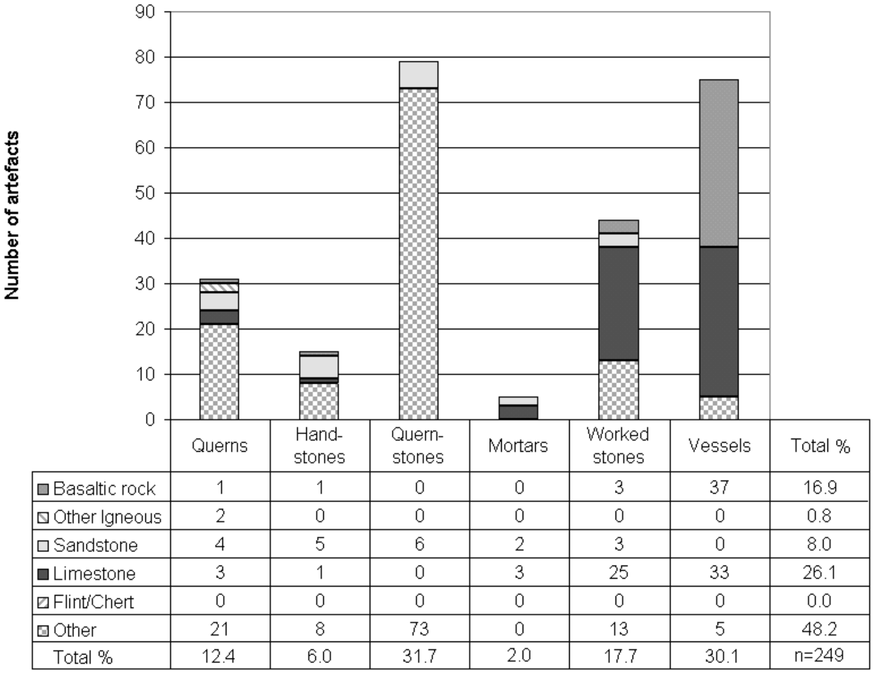
From Levy and Alon (1985, pl. xlv).

The most probable explanation, especially given the small size of the statuette, is that it was re-worked from a broken artefact. The alternatives are that the basaltic rock was imported unworked and manufactured locally, or that it was manufactured to local specifications, thereby indicating direct long-distance contacts. These explanations are less likely, given the uniqueness of the artefact, but to properly test the alternatives requires a detailed examination of the ground stone artefacts, and for future excavations at the site and surrounding area to actively search for basaltic working debris and unfinished artefacts. Only if there are significant numbers of, especially larger, artefacts with clear indications of local stylistic influences will these alternatives become more likely, with the choice depending on the presence or absence of the evidence for local manufacture.

Grar

Grar was a mixed farming village, situated on the right bank of Nahal Grar, north of Beersheva, in the northern Negev. The settlement consisted of isolated structures, surrounded by pits, with most daily, domestic activities carried out in the open courtyards adjacent to the buildings (Gilead 1995:1,463f). In the published excavation report, Gilead (1995) presents a relatively detailed analysis of the 249 ground stone artefacts discovered, summarised in Fig 6.8.

Fig 6.8: Grar ground stone categories and materials



	Querns	Hand-stones	Quern-stones	Mortars	Worked stones	Vessels	Total %
■ Basaltic rock	1	1	0	0	3	37	16.9
▧ Other Igneous	2	0	0	0	0	0	0.8
□ Sandstone	4	5	6	2	3	0	8.0
■ Limestone	3	1	0	3	25	33	26.1
▨ Flint/Chert	0	0	0	0	0	0	0.0
▩ Other	21	8	73	0	13	5	48.2
Total %	12.4	6.0	31.7	2.0	17.7	30.1	n=249

Data from Gilead (1995:330-332,356-359).

As Gilead (1995:309f) reports, the main rock types found at the site are beach rock[1] (41%), limestone (26.1%) and basaltic rock (16.9%), with beach rock and limestone locally available.

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[1] Beach rock is cemented beach sand, which develops in the inter-tidal zone and so may include shells and pebbles (Allaby and Allaby 1999:55; Gilead 1995:327).

As can be seen, basaltic rock was used almost exclusively for vessels, whilst limestone vessels were almost as common (Gilead 1995:331). The other five vessel fragments were identified as phosphorite, and were similar in appearance to the basaltic vessels. However, Gilead (1995:315) reports that two of the fragments had a thick section below the neck of the rim, unlike those manufactured from basaltic rock. A further two fragments had chevron decoration, similar in nature to the basaltic vessels, but the triangles were larger and the incisions were deeper and coarser than those of the basaltic vessels (ibid.). These observations support the argument, discussed above, that the phosphorite vessels were manufactured locally by less skilled craft workers, contrary to Gilead's (1995:318) assertions.

Gilead (1995:319) reports that the vessels, both basaltic and limestone, were found in a variety of contexts, but primarily from domestic areas, leading him to question their level of value, as discussed above. He (Gilead 1995:326) also notes that most of the limestone vessels were stylistically different from the basaltic vessels, and were probably locally produced. However, two of the vessels were stylistically similar to the basaltic vessels, with one being a fenestrated vessel and one a V-shaped bowl. Gilead (ibid.) argues this shows that, although the local craft workers were capable of producing limestone imitations of basaltic vessels, they generally chose not to, which "demonstrates the vitality of traditions, the overall homogeneity of the material culture, and the ongoing contact with either distant sources of raw material or distant communities." This corresponds with the observation of Cross (1993:80), discussed in Chapter 5, on the habitual restriction of certain categories of objects to specialists, primarily for the creation of inter-personal ties.

The main stone type used for grinding tools was beach rock, which Gilead (1995:327) reports has an irregular surface, with "numerous small cavities", which would have been advantageous for grinding. However, given its composition, it is very probable that pieces of grit would be detached during the grinding, unlike basaltic rock. Unfortunately, no experimental work on this is reported. One problem with examining the grinding tools is that it was not usually possible to separate them into handstones and querns due to the broken nature of the pieces. One of the querns was made of vesicular basaltic rock, which, from the drawing provided (Gilead 1995:329), was over 30 cm long (one end is broken), c.11 cm wide, and c.5 cm thick. That such a large, heavy artefact was transported the long distances from the basaltic outcrops illustrates the importance of basaltic rock and also strongly indicates that pack animals, probably donkeys, were used. Furthermore, although also a domestic utensil, there was very probably some level of prestige attached to owning such an item (whether it was owned by a household or wider group), given its exotic nature and advantageous properties. This strengthens the argument made in Chapter 5 that 'luxury' goods constitute a broader category than simply elite-owned items.

There were also two small querns made of pumice (which can be found along the Mediterranean coast), containing traces of red ochre (Gilead 1995:33). Of the worked stones, three were polished basaltic rock, of which one was a disc with a perforated centre, and the other two were flat fragments, interpreted as stone palettes (Gilead 1995:330).

Megiddo

Megiddo is situated in the Jezreel Valley in the Galilee, close to a number of basaltic outcrops. This is reflected in the ground stone assemblage, which is predominately manufactured from basaltic rock. Sass (2000) presents a catalogue of the small finds from the 1992 to 1996 seasons of excavation, which includes the ground stone artefacts. He reports (Sass 2000:349) that the research on the small finds was not complete when the volume went to press, and so simply presents a list of the artefacts, with pictures. The earliest level excavated during this time was a mixed Chalcolithic and Early EBI phase, with 10 basaltic fenestrated vessels definitely originating from the Chalcolithic and with 4 basaltic V-shaped vessels being from either the Chalcolithic or EBI. One broken vessel fragment is also reported as having been reused, although as what is not reported (Sass 2000:350,356). The rest of the artefacts will be discussed in the relevant periods. Sass (2000:350) reports that none of the artefacts discussed were found in an in situ Chalcolithic context, raising the possibility that at least some of these artefacts were curated into the EBI. This possibility is strengthened, as Finkelstein and Ussishkin (2000:576f) report that, although no Chalcolithic architectural features were discovered, the area excavated was probably cultic in nature in both the Chalcolithic and EBI.

Teleilat Ghassul

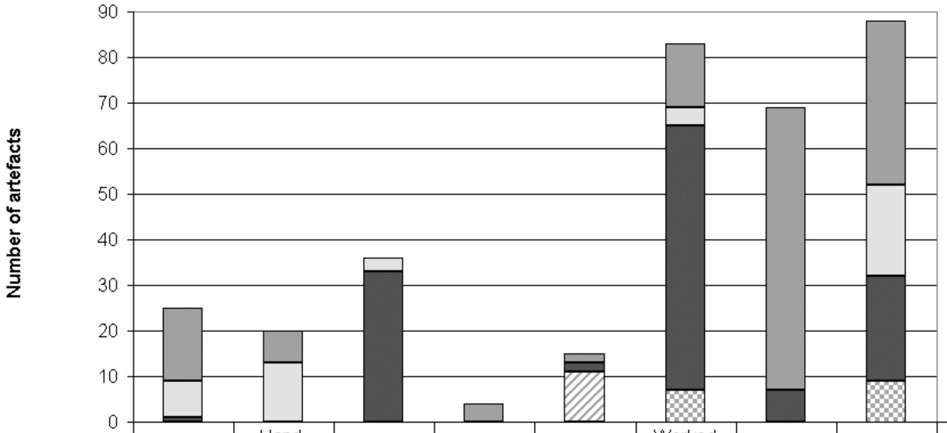
Teleilat Ghassul was a mixed farming village and was one of the largest permanent Chalcolithic settlements. It consisted of large rectilinear mudbrick buildings with stone foundations and is situated about 5 km north-east of the Dead Sea, and less than 5 km from the Sweimah outcrops (Hennessy 1989:230,232,235; see Chapter 4 for information on the outcrops). Wright et al. (in press, p.11) petrographically examined two vessels from the site. These were similar, but not identical, in composition to the Yarmouk outcrops, probably indicating that they originated from another northern Cis/Transjordan outcrop. Wright et al. (ibid.) report that Sweimah can be definitely excluded as a potential source, despite its proximity. This observation is confirmed by Philip and Williams-Thorpe (2001:11), who also note that Sweimah was not the source of the basaltic artefacts they examined from Ghassul.

Tell Abu Hamid

One of the few sites on which a detailed investigation of the ground stone assemblage has been undertaken is that of Tell Abu Hamid by Wright et al. (in press). Unfortunately the excavation report of the 1986-7 season (Dollfus and Kafafi in press), which includes this paper, has not yet been published, thereby illustrating another problem when attempting to evaluate such data.

Wright et al. (in press, p.6) report that of the 340 ground stone artefacts found, 41.5% were manufactured from basaltic rock, despite the nearest basaltic outcrop being 10 km away and with more substantial outcrops being 20 to 30 km away. The data are summarised in Fig 6.9.

Fig 6.9: Abu Hamid ground stone categories and materials



	Querns	Hand-stones	Mortars	Pestles	Pounders	Worked stones	Vessels	Other	Total %
■ Basaltic rock	16	7	0	4	2	14	62	36	41.5
▧ Other Igneous	0	0	0	0	0	0	0	0	0.0
□ Sandstone	8	13	3	0	0	4	0	20	14.1
■ Limestone	1	0	33	0	2	58	7	23	36.5
▨ Flint/Chert	0	0	0	0	11	0	0	0	3.2
▩ Other	0	0	0	0	0	7	0	9	4.7
Total %	7.4	5.9	10.6	1.2	4.4	24.4	20.3	25.9	n=340

Data from Wright et al. (in press, p.9).

From Fig 6.9 it can be seen that basaltic rock was the most used material for pestles, querns and vessels (with basaltic vessels making up almost 18% of the total repertoire). For querns and handstones, Wright et al. (in press, p.10) note that the proportions manufactured from sandstone and basaltic rock are almost reversed, leading them to suggest that these may have been used in pairs. This argument is strengthened as four paired basaltic querns and sandstone handstones were found together in closed contexts. This argument is supported by Stol (1979:83,97ff) who notes that there is ethnographic, archaeological and literary evidence which indicates that, while the lower millstone was generally basaltic, the upper millstone was more regularly manufactured from other rock types, with sandstone being a common choice. This observation also illuminates the opening quotation from Deuteronomy, which seems to ascribe less importance to the upper millstone; this could be explained if this was more usually manufactured from locally available rock.

At Abu Hamid there is also evidence for the curation and on-site re-working of basaltic artefacts, with a number of artefacts showing signs of modification. These include a hoe, refashioned from a broken handstone, and a vessel with an uneven base, which Wright et al. (in press, p.10) interpret as having been a fenestrated vessel, which had been broken and then ground down. Wright et al. (in press, p.11) also report that a few basaltic flakes were recovered, which are probably debitage from the re-working of basaltic artefacts. They are unlikely to represent primary manufacture, as no unworked basaltic rock and only one potentially unfinished artefact were discovered at the site (ibid.). It is also notable that, if the vessels category is excluded, basaltic rock was only used for 29.2% (79 of 271 artefacts) of the artefacts, whilst limestone was used for 43.2% (117) of the artefacts.

Wright et al. (in press, p.10) also note that most of the basaltic vessels and pestles were of fine-grained, but vesicular, basaltic rock with olivine phenocrysts, whereas the rock in the other artefact categories were usually coarser-grained and vesicular, probably indicating at least two distinct sources. In a small-scale provenance study, thin sections of five vessels and one quern were taken, along with samples from three potential source outcrops. These outcrops were Sweimah, the Yarmouk valley and the nearby source of Ghor al-Katar. However, Wright et al. (in press, p.11) report that this outcrop was too highly eroded to have been workable, and note that the five vessel fragments are generally consistent with Yarmouk, or a similar northern Cis/Transjordan outcrop and are unlike the other potential sources. Nonetheless, Wright et al. (in press, p.10) caution that as the West Bank sources were not sampled it is difficult to securely provenance any of the samples. The quern sample did not petrographically resemble any of the three outcrops analysed, and so could not be sourced.

Tell esh-Shuna

Shuna is located on the east bank of the Jordan Valley, at the foot of the northern uplands, with two major phases of occupation during the Chalcolithic. The first phase consisted of densely packed, multi-cellular, rectangular, mudbrick buildings, whilst the second phase also contained open areas with special-purpose installations and large pits (Baird and Philip 1994:111,131). Rowan (n.d.) presents a report on the ground stone artefacts excavated between 1989 and 1994 on the site. Unfortunately, only a draft version of this paper was available for examination, which did not include the breakdown by period of the raw material of the artefacts. This therefore prevents the type of analysis undertaken, above.

However, Rowan (n.d.:20) reports that basaltic rock was used to manufacture 81% of the artefacts. The main periods of occupation were the Chalcolithic (34% of the total assemblage) and the EBI (39%), although some later and unstratified artefacts were also found. (Rowan n.d.:3f) reports that all the 57 querns recovered from Shuna were manufactured from basaltic rock, as were 54 of the 59 handstones, with the other 5 being manufactured from limestone. The third largest artefact category was the stone vessel, with 41 fragments and one complete (limestone) vessel being recovered (Rowan n.d.:11,13,19). Of the fragments, 5 were limestone, 1 was sandstone and the other 35 were basaltic (Rowan n.d.:13). A further 29 rim fragments, 26 basaltic, were also found (Rowan n.d.:15). Most of the vessels were not pedestalled, with the exception of one fenestrated pedestalled bowl from the Early Chalcolithic and an EBI example, discussed below (Rowan n.d.:14). Other artefact types found in the Chalcolithic layers include perforated stones, mortars, pounders, a pestle and a few multi-function artefacts (Rowan n.d.:1). Given the proximity of Shuna to the basaltic outcrops, it is unsurprising that a high percentage of artefacts were manufactured from basaltic rock.

The Golan

The most heavily settled area of the Golan during the Chalcolithic was the central part, due to the greater abundance of perennial streams in this area. These are caused by the essentially impermeable underlying basaltic rock (Epstein 1998:2). This is covered by only a thin layer of soil, meaning that there is a great deal of rock available on the surface (Epstein 1998:4f). Basaltic rock was therefore used for virtually all purposes that required stone, from building blocks to gaming boards, as well as the more usual querns and vessels (Epstein 1998:8,30,234f). As already discussed, high quality figurines, not found elsewhere in the southern Levant, were manufactured in the Golan, with over 50 having been discovered so far (Epstein 1998:230ff). Epstein (1998:234) also reports that three unfinished bowls have been found on three separate sites, providing evidence that the bowls were at least finished on-site. Epstein (1998:235) notes that fenestrated bowls are virtually unknown in the Golan, in contrast with other areas of the southern Levant, whilst the few examples that do exist are not decorated. However, pottery fenestrated bowls were common, and also generally had features such as horns and a nose, making them resemble the pillar figurines (Epstein 1998:167). These vessels were generally found in domestic contexts, although Epstein (1998:168) argues that they were clearly cultic, given their distinctive decoration. Finally, Epstein (1998:333) notes that there was very limited exchange between the Golan and other areas of the southern Levant. If correct, this implies that the basaltic artefacts found in the rest of the region do not originate from the extensive basaltic outcrops of the Golan.

Summary

Close to the outcrops, basaltic rock was a widely used raw material for a range of artefacts. Further away, only basaltic vessels are widely found, with only occasional examples of other artefact types. This indicates that the value of basaltic rock for utilitarian objects was not generally high enough to overcome the high transport costs required for this heavy, bulky material. However, the basaltic vessels were obviously valued highly enough for their transport to be worthwhile, although how and by whom they were transported is unclear. That these artefacts were valued is also indicated by the inferior phosphorite imitations that were made. How the basaltic vessels were used, and by which segment of society, is also unclear. Only better recording and analysis of these artefacts can help to answer these questions.

Early Bronze Age I (3600-3000 BC)

As discussed in Chapter 1, the EBI settlement patterns shift towards more autonomous, small, sedentary farming villages in the wetter hills, plains and valleys (Levy 1995:241; Ben-Tor 1992:83). Towards the end of the EBI, walled towns start to appear, including Erani, Ai and Tell al-Fara'ah North (Ben-Tor 1992:86). There is substantial evidence for exchange between sites in the Egyptian delta and sites in southern Cisjordan, including basaltic artefacts (Harrison 1993:81; Philip and Williams-Thorpe 2001:26), with evidence for both overland and maritime links. Harrison (1993:89f) also argues that at least the overland exchange system was operated by freelance traders, who exchanged goods at central places such as Maadi and Taur Ikhbeinah, in southern Cisjordan, from where they could be redistributed to the surrounding region.

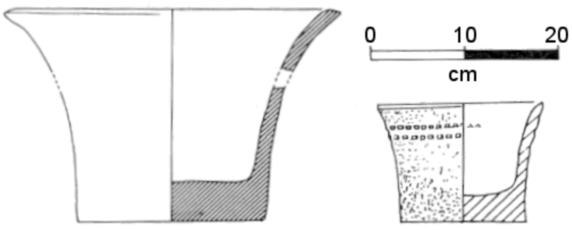
The Chalcolithic tradition of prestige artefacts ends at the start of the EBI, probably due to a shift from a hierarchical to a heterarchical society (Philip 2001:188f). In a heterarchical society, there are multiple, coexisting sources of power, which have overlapping functions and shifting relationships, with no single rank order. Different types of relationship, including procurement systems, are organised in different ways, with the power between groups shifting over time (Philip 2001:167f). Heterarchical societies are also capable of supporting specialist craft workers (Philip 2001:202f), thereby explaining both the absence of elites and the continuing presence of specialist craft products, including basaltic bowls.

Basaltic artefacts

Philip (2001:212) comments that "the ground stone industry of the Early Bronze Age has not been subject to a comprehensive study and is often inadequately reported in archaeological publications." Again, this restricts the amount of analysis that can be undertaken. Large numbers of ground stone were artefacts used, including querns, handstones, mortars and pounders. These were usually manufactured from the locally available stone, including basaltic rock (Philip 2001:212).

Basaltic vessels are commonly found at EBI sites, with Braun (1990:87) arguing that they are one of the diagnostic features of the EBI. He (Braun 1990:87) identifies three main types of vessel, with the most common type being very similar to the Chalcolithic bowl, with a flat base and flaring walls. These are found in both occupation and mortuary contexts on virtually all EBI sites and disappear at the start of the EBII (Braun 1990:87,91f). The main form of decoration is a single or double ring around the upper half of the bowl, which was usually rope-like, although was sometimes a row of cylindrical knobs (Fig 6.10; Braun 1990:92).

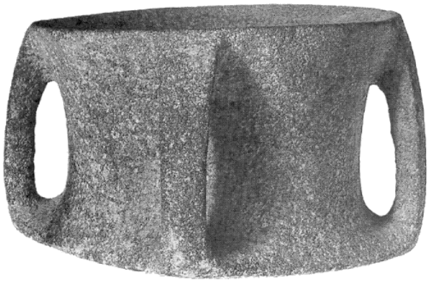
Fig 6.10: EBI basaltic bowls



After Braun (1990:89).

No fenestrated stone bowls were manufactured during the EBI (Rosen 1997b:380), although a four-handled stone bowl was manufactured (Fig 6.11). Amiran and Porat (1984:17) argue that this is a clear development of the fenestrated bowl, which was easier to manufacture and was sturdier and more stable. This type of bowl is not as common as the Chalcolithic fenestrated bowl, but has also been found at sites throughout the southern Levant, in both settlement and mortuary contexts. Furthermore, it has been argued that fenestrated basaltic bowls were replaced by the fenestrated pottery bowls of Grey Burnished Ware (Ben-Tor 1992:90; Rosen 1997b:380). Ben-Tor (ibid.) argues that these closely resemble, in both colour and typology, the Chalcolithic basaltic vessels. Grey Burnished Ware was only produced in a limited number of forms, predominately bowls or fenestrated bowls, and was primarily manufactured in the Yizreel Valley, Lower Galilee, throughout the EBI (Goren and Zuckerman 2000:167). Therefore, as Goren and Zuckerman (ibid.) argue that it was more for decorative or social purposes than for everyday use, it is very probable that some of the functions ascribed to Chalcolithic basaltic vessels were appropriated by this new pottery type.

Fig 6.11: EBI four-handled bowl



From Braun (1990:90).

Nonetheless, as with the Chalcolithic bowls (cf. van den Brink et al. 1999:182), the EBI bowls seem to have had multiple meanings and functions, with use-wear noted on four-handled bowls in settlement, but not mortuary, contexts (Braun 1990:93f). The third type of bowl which was manufactured was a small, one-handled "mug", although only a few have been found so far, exclusively in tombs (Braun 1990:87).

Although these bowl types can be seen as a direct continuation of the Chalcolithic tradition, they were not generally as finely manufactured, with Braun (1990:94) noting:

> "The basic bowl of the EBI lost something of the refinement and elegance of its Chalcolithic predecessor as well as its incised decoration. It gained a thicker base and often became a less graceful, even stubby and more roughly finished artifact."

Braun (1990:93) argues that the thicker base may be a functional difference, and notes that there are a number of examples with use-wear grooves, consistent with having being used as a grinding mortar. However, this does not fully explain the differences, especially the bowls found in tomb contexts, which do not have use-wear marks (Braun 1990:94).

It is therefore possible that the poorer manufacture and the absence of the more technically demanding fenestrated bowls is at least partially related to the replacement of flint celts with copper tools, discussed above. If copper tools were less efficient for working (Rosen 1997a:161), this would have affected the manufacture of basaltic artefacts, which would account for most of the observed differences between the Chalcolithic and EBI bowls. That they remained important is indicated by their inclusion in mortuary deposits (cf. Braun 1990:91ff and the discussion of Bab edh-Dhra', below) and the continued use of fenestrated (pottery) bowls.

This raises the question of why the flint celts were abandoned, which Rosen (1997:161) suggests is related to the fact that copper celts can be mass-produced, unlike flint. This, coupled with the disruption in procurement systems, may have led to the replacement of the flint celts, whether or not they were actually more efficient for working. It would then probably have been too costly, in terms of time and resources, for basaltic-rock craft workers to attempt to revert to flint celts (assuming their superior properties had not been forgotten). This is especially the case as if the heterarchical society of the EBI did not rely on prestige artefacts (Philip 2001:167,188), there would probably not have been the same requirement for high quality basaltic artefacts as during the hierarchical Chalcolithic. Furthermore, it is possible that the limitations of copper celts were only evident when attempting to work a narrow range of harder materials, including basaltic rock, meaning there was little demand for flint celts. Experimental archaeology and the location and careful excavation of the workshops are the only ways that these questions can be properly resolved.

Braun (1990:92) also notes that there were a number of regional variations in the different types of basaltic bowl, with small variations in both the vessel morphology and the precise type of decoration used. On the basis of these, Braun (1990:92) identified a number of sites including Bab edh-Dhra and Tell el-Far'ah (N) as either centres of production or major import centres. As discussed in Chapter 1, Philip and Williams-Thorpe (2001) have demonstrated that there was more than one centre of basaltic artefact production, with sites south-east of the Dead Sea using material from the Kerak area, whilst sites in the rest of the southern Levant seem to have procured the vessels from the north of the region. This could support Braun's assertions, although more work is required, including plotting distribution maps of the regional variations. These procurement systems probably operated independently from the procurement of utilitarian basaltic artefacts (Philip and Williams-Thorpe 2001:27), but the mechanism by which they operated has not been elucidated.

Braun (1985 and 1997) has published small-scale examinations of the ground stone artefacts from the EBI sites of En Shadud and Yiftah'el, both situated in the Galilee. Given their location, it is unsurprising that most of the ground stone artefacts were manufactured from basaltic rock. From En Shadud, Bruan (1985) reports that a four-handled bowl, bowls, mortars, pestles, quern-stones and stone rings were found, all manufactured from basaltic rock, except one pestle and one decorated stone, which were manufactured from limestone. Braun (1985:99) argues that the artefacts can be divided into those which were well made and those which were roughly made, probably on an ad hoc basis. The artefacts are not tabulated, and Braun (ibid.) simply reports that "a number" of quern-stones were discovered, of which "several" are illustrated. Whilst better than most reporting, it is still not possible to properly quantify the ground stone assemblage.

The situation is similar in the report from Yiftah'el, with Braun (1997) reporting on the bowls, querns and two stone rings. Again, not all the querns are listed and there is no attempt at quantification. The majority of artefacts are again basaltic, with the exception being a single bowl (Braun 1997:99). Braun (1997:100) argues that the bowls had multiple uses, both in domestic, utilitarian activities (given their context and use-wear), and also as prestige artefacts. He (ibid.) notes that whilst some querns show evidence of high levels of skill, others were roughly manufactured from already detached and rounded basaltic stones. This supports the observations made in Chapter 3 that both outcrops and previously detached boulders would be used to manufacture artefacts. Sites with more detailed discussions of ground stone artefacts will be examined individually, below.

Megiddo

As discussed in the Chalcolithic section, Sass (2000) published a catalogue of the ground stone artefacts excavated during the 1992 to 1996 seasons at Megiddo. Excluding the 4 V-shaped vessels discussed above, 19 ground stone EBI artefacts were recovered. Four worked stones and four other fragments were manufactured from limestone, whilst the other 11 objects were manufactured from basaltic rock. These comprised 5 worked stones, 3 bowls or mortars and 3 four-handled vessels. The lack of more utilitarian artefacts is probably related to the fact that most of the EBI excavations were in areas identified as cultic (Finkelstein and Ussishkin 2000:577ff), although as discussed below (cf. Ebeling 2001) this does not necessarily exclude the use of such artefacts.

Bab edh-Dhra’

This site on the shores of the Dead Sea has both a settlement and a cemetery. The cemetery began during the EBIA, whilst the settlement was founded in the EBIB (Rast 1999:166). During the EBIA the cemetery was probably used by mobile pastoralists, who transported their dead for reburial at Bab edh-Dhra’, whilst during the EBIB the cemetery was used by the settled agriculturists from the village, with clear links between the artefacts at the settlement and in the cemetery (Rast 1999:166f).

This shift is reflected in differing mortuary practices between the two phases. During the EBIA shaft tombs were used, each of which probably originally contained between 4 and 10 individuals, of mixed ages and sex, although only one individual was actually found in several (Rast 1999:171; Schaub and Rast 1989:183). Rast (1999:167) argues that individual tombs were used by a particular kin-group. Twenty-seven shaft tombs, with 47 individual chambers, were excavated in the main cemetery (Cemetery A), whilst 6 tombs were excavated from Cemetery C, situated less than 200 m to the north-west of Cemetery A (Schaub and Rast 1989:23ff).

Rast (1999:171f) notes that there was only limited variability between the tombs, which was expressed through the quantity of pottery present and the presence or absence of artefacts including basaltic bowls, as well as maceheads, beads and figurines. Twenty-eight basaltic bowls were found in the tombs, with 27 tombs containing no bowls, 20 containing one bowl and 4 containing two bowls (Schaub and Rast 1989:184,203). Thirteen stone maceheads were found from 10 chambers, of which 8 also contained basaltic bowls (Schaub and Rast 1989:184,203). Most of the maceheads were manufactured from limestone or chalkstone, although one was manufactured from diorite. This was the only macehead which was identified as potentially functional, while the chamber from which it came did not contain a basaltic bowl (Schaub and Rast 1989:289-292,184). Rast (1999:172) argues that these variations indicate moderate differences in the ranking of families or tombs. It is also noteworthy that of the 9 figurines found, only one was in the same chamber as a basaltic bowl, whilst the two chambers containing 3 or 4 figurines had neither basaltic bowls nor maceheads (Schaub and Rast 1989:184). This could therefore be evidence for the heterarchical organisation suggested by Philip (2001:167).

Schaub and Rast (1989:294) also report that 7 ceramic vessels were present in 6 different chambers which closely resemble the basaltic bowls, although they are smaller than most (although not all) of these. Four of these chambers did not contain any basaltic bowls. When the ceramic vessels are included, 53% (28 of 53) of the chambers contained at least one basaltic bowl or imitation (Schaub and Rast 1989:294). Furthermore, it was possible to phase the 47 chambers from Cemetery A into earliest, middle and latest. Of these, Schaub and Rast (1989:301) report that 66% (21 of 32) of the early and middle phase tombs, but only 33% (5 of 15) of the late phase tombs, contained basaltic bowls or imitations.

During the EBIB there was a shift in mortuary practice to mudbrick-built circular tombs, although only two have so far been excavated (Rast 1999:172f). However, Rast (1999:172f) reports that there were no variations between these two tombs, neither of which contained basaltic bowls (Schaub and Rast 1989:233). Schaub and Rast (1989:301) therefore argue that the EBIA basaltic bowls were "the final manifestations of Late Chalcolithic basalt craftsmanship."

Although the sample is small, and so any conclusions can only be preliminary, it appears that basaltic bowls at Bab edh-Dhra' were used as some form of status-marker during the EBIA, but were not used in this way during the EBIB, at least in mortuary practice. Furthermore, it seems that, although basaltic bowls were preferred, ceramic imitations were acceptable. Again, this is probably evidence of import substitution, although with pottery rather than phosphorite. Petrographic analysis of the imitations could confirm this suggestion, as the pottery vessels should have been manufactured closer to the site than the basaltic vessels.

Tell es-Shuna

Shuna has a long, well-stratified EBI sequence of occupation, with both early and late phases, before it was abandoned at the end of the period. A large number of mudbrick structures, including public buildings, were present (Baird and Philip 1994:131,116ff). As discussed above, Rowan (n.d.) examined the ground stone artefacts excavated at the site from 1989 to 1994. The general statistics have already been discussed, but it is worth noting that the EBI has the highest concentration of ground stone artefacts (39% of the total). Nineteen vessels were found in the EBI levels, as were 13 unidentified basaltic fragments (Rowan n.d.:1,11). Rowan (n.d.:14) notes that one of the basaltic vessels was a solid pedestalled bowl, which are more usually found in the PN or Chalcolithic, possibly indicating that this artefact was curated. Other artefact types found in the EBI layers include pestles and mortars, pounders, a perforated stone and a few multi-function artefacts (Rowan n.d.:1).

Summary

At the start of the EBI there is a decline in the quality of the basaltic bowls, possibly linked to the replacement of flint tools with copper tools. The fenestrated bowl vanishes, and is replaced by the rarer four-handled bowl. As in the Chalcolithic, close to the outcrops, basaltic rock was a widely used raw material for the manufacture of a range of tools. The bowls were again widely distributed and used in different contexts for different purposes. Their value is indicated by their imitation in pottery, but nonetheless they disappear by the late EBI, although other artefacts manufactured from basaltic rock continue to be used. Again, it is unclear how and by whom any of the basaltic artefacts were manufactured or procured, whilst the ways in which they were used are only partially known.

Late Bronze Age (1500-1200 BC)

As discussed in Chapter 1, the start of the LBA is marked by the conquest of the southern Levant by Egypt, leading to a decline in the size and number of settlements (Goren 1992b:217f; Bunimovitz 1995:324). The main Egyptian interests were maintaining the trade routes to the north and extracting a surplus from the local population, with the main exports being wine and oil, although basaltic artefacts were also exported, as will be discussed below (Strange 2001:294; Goren 1992b:247f; Williams-Thorpe and Thorpe 1993). Monroe (2000:101ff,260) notes that both palace elites and private entrepreneurs imported and exported goods, and argues that "Levantine merchants carried out most of Egypt's long-distance commerce." However, Monroe (2000:340) also cautions that "determining the means and relations of exchange in the Late Bronze Age relies on subjective, fragmentary, and inherently biased material." This comment is even more applicable to the procurement of basaltic artefacts.

Intra-regional procurement was also common, as shown by the distribution of Chocolate-on-White Ware and gypsum bowls. Using petrography, Fischer (1999) has been able to demonstrate that Chocolate-on-White Ware was distributed throughout the northern part of the southern Levant from two main production centres, in the North Jordan Valley and the Mount Hermon area. A similar pattern of widespread distribution from a small number of production centres has been revealed by Sparks (2002) in her examination of gypsum imitations of Egyptian calcite bowls. She (Sparks 2002) reports that gypsum vessels were manufactured from the MBII to the IAI from several production centres, including Jericho, Beth Shean and Pella. It was during the LBA that these artefacts were produced and distributed most widely, with a number of regional variations in the style of the vessels. Sparks (2002) reports that there are a number of gypsum outcrops in the area, but unfortunately no provenancing work has so far been attempted for the southern Levant. This is a good example of both import substitution and intra-regional procurement. These examples also reveal the existence of intra-regional procurement systems, which could have been interlinked with the basaltic procurement systems.

Basaltic artefacts

The problem with most excavations from the LBA, and indeed from the Bronze and Iron Ages in general, is summarised by Elliott (1991:9):

> "A problem relevant to any study of the ground stone industries of the Late Bronze Age Levant is the dearth of published comparanda. In the reports of Hazor, Megiddo, Lachish and other major sites, emphasis was placed on the publication of architecture, ceramics, bronze, precious and cultic objects. The few ground stone artefacts which appear in such reports are either of special interest (e.g. potter's wheels, roof-rollers) or must have been considered by the excavators to be of a quality or character worthy enough to merit inclusion (tripodic and other mortar types for example). It is the mundane tool in everyday use in household and courtyard which appears only rarely in the archaeological record as published so far. Grinders, pounders, rubbing stones and many other tool types are seldom mentioned."

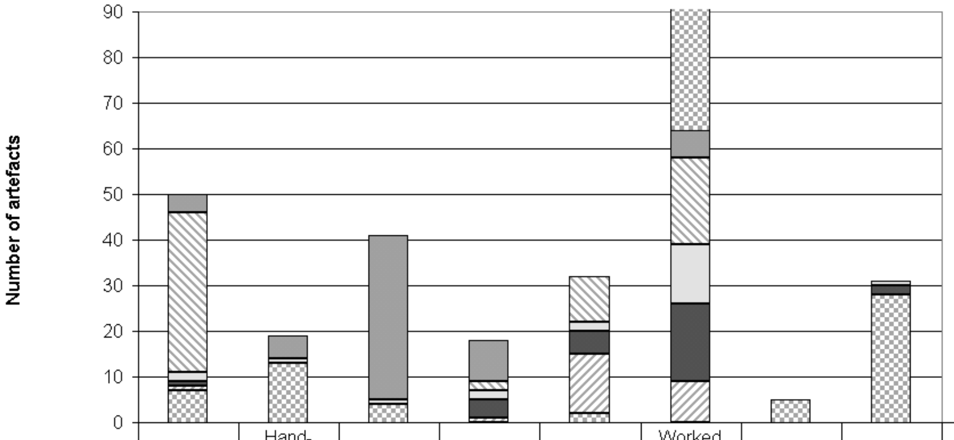
As Ebeling (2001:52) comments, the problems with publications merely reflect the fact that ground stone artefacts are not properly collected or recorded during excavation. These limitations make the analysis and inter-site comparison of ground stone artefacts very difficult, preventing a complete understanding of their procurement systems. Basaltic rock was still widely used for a variety of artefacts, including bowls, mortars, handstones and querns (Strange 2001:300). Building blocks, orthostats and stelae were also carved from basaltic rock at sites including Hazor and Beth Shean (Goren 1992b:226ff). Rosen (1997b:378) notes that the introduction of bronze tools enabled a greater quantity of better quality and larger stone artefacts to be manufactured, a situation which is paralleled in the ethnoarchaeological work of Hayden (1987b). This improvement in quality is also evident in the basaltic vessels, with the introduction of, sometimes decorated, tripod-based bowls during the MBA, which continued through the LBA and IA (Rosen 1997b:380). Mortars were usually either ring-based or tripodic in form (Petit 1999:154).

Basaltic artefacts are also found in mortuary contexts, including a tomb at Tel Dan, which contained 40 individuals and a large number of valuable artefacts, including Mycenaean pottery, weapons, gold plagues and earrings, bronze artefacts and ivory carvings, as well as basaltic artefacts (Goren 1992b:243). This seems to indicate that some value was placed on these artefacts, given their association with artefacts which are known to have been valued. Stone vessels were also placed as grave goods in other tombs, including at Pella where the grave goods included a basaltic hammerhead (Strange 2001:311ff).

As discussed in Chapter 2, provenance studies have shown that basaltic quern-stones were exported from the southern Levant to Cyprus. Williams-Thorpe and Thorpe (1993:292f) argued that the well-made, thin millstones of vesicular basaltic rock were more highly valued than those made from the locally available rocks and suggest that their import may have been facilitated by the intensification of metal-working and ceramic exports. They also note (op cit. p.293) that there is no evidence for specialisation or standardisation at the production sites.

Another example of the procurement of basaltic artefacts is given by an analysis of Ugarit's LBA ground stone assemblage, published by Elliott (1991). Of the 415 artefacts, only 14.5% (60) were manufactured from basaltic rock. However, when the data are analysed (Fig 6.12) it can be seen that 87.8% of mortars, 50% of pestles and 26.3% of handstones were manufactured from basaltic rock.

Fig 6.12: Ugarit ground stone categories and materials



	Querns	Hand-stones	Mortars	Pestles	Pounders	Worked stones	Vessels	Other	Total %
▦ Basaltic rock	4	5	36	9	0	6	0	0	14.5
▧ Other Igneous	35	0	0	2	10	19	0	0	15.9
□ Sandstone	2	1	1	2	2	13	0	1	5.3
■ Limestone	1	0	0	4	5	17	0	2	7.0
▨ Flint/Chert	1	0	0	1	13	9	0	0	5.8
▩ Other	7	13	4	0	2	155	5	28	51.6
Total %	12.0	4.6	9.9	4.3	7.7	52.8	1.2	7.5	n=415

Data from Elliott (1991).

A further 15.9% of the assemblage was manufactured from other igneous rocks, mainly diabase and gabbro, which were used for querns, pounders and occasionally pestles. This is notable, as Elliott (1991:10ff) reports that diabase and gabbro are both locally available, unlike basaltic rock, which must therefore have been imported, probably from other areas of the Levant. The nearest extensive basaltic outcrops are those of the Shin plateau approximately 50 km to the south-east (Philip et al. 2002:5), whilst the outcrops to the north-east have been discussed in Chapter 2 (Lease et al. 1998; 2001). Given the known maritime contact with the southern Levant it is also possible that the basaltic artefacts originate there, especially as the basaltic rock was almost as widely used as other mafic rocks with similar properties. This level of usage implies that non-utilitarian reasons may have played a part in the choice of rock, which is recognised by Elliott (1991:17) in her discussion of basaltic pestles:

> "The desirability of vesicular and non-vesicular olivine phyric basalt pestles is clear from their widespread distribution, including sites far from basalt areas and reaching western Cyprus. … This hard-wearing material is ideal for pestles used in food, cosmetic or colouring production as no grits are dislodged – though this property would be shared by those of gabbro, dense limestone and chert."

One advantage of basaltic rock is that its vesicles make it an ideal grinding material, but Elliott's argument implies that the creation and maintenance of a procurement system, and the social relations which underpin this, were as important to the people of Ugarit as the actual material from which the artefacts were manufactured.

Two studies of southern Levantine MBA and LBA ground stone artefacts have been undertaken by Sparks (1998)[2] and Ebeling (2001). Sparks (1998) examined, catalogued and developed a typology for MBA and LBA stone vessels from sites throughout the Levant. Two limitations of this study are that the two periods are examined together and that other artefact types such as querns and pestles are not examined. She was able to catalogue 315 basaltic vessels, which she reports was the third most common material, after calcite and gypsum. She notes that there were only very few imported artefacts, including an Egyptian palette and a Minoan lamp, with the vast majority of artefacts being manufactured in the region. A wide variety of vessel types were manufactured from basaltic rock including plates, palettes, bowls, mortar-bowls, mortars and basins, as were cultic tables. Sparks (1998) notes that these were all usually manufactured from non-vesicular basaltic rock, although vesicular rock was occasionally used for mortars and mortar bowls. These artefacts ranged from crude to high quality items and were found in domestic, funerary, elite and cultic contexts.

Sparks (1998) also reports that the most widely distributed forms are bowls with everted rims and tripod bowls. Most everted rim bowls date from the LBII, with basaltic rock being the preferred material (54 examples), although gabbro, granite and limestone were also used. This type is found in northern Cisjordan and the adjoining areas of the northern Levant. On the basis of typological differences, Sparks (1998) argues that there were a number of separate workshops producing this artefact form, although there is a general standardisation in form. This argument can only be properly demonstrated by locating the workshops and quarries, but could be tested by provenance studies revealing the origins of the basaltic rock, which could also aid the identification of the quarries and workshops.

Tripod bowls were first manufactured in the EBA, but were not common until the MBA, and then remained common throughout the LBA. Basaltic rock was again the preferred material (82 examples), although trachyte, granite-monzonite and limestone were also used. Ceramic versions were also manufactured (Sparks 1998). They were widely distributed, and Sparks (1998) argues that there was, again, probably several production centres. She states that this artefact type was used primarily as a mortar, as use-wear is usually visible on the bowl's interior and they are regularly associated with basaltic pestles. The tripod bowls are generally found in domestic, kitchen contexts, whilst some also contain traces of ochre, although none show evidence of burning. These artefacts were also well-made and generally lighter than mortar bowls, and were therefore probably manufactured so they could be easily transported.

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[2] I am very grateful to Dr Sparks for sending me the relevant parts of her thesis. However, this means that page numbers could not be referenced.

Mortar bowls and mortars were generally made of local material, meaning that they were manufactured from basaltic rock near the outcrops, and from limestone or sandstone further away. Sparks (1998) notes that mortars are not generally included in excavation reports, thereby making it difficult to properly examine this artefact category.

Sparks (1998) also reports that Levantine ground stone vessels were only very rarely decorated, with only 16 (3.6%) of the 439 vessels she examined having decoration, of which 11 were manufactured from basaltic rock. Eight of these were from the northern Levant, with the other three being from Hazor, which has considerable north Levantine influences. Sparks also notes that north Levantine, Hittite and Mesopotamian sculpture was commonly manufactured from basaltic rock. She concludes by arguing that there were a great many ground stone workshops in the Levant, producing artefacts for local use, alongside a smaller number of more specialised workshops, which produced high quality, portable goods for widespread distribution. She notes that 95% of these artefacts were produced from basaltic or other igneous rocks (such as granite), with production expanding dramatically in the LBII. Given the material used, she argues that it is very probable that sites such as Hazor, Beth Shean and Megiddo were the main manufacturing centres.

Ebeling (2001) examined the use of a wide range of ground stone artefacts, including querns and pestles, but only from settings within the many MBA and LBA temple complexes and other cultic sites. She (Ebeling 2001:29f) notes that ground stone artefacts, especially utilitarian tools, are generally ignored during excavation and analysis, making reconstructions of cultic activities very difficult. Ebeling (2001:14f) therefore examined the ground stone artefacts from these structures at a variety of sites in order to gain a better understanding the types of activities that were undertaken in cultic areas. She (Ebeling 2001:185) concludes that they were used for a wide variety of purposes, but, unfortunately, does not usually present summary statistics for either the various artefact categories or for the sites studied, making it more difficult to reanalyse the data. Many of the artefacts were types found in other contexts, and were therefore probably used for domestic and industrial purposes, such as the preparation of food, pigments and incense, pottery production, and bone and ivory working (Ebeling 2001:191f). However, Ebeling (2001:185) notes that there were a number of basaltic artefact types which have only been found in cultic contexts, including pedestalled bowls, basins and tables. She therefore argues that there was a basaltic manufacturing industry related to the temple cult, although she does not discuss whether the specialists were attached to the temple or independent from it. The absence of stone manufacturing workshops in the temple complexes suggests that the specialists retained their independence; but, given the generally poor levels of excavation and recording of ground stone artefacts noted by Ebeling, this is by no means certain. Individual sites where the ground stone artefacts have been analysed will now be discussed.

Manahat

Milevski (1998) reports on the ground stone assemblage from Manahat, a small settlement less than 2 km from Jerusalem. This was mainly a MBA site, although there was a smaller settlement in the LBA (Milevski 1998:73). Milevski (1998:62) reports that the artefacts were manufactured from five types of stone, namely quartzolite[3], limestone, flint, sandstone and basaltic rock. He notes that the first four were all available locally, whilst the basaltic rock must have been imported. Unfortunately, he does not provide the figures showing what proportion of artefacts were manufactured from each rock type. He (Milevski 1998:74f) does, however, provide some spatial analysis of where the artefacts were discovered, thereby going beyond the vast majority of published ground stone reports. This is not divided by period, but does illustrate the types of analysis that can be undertaken.

An appendix listing the raw data of "selected" ground stone artefacts is also given, although it is not clear on what basis artefacts were included. Milevski (1998:61) reports that: "Bodies are classified according to geometric shape… Type 10 (other) is not represented in Appendix 1." No further information is given. Of the 661 artefacts that Milevski (1998:73) reports were excavated, 535 are reported in the appendix. The rock types of these artefacts are summarised in Table 6.1.

Table 6.1: Rock types of reported artefacts from Manahat

Rock types	Number	Percentage
Quartzolite	62	11.6
Limestone	72	13.5
Flint	333	62.2
Sandstone	6	1.1
Basaltic rock	31	5.8
Other/Unknown	31	5.8

The large percentage of flint is explained by the fact that 52.5% of the assemblage consists of what Milevski (1998:71) defines as hammerstones, which probably correspond to Wright's (1993:95) definition of pounders. To add to the confusion, Milveski (1998:71) defines one basaltic artefact as a pounder, which probably corresponds to Wright's (1993:95) definition of a hammerstone! As discussed in Chapter 1, Wright (1993:95) distinguishes between these two categories on the basis of whether the pounding marks are on a sharp edge (pounders) or not (hammerstones). This confusion over terminology clearly illustrates the problems currently inherent in the analysis of ground stone artefacts. The majority of basaltic artefacts are pestles (14) and rubbing stones (7). This is possibly due to the fact that these are small and so could be more easily transported.

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[3] A relatively uncommon igneous rock, similar to granite, but with a higher proportion of quartz (Le Maitre 2002:23).

The LBA assemblage consists of only 27 artefacts, of which 10 were hammerstones and a further 10 were quern-stones (Milevski 1998:76). Unfortunately, it was difficult to identify these artefacts in the appendix, thereby preventing an examination of the stone types.

It is also worth noting that in their conclusion, Edelstein et al. (1998:131) state that “the quartzolite quarries in the vicinity indicated that the inhabitants of Manahat made many of their own tools.” Unfortunately, no reference is given or more information provided. This is important as the discovery of such a quarry could well provide information which could be relevant to the discovery and examination of basaltic quarries, especially as similar methods were probably required to quarry and manufacture these two igneous rocks. It is also therefore surprising that only 11.6% of the ground stone assemblage was manufactured from quartzolite, but this point is not discussed, showing the importance of quantifying the proportions of raw materials. Despite these limitations, this report shows the possibilities of analysing ground stone artefacts, which can aid the understanding of the site.

Megiddo

Megiddo is situated in the Jezreel Valley in the Galilee. Finkelstein and Ussishkin (2000:592) report that very few remains from the LBI were found during the 1992 to 1996 excavations. This is reflected in the ground stone assemblage, with only one basaltic quern being recovered from this period. During the LBII, the site grew to 11 ha in size, making it one of the largest settlements in the LBA southern Levant, although it remained unfortified. Most of the upper tell was covered with public buildings, with domestic buildings being largely confined to the lower tell (Finkelstein and Ussishkin 2000:593). However, only 12 ground stone artefacts are reported as having been discovered, of which 7 were manufactured from basaltic rock. These were a handstone, a bowl or mortar, a tripod mortar, 3 pestles and one worked stone. There were also two limestone and two flint artefacts as well as a probable statuette fragment manufactured from diorite (Sass 2000). There is also evidence for the reworking of vessels, with one of the pestles being described as “probably recycled leg of tripod bowl” (Sass 2000:363).

Hazor

During the LBA, Hazor was a large, flourishing city. The MBA level ends in a destruction layer, but there is good evidence for population continuity into the LBA. Both the 7 ha upper tell and 80 ha lower city were occupied before and after the LBIB destruction level (Ben-Tor 1997:1,3). During the LBII there were major changes in the domestic and cultic architecture, followed by a decline during the LBIIB in the settlement and in the procurement systems, with much less imported Cypriot and Mycenaean pottery present. The LBII city ended with a large destruction layer followed by a period of squatter settlement (Ben-Tor 1997:3). Ebeling (2001:108) argues that Hazor had stronger links with the northern Levant, Mesopotamia and Anatolia than other sites in the southern Levant, and concludes that the site remained outside Egyptian control.

The LBA temples used a wide variety of basaltic artefacts including pillar bases, offering tables and stelae. A number of basins, including one 50 cm in diameter, and one decorated with a Mycenaean-style running spiral have also been found (Goren 1992b:226f). Sparks (1998) argues that this vessel resembles ceramic and metal vessels dating from the MBII and was therefore very probably curated. Other ground stone vessels include a rare basaltic pedestal bowl, of which Sparks (1998) only catalogued 6 examples. Two fragments of a basaltic statue, part of a male torso and part of the base which was carved into a bull shape, were also found. A basaltic orthostat, 1.9 by 0.9 m, with a lion carved in relief probably formed part of the main entrance to the temple (Goren 1992b:227f). Ebeling (2001:111,131) reports that a basaltic potter's wheel and a large number of basaltic vessels were found in the temples, some associated with pestles and organic remains. This shows the range of activities that took place in such areas.

Hunt notes (1991:206ff) that Hazor is proximal to both limestone and basaltic outcrops (the nearest being less than 5 km away), thereby providing the inhabitants with a choice of material. He notes that basaltic rock was selected for both a range of utilitarian functions, and also for a wide variety of cultic artefacts, which, he argues, is evidence of the preferential, deliberate selection of basaltic rock for these purposes. This is supported by Sparks (1998) who notes that in the southern Levant mortar bowls were generally manufactured out of locally available stone, including limestone, but notes that at Hazor 17 mortar bowls were basaltic, whilst only one was limestone. As discussed in Chapter 2, Hunt (1991:219ff) analysed peterographically 6 basaltic artefacts from Hazor, which he was able to demonstrate all originated from the same, non-local source. This suggests that either these artefacts were manufactured elsewhere and then imported to Hazor, or that the raw material was procured on the basis of its advantageous physical properties.

Although more work is required, Sparks (1998) argues that, given the concentration of basaltic artefacts (including unusual and rare types), Hazor was a major production and distribution centre for basaltic artefacts. Evidence for on-site manufacturing has now been recognised by Ebeling (2001 pers. com.) in her re-examination of the ground stone artefacts excavated from Hazor. This therefore increases the possibility that raw material was selected on the basis of its physical properties, not necessarily from the most proximal sources. Sparks (1998) also notes that broken basaltic vessels were frequently reused at Hazor, including as paving stones, door pivot stones and in benches and walls.

Amman Airport building

This unusual LBA structure, essentially a single-phase, isolated building only 14 m^2, was excavated in 1955, 1966 and 1976 (Hankey 1974:131; Herr 1983). There is no settlement anywhere in the vicinity and it was most probably connected with funerary ceremonies for mobile pastoralist groups (Herr 1983a:24,28).

Hankey (1974:161) discusses the stone artefacts discovered during the 1955 and 1966 excavations, and reports that 8 whole or restorable vessels were recovered, along with approximately 290 fragments, although a total of only 62 artefacts were catalogued. Of these, 27 (and about 100 unpublished fragments) were Egyptian banded calcite vessels, whilst 6 were Cretan limestone vessels. Five of the catalogued artefacts were identified as basalt, all of which were ring-base mortars (Hankey 1974:162ff,177).

Herr (1983b:57) discusses the 33 ground stone artefacts recovered during the 1976 excavation, which were examined petrographically by a geologist. He identified the calcite vessels specifically as travertine[4], whilst many of the mafic artefacts were identified as being gabbro or diorite, rather than as basalt. However, it is unclear whether any of the 5 'basalt' artefacts identified by Hankey should be reclassified, especially as she identified another artefact as diorite. Herr (1983b) identifies 10 bowls or mortars as diorite and 6 as gabbro, whilst only 1 bowl was identified as being manufactured from basalt. One handstone was also discovered, which was manufactured from gabbro. Five bowls were manufactured from travertine, and 6 bowls or mortars were manufactured from limestone, two of which were black limestone (Herr 1983b:58f). Herr (1983b:57) argues that the probable reason for the much higher percentage of mafic artefacts from the later excavation is that these types were among the 228 pieces not published for the earlier excavation.

This site clearly demonstrates both the inter- and intra-regional procurement of stone artefacts. Furthermore, Hankey (1974:166ff) notes that two of the calcite vessels were probably Predynastic or 1st Dynasty in date, whilst Herr (1983b:57) reports that a limestone bowl also dates from this period. These three finds demonstrate the long period of use and curation possible for durable stone artefacts. These reports also demonstrate both the widespread use of basaltic rock and the importance of properly analysing the ground stone assemblage.

Tell Deir 'Alla

Tell Deir 'Alla is located on the east side of the Jordan Valley, 1.5 km from the mouth of Wadi al-Zarqa (van der Kooij 1993:338). The LBA settlement included a sanctuary with very thick mudbrick walls and stone pillar bases, which contained a wide range of artefacts including an Egyptian faience vase, faience beads, cylinder seals, small armour plates and pottery (including Mycenaean pottery). These artefacts also reveal the Egyptian influence on, and probably control of, the site (van der Kooij 1993:339). Van der Kooij (1993:339f) also reports that mineralogical analysis of the pottery shows that most of it was not produced at the site itself, but from the

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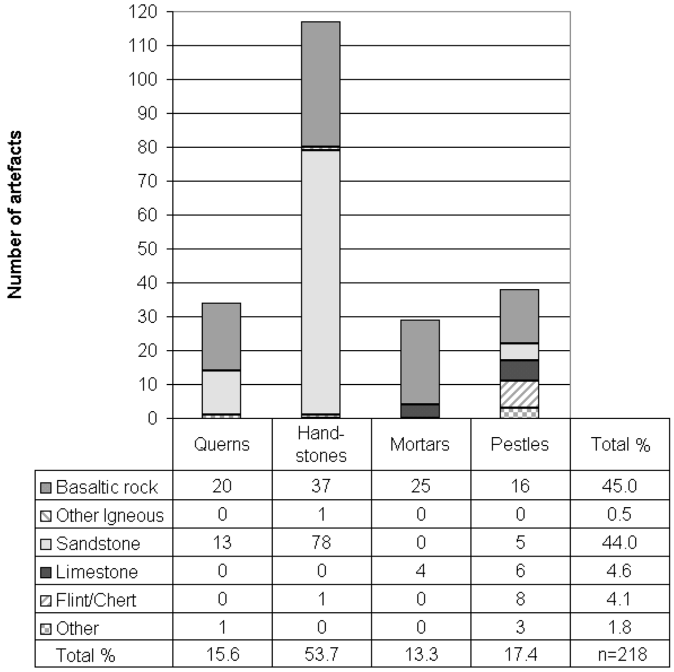
[4] Travertine is formed from calcite, but is usually deposited from hot springs, giving it a distinctive physical structure (Allaby and Allaby 1999:558).

surrounding region, thereby strengthening the argument that Deir ‘Alla was an Egyptian trading centre. This settlement was destroyed towards the end of the LBA (van der Kooij 1993:340).

Petit (1999) reports on his analysis of the LBA and IA grinding stones at Tell Deir ‘Alla, although unfortunately he does not distinguish between the two periods and does not examine the other types of ground stone artefact (Petit 1999:145). This makes both proper comparisons between assemblages and the identification of diachronic change impossible, despite the fact that Petit (1999:157) reports that around 750 BC imports increased dramatically from 30% to 60% of the total assemblage. Furthermore, van der Kooij (1993:340f) reports on a number of abandonments at the site at the end of the LBA and during the IA, which would obviously affect the ground stone assemblage. The combined data are summarised in Fig 6.13.

Fig 6.13: Tell Deir ‘Alla ground stone categories and materials



	Querns	Hand-stones	Mortars	Pestles	Total %
■ Basaltic rock	20	37	25	16	45.0
▧ Other Igneous	0	1	0	0	0.5
□ Sandstone	13	78	0	5	44.0
■ Limestone	0	0	4	6	4.6
▨ Flint/Chert	0	1	0	8	4.1
▩ Other	1	0	0	3	1.8
Total %	15.6	53.7	13.3	17.4	n=218

Data from Petit (1999:160).

As Petit (1999:155) notes, sandstone and basaltic rock were used in roughly equal proportions, with basaltic rock being used slightly more, despite the fact that sandstone is locally available. Petit (1999:155ff) therefore concludes that basaltic rock was more suitable for grinding than the local rocks, which were therefore used only when basaltic rock was not available or was too “expensive”. Furthermore, the majority of both querns (58.8%) and mortars (86.2%) were basaltic, which are more important for grinding than the hand tools, especially to avoiding grit contaminating the ground material.

Whilst Petit's explanation cannot be ruled out it is interesting to note that for the querns and handstones the proportions manufactured from sandstone and basaltic rock are similar to those from Abu Hamid (Table 6.2). As discussed above, Wright et al. (in press, p.10) argued that sandstone and basaltic artefacts at Abu Hamid were used in pairs. It is therefore possible that this practice also occurred at Deir 'Alla, although as Petit (2001) reports that the proportions of basaltic rock and sandstone changed through time only the periodisation of the data could conclusively show this. This hypothesis could also be tested if there were proper contextual data for the artefacts, as at Abu Hamid. However, Petit (1999:162) reports that the contexts were not recorded, making such an analysis "almost impossible." Furthermore, most of the ground stone tools were reused, usually in foundations or as pit-lining and occasionally as hammerstones, polishing stones or rubbing stones, whilst broken querns were also reused as handstones (ibid.). This therefore makes analysis very difficult, although Petit (1999:162) argues that use-wear analysis may enable the original usage to be determined.

Table 6.2: Percentage of handstones and querns by rock type

	Tell Deir 'Alla		**Tell Abu Hamid**	
	Querns	Handstones	Querns	Handstones
Sandstone	38.2	66.7	32.0	65.0
Basaltic rock	58.8	31.6	64.0	35.0

Ebeling (2001:171ff) also examined the ground stone tools from the LBA temple at Deir 'Alla, which included another basaltic pedestalled bowl, as well as a rare basaltic pedestalled mortar bowl, a basaltic bowl fragment and basaltic quern and handstone fragments. Sandstone handstones and a flint hammerstone were also found. Ebeling (2001:192) also notes that the were a large number of auxiliary rooms in the temple complex, which contained a large number of grinding tools, although whether this processing was for the rituals or for the priests and temple workers is unclear.

Summary

During the LBA ground stone objects were still widely used for a range of activities, in domestic, mortuary and ritual contexts. A number of workshops manufacturing basaltic ground stone artefacts seem to have operated, serving their local communities and also exporting artefacts both regionally and internationally. Basaltic rock seems to have been valued for its physical properties, both for utilitarian tools and also for high quality artefacts for temples and tombs. There was therefore probably still some level of prestige attached to the ownership of basaltic artefacts, especially as locally available materials (including sandstone and limestone) were still predominately used for utilitarian tools (Ebeling 2001:84). Only a limited amount of work has been undertaken on LBA basaltic artefacts, meaning the much of their 'life cycle' remains unknown.

Iron Age (1200-540 BC)

As discussed in Chapter 1, at the end of the LBA Egyptian imperial power waned and was replaced by local polities (including Israel, Philistia, Phoenicia, Ammon, Moab and Edom), which were probably some form of kingdom (cf. Holladay 1995; Herr 1997; Blakely 2002). There were substantial changes in the settlement patterns, with a large number of small sites being established in the Cisjordan hill regions, whilst in Transjordan there was a slow southwards spread of sedentary settlements throughout the Iron Age (Mazar 1992:285f; Herr and Najjar 2001:323). The Iron Age is usually divided into IAI (1200-1000 BC) and IAII (1000-540 BC), although there is a basic continuity in the material culture (Holladay 1995:372).

During the IAI there was virtually no inter-regional trade, which only reappeared during the IAII (Mazar 1992:300; Barkay 1992:325). Silver hoards have been found at Eshterra, Ein Gedi and Tel Miqne (Herr 1997:140,159), which Herr (1997:144ff) suggests could have been used as a means of payment for goods. There is also good evidence for the operation of intra-regional procurement systems, including the large-scale production of wine at Gibeon and olive oil at Miqne (Herr 1997:144,151). Holladay (1995:389ff) implies that the state, religious authorities and private individuals all had the means to exploit surplus produce by exchanging it for non-local goods. There therefore may have been several different modes of procurement operating simultaneously, including for basaltic artefacts.

Basaltic artefacts

Ground stone artefacts were still commonly used, including saddle querns and handstones, which were usually made from basaltic rock, as well as flint blades, limestone mortars and stone pestles (Herr 1997:119). Rosen (1997b:378) notes that during the IA larger handstones and querns were used, as these enabled the more efficient processing of large quantities of grain.

Other types of basaltic artefacts include the three major royal inscriptions so far found in the southern Levant, namely the Amman Citadel Inscription, the Tel Dan Stela and the Mesha Stela (Herr 1997:148f). The use of basaltic rock for these inscriptions probably indicates that the hard-wearing properties of basaltic rock were recognised and exploited.

Rosen (1997b:380) also argues that “the absence of chipping debris and rough-outs at virtually all sites, along with the common use of non-local raw materials, such as basalt and sandstone, is indicative of production specialization and exchange.” However, Herr (1997:119) comments that aspects of material culture, such as ground stone artefacts, which occur frequently and do not change over long periods of time are usually ignored in archaeological studies. Very few analyses of IA ground stone artefacts have been undertaken. Sites where analyses have occurred will now be discussed individually.

Tel Miqne

Tel Miqne was one of the largest IAI sites in the southern Levant, and has been identified as Ekron, one of the five major cities of the Philistine kingdom (Gitin 1998:1). It was heavily involved in both inter- and intra-regional procurement systems, with a wide variety of imported goods present, including a large number of basaltic artefacts. In an unpublished report, Williams-Thorpe (n.d.) discusses the analysis of a representative sample of 36 mafic ground stone artefacts from the site. Samples were taken from handstones, querns, bowls and an altar, with all the artefacts dating between the 12th and 6th centuries BC (Williams-Thorpe n.d.:1). Williams-Thorpe (n.d.:1f) reports that 35 of the samples were grey vesicular basalt, many with thin (<1mm) weathered surfaces. In thin section, the main phenocrysts were shown to be feldspar, pyroxene and olivine, which was usually partially iddingitized. The vesicles were usually lined with brown or white secondary mineralization. She notes that these features are characteristic of young volcanic outcrops, dating from the Miocene or later.

The final sample was a grey, non-vesicular, medium-grained gabbro. In thin section, it contained pyroxene and feldspar crystals 1 to 2 mm in diameter (Williams-Thorpe n.d.:2,6). Williams-Thorpe (n.d.:4) notes that the most proximal sources of gabbro are near Eilat, or on the north Levantine coast, or on Cyprus. All the samples were analysed using energy-dispersive X-ray fluorescence (EDXRF) for trace elements, whilst 8 representative samples were also analysed for major elements, which fell in either the alkali basalt or hawaiite fields. The 35 basaltic samples clustered into 5 main groups, with 3 individual outliers (Williams-Thorpe n.d.:5f). There was no correlation between the find location or date of the artefact and which group it belonged to, although most of the bowls and the altar were from Group 2, as was a mortar. Group 4 (9 samples) consisted of artefacts found in levels dating from between the 12th and 7th centuries BC, probably indicating a long history of exploitation of this source (Williams-Thorpe n.d.:6f). This data will be re-evaluated in Chapter 7, in the light of the more extensive database of geochemical analyses collected for this thesis.

Williams-Thorpe (n.d.:10f) reports that the most likely source for these different groups is the various Galilee outcrops, although Group 2 also overlaps with the northern Levantine outcrops and Group 4 also overlaps with the Harrat Ash Shaam. None of the samples plot near the Dead Sea fields. The gabbro sample plots within the Cyprus analyses, but Williams-Thorpe (n.d.:11) notes that she does not have any analyses from the northern Levant, and so this provenance cannot be considered completely secure.

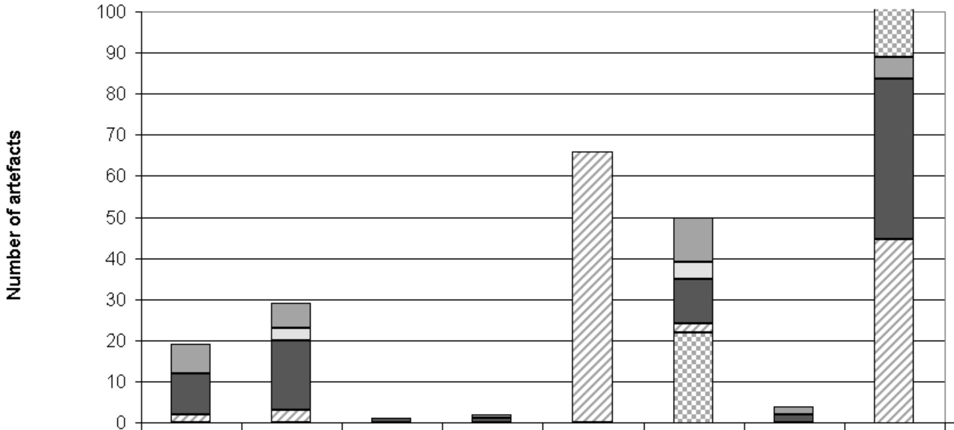
This provenance study therefore reveals that Miqne in Philistia maintained contacts with the Galilee region, in Israel, throughout the Iron Age, seemingly regardless of the changing political situation between these two kingdoms.

Jerusalem

Hoover (1996:174) reports on the analysis of the 190 ground stone artefacts recorded by the City of David excavations between 1978 and 1985, of which 40 were complete. She notes (ibid.) that this cannot be considered a complete sample, as some artefacts were not saved, some were too large for removal and could not be re-located, and some could not be found after being placed in storage. The artefacts date from the Chalcolithic to the Islamic periods, although very few were from the Chalcolithic and EBI levels and none were found from the LBA (Hoover 1996:174).

Hoover (1996:174f,181) presents data on the distribution of the artefacts by area, on the variation of types of artefacts and on the variation in raw material, all shown distributed by strata. Unfortunately, she does not give data showing the variation of artefact type by raw material. However, the appendix providing all the raw data enables this to be examined. Furthermore, the 66 flint pounders are dealt with by Rosen (1996) with the other flint tools. This is noted by Hoover (1996:172) and the data are presented separately by Rosen (1996:259), due to "essential contrasts in technology and raw material" (Rosen 1996:258). Another category of ground stone artefacts dealt with separately is the stone weights (Eran 1996), although this is not mentioned by Hoover. However, these were included in the analysis of the data summarised below.

Fig 6.14: Jerusalem ground stone categories and materials



	Querns	Hand-stones	Mortars	Pestles	Pounders	Worked stones	Vessels	Stone weights	Total %
▩ Basaltic rock	7	6	0	1	0	11	2	5	11.0
▧ Other Igneous	0	0	0	0	0	0	0	0	0.0
□ Sandstone	0	3	0	0	0	4	0	0	2.4
■ Limestone	10	17	1	1	0	11	2	39	27.7
▨ Flint/Chert	2	3	0	0	66	2	0	45	40.4
▦ Other	0	0	0	0	0	22	0	32	18.5
Total %	6.5	9.9	0.3	0.7	22.6	17.1	1.4	41.4	n=292

Data from Hoover (1996:189-192), Rosen (1996:259) and Eran (1996:225-230).

Before considering Fig 6.14 further it should be noted that many of the artefacts in the ‘Worked stones’ category are broken, making proper identification impossible. It can also be seen that the single largest category are the stone weights, with a total of 121 being found in the IA levels (Eran 1996:221). Most of these are from local material, namely flint and limestone, but a number were manufactured from non-local material, including 5 basaltic examples. The second largest category is the flint pounders, as was also noted for Manahat, above. If these two categories are removed from the calculations, then basaltic rock comprises the raw material of 25.7% (27 of 105) of the other artefacts, the second largest rock type, after limestone (40% or 42 artefacts). This variation from the overall percentages, shown in Fig 6.14, illustrates the problems with simply examining percentages from the total assemblage, especially given the current variations in what artefact types are included in the ‘ground stone assemblage’.

Hoover (1996:172) also distinguishes between ‘fine-grained basalt’ and ‘vesicular basalt’, which, although combined in Fig 6.14, are shown separately in Table 6.3. Hoover (1996:176) questions how useful the vesicular basaltic rock would be for querns, as the vesicles were up to 20 mm in diameter and so, she argues, some of the flour would have been lost in the holes. However, she also notes that the type of limestone used for most of the quern-stones had a coarse matrix and cavities left by fossils, making it very similar to the vesicular basaltic rock. This was deliberately chosen as both this and fine-grained limestone were available locally (Hoover 1996:181). It can therefore be concluded that the improved grinding efficiency was considered more important than the loss of flour. Experimental grinding using these artefacts would help quantify these points, but no such work is reported.

Table 6.3: Distribution of basaltic rock types

	Querns	Handstones	Pestles	Bowls	Other	Total
Vesicular	6	5	1	0	6	18
Fine grained	1	1	0	2	5	9

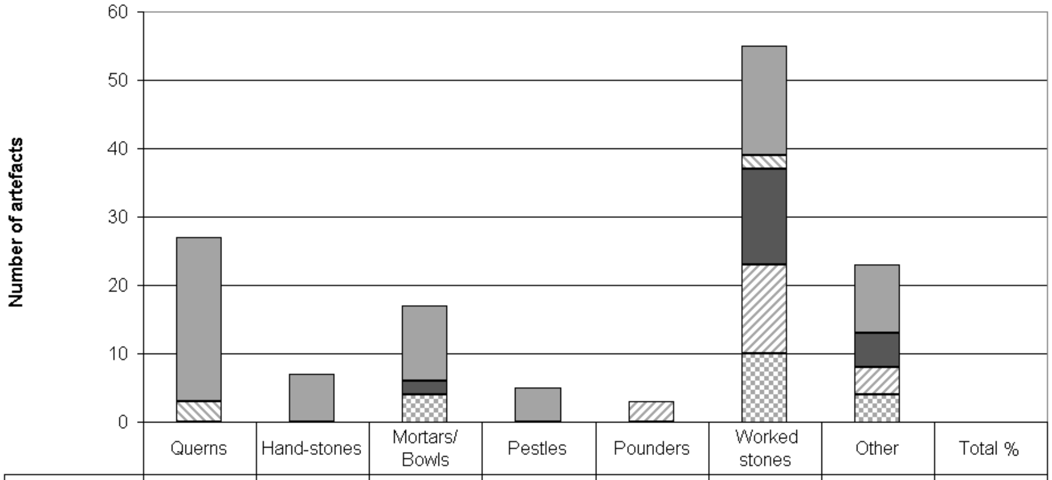
Data from Hoover (1996:189-192).

It can be seen that, overall, vesicular basaltic rock was preferred, mainly as the majority of artefact types were manufactured for grinding or pounding. It is also notable that the two bowls were manufactured from non-vesicular rock. Nonetheless, this sample is too small to be certain that these conclusions, however probable, are valid.

Megiddo

Finkelstein and Ussishkin (2000:595) report that during the IAI the site declined, before again growing during the IAII. This is reflected in the levels, with only one mixed level of IAI and IAII being reported, as opposed to a number of levels dating from the IAII. Therefore all these artefacts have been included together, with the data summarised in Fig 6.15.

Fig 6.15: Megiddo ground stone categories and materials



	Querns	Hand-stones	Mortars/ Bowls	Pestles	Pounders	Worked stones	Other	Total %
■ Basaltic rock	24	7	11	5	0	16	10	53.3
▧ Other Igneous	3	0	0	0	0	2	0	3.6
□ Sandstone	0	0	0	0	0	0	0	0.0
■ Limestone	0	0	2	0	0	14	5	15.3
▨ Flint/Chert	0	0	0	0	3	13	4	14.6
▩ Other	0	0	4	0	0	10	4	13.1
Total %	19.7	5.1	12.4	3.6	2.2	40.1	16.8	n=137

Data from Sass (2000).

From Fig 6.15 it can be seen that the majority (53.3%) of the 137 artefacts recorded were, as in earlier periods, manufactured from basaltic rock. Mortars and bowls are included together, as it is not always clear from the brief descriptions into which category an artefact should be placed. The four vessels in the 'Other' category are manufactured from alabaster and are described as "Egyptian or Egyptianized" (Sass 2000:355). The 11 basaltic vessels include ring base and tripod vessels. There is again evidence for the reworking of broken vessels, with one of the pestles described as a "recycled vessel base" (Sass 2000:363).

Tell Deir 'Alla

The analysis by Petit (1999) of the IA grinding stones from Deir 'Alla has already been discussed in the LBA section. After the destruction of the LBA settlement there was only seasonal occupation during the early IAI. This was followed by a period of sedentarisation, culminating in the construction of a mudbrick wall and tower. This settlement continued into IAII, before being destroyed by an earthquake. There was then a period of abandonment, before the site was re-settled (van der Kooji 1993:340f). These variations in settlement probably influenced the ground stone assemblage, but this cannot be analysed using the published data.

Van der Kooji (1993:341) reports that during the settlement prior to the earthquake there were a large number of imports, including Phoenician pottery and a pedestalled basalt bowl, which remained in use even after being broken. As Petit (1999) does not analyse these categories of artefacts, the significance of this one artefact is difficult to evaluate, although its curation after breakage shows that it was of some value.

Summary

Even less work has been undertaken on IA ground stone artefacts than has been on LBA artefacts. The limited research that has been conducted shows that ground stone artefacts still played a significant role in everyday life. Basaltic rock was still the material of choice for certain artefact types, including quern-stones, and so was widely distributed. Sites, such as Hazor, located close to the basaltic outcrops, utilised the rock for statues and sculptures. It is also notable that all three of the IA southern Levant royal inscriptions so far discovered were on basaltic rock, very probably as its durable qualities were recognised. Given these recognised qualities and limited natural distribution, it is very probable that there was still some prestige attached to owning even a seemingly utilitarian basaltic artefact. Considerable work needs to be undertaken before the manufacture, procurement and use of IA ground stone artefacts in the southern Levant are understood in any detail.

The provenancing work that has been undertaken (Williams-Thorpe n.d.; Petit 2001) has shown that the borders between the various IA kingdoms were essentially porous, at least to the people transporting ground stone artefacts.

Conclusion

There has been comparatively little research undertaken on ground stone artefacts, including those manufactured from basaltic rock. This is especially the case in the later periods, but even in the Chalcolithic and EBI most excavations have not recorded and analysed the ground stone artefacts with the same rigour afforded to pottery or chipped stone artefacts. This has therefore limited the amount of synthesis and analysis that can be undertaken. To rectify this, Peterson (2001; 1999:1) argues that ground stone artefacts from all periods need to be properly analysed, with every excavation producing a complete inventory of all the ground stone artefacts excavated, containing metric data, contextual information and macroscopic use-wear descriptions for all the artefacts. In addition to this, the type of stone used should be accurately determined, preferably by a geologist or geoarchaeologist.

The spatial analysis of the ground stone artefacts should also be undertaken, either by area, or more preferably by type of area (for example, courtyards or rooms), as undertaken by Milevski (1998). It is also recommended that ground stone reports show the variation through time of the raw materials used to manufacture each artefact category. This can be most easily shown on a series of tables, such as the example shown in Fig 6.16.

Fig 6.16: Table for each artefact category

	Basaltic rock	**Limestone**	**Sandstone**	**Other**	**Total**
LBI					
LBII					
IAI					
IAII					
Total					

This can, of course, be modified by changing the raw materials and periods or strata as appropriate. However, if this type of data is routinely published it would both encourage a greater examination of the ground stone artefacts and also enable further analysis of the ground stone assemblage to be more easily undertaken.

With the limited amount of evidence that is available it is possible to reach the following conclusions. The advantageous properties of basaltic rock were recognised throughout the periods examined. This made it the preferred material for quern-stones, leading them to be transported over long distances, especially in the later periods. More prestigious artefacts were also manufactured from basaltic rock, including the vessels of the Chalcolithic and EBI, but also including vessels and statuary in the LBA and IA. However, it is generally unclear how and where these artefacts were manufactured, how and by whom they were procured and, usually, even how they were used. Basaltic artefacts were also very probably used and procured in ways that are not directly archaeologically visible, whilst there is a wide diversity of potential procurement mechanisms which could have operated simultaneously in the past (cf. Chapter 5).

As mentioned in Chapter 1, Ebeling (2001:54) calls for future research on ground stone artefacts to use iconographic and textual sources, ethnographic accounts, experimental work and scientific analysis to properly understand them. Previous chapters have demonstrated the validity of geochemically provenancing basaltic artefacts, whilst this chapter has clearly shown the need for such work to be undertaken. The next chapters will therefore deal with the geochemical analysis of basaltic artefacts and a small amount of experimental work, in order to shed more light on how basaltic artefacts were procured and why certain outcrops were preferred.

Chapter 7: Sample collection and data analysis

"If you are ever confronted by a frightening number of theoretical archaeologists (two), you should first try to talk positively about the merits of fieldwork. If they persist, try quoting Kant's dictum that 'concepts without percepts are empty' (i.e. you can't get a grasp of the whole without delving into some minutiae – in other words, get on and do some real work)."
(P. Bahn Bluff your way in archaeology*, 1989:15)*

Sample collection

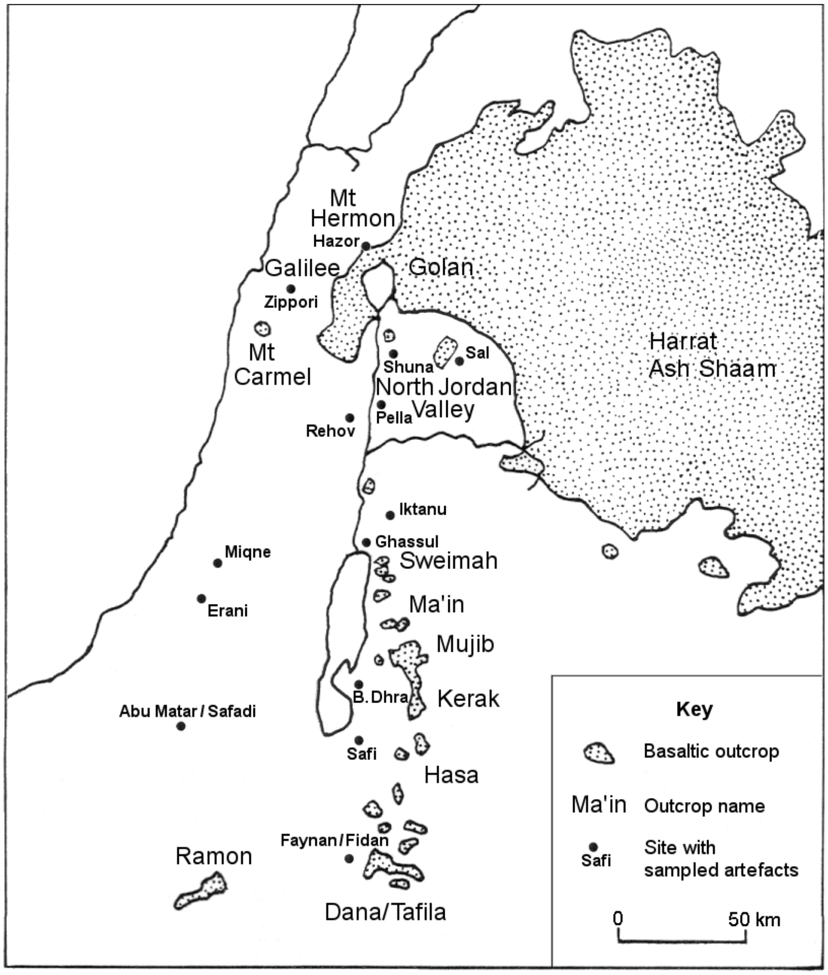
As both the opening quote and previous chapters have shown, it was necessary to collect new archaeological and geological samples. Fieldwork was therefore undertaken during the summer and autumn of 2000. Additional archaeological samples were taken from artefacts already in the UK or which were sent by the excavators for sampling. This resulted in a total of 101 archaeological samples and 55 geological samples being collected.

Pearce (1996:82) comments that the aim of geological sampling "must be to collect a random sample of the exposed volcanic terrain and to collect sufficient samples that the main geochemical variations are adequately represented." He goes on to note that approximately 15 samples are usually required to fulfil this. However, it was not possible to meet this standard, due to constraints on cost and time, meaning that there is a strong probability that the variability of the outcrops has not been fully represented by the samples collected. Furthermore, the archaeological samples were chosen purposively not randomly (Shennan 1997:361f), as they were selected in co-operation with the site directors, with each director having different criteria for selection. However, the main criterion was always what material was actually readily available, either on-site or in storage. For some this meant that only utilitarian tools were available, for others, only the vessels. None of the samples can therefore be regarded as being truly representative of either the whole assemblage of basaltic artefacts, or a sub-section of these (e.g. vessels or utilitarian tools). Therefore, any conclusions can only be partial and preliminary in nature, as it is not possible to evaluate how representative the sample is (Shennan 1997:362). This situation can only be properly rectified if the probabilistic sampling and analysis of basaltic artefacts becomes a routine part of post-excavation analysis. With these caveats, the analysis and provenancing of the artefacts will now be discussed.

Archaeological samples

The sampled artefacts were collected from sites either currently or recently under excavation and for which reliable contextual data should be forthcoming; sites were selected to provide a broad geographical spread throughout the southern Levant. These sites were: Tel Miqne, Tel Hazor, Tel Rehov, Tel `Ain Zippori, all in Cisjordan; and Tell esh-Shuna, Tell Iktanu and Pella, in Transjordan (Fig 7.1). The samples were cut from artefacts, generally using a geological hammer and chisel, although a few of the artefacts from Miqne and Iktanu had to be sampled in the Geological Workshop at the University of Durham, using a diamond periphery Norton clipper. After collection, the samples were washed to remove surface dirt. Information on the sites and artefacts is now given, ordered from south to north for Cisjordan and then Transjordan.

Fig 7.1: Location map of sites with sampled artefacts and major outcrops



Map after Philip and Williams-Thorpe (2001:13).

Tel Miqne

Tel Miqne is situated on the western edge of the inner coastal plain, 20 km east of the Mediterranean (Gitin 1998:1). The size of the settlement is unclear during the EBI, as most of the evidence is from disturbed levels, but pottery and basaltic artefacts have been found dating to this period (Dothan and Gitin 1993:1051f). During the LBA, Miqne was only a small settlement, confined to the north-east acropolis, which was destroyed at the end of the period (Gitin 1998:3). However, as discussed in Chapter 6, during the IAI Miqne was one of the largest sites in the southern Levant, and has been identified as Ekron, one of the five major cities of the Philistine kingdom. It was heavily involved in both inter- and intra-regional procurement systems, with a wide variety of imported goods present, including a large number of basaltic artefacts. Ekron declined during the early IAII, but by the 7th century BC was a very important olive oil production centre (ibid.). Williams-Thorpe (n.d.) reported that the 35 IA basalt artefacts she analysed probably originated from the Galilee area.

19 artefacts were sampled, of which 9 were analysed, as summarised in Table 7.1 (artefacts from different periods are separated by a double line). It can be seen that there is a spread of artefacts both temporally and in different categories, including vessels and utilitarian artefacts.

Table 7.1: Artefacts analysed from Tel Miqne

ID	Artefact	Period
A071	Bowl	EBI
A072	4 handled bowl	EBI
A060	Quern	LBA
A055	Bowl	IAI
A066	Pestle	IAI
A067	Pestle	IAI
A068	Rubbing stone	IAI
A061	Bowl	IAII
A062	Drill cap	IAII

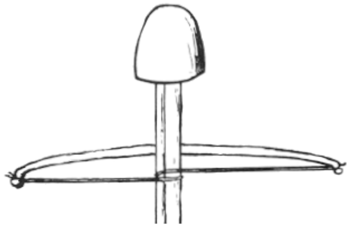
When sampled, a thin weathering rind was observed on the freshly broken surface of A055 (see Fig 7.3, below). This weathering rind was similar in appearance to those observed by Hunt (1991), being darker than the fresh rock. It was 1 to 3 mm thick, which, coupled with the small size of the sample itself, meant that it was impossible to separate the rind for further analysis.

Artefact 062 is shaped like a pestle, but has a smoothed depression at one end, 25 mm in diameter and 12 mm deep (Plate 4), and was not positively identified by the excavators. However, two similar artefacts from the LBA levels at Ugarit were discussed by Elliott (1991:35). These were manufactured from diabase and were of a similar shape, with depressions of 2 mm diameter and 0.9 mm deep, and 0.7 mm diameter and 0.5 mm deep. She (ibid.) argues:

> "It is suggested here therefore that the depression is a rotation cavity and that the artefacts are handles or "caps" pressed onto the rotating end of a bow drill to protect the hand of the person drilling small perforations through objects such as beads and spindle-whorls."

Elliott also argues diabase would be a good material as it would not crack or be quickly worn. A similar artefact was discovered by Wolley (1955:14) in his excavations at Ur (Fig 7.2).

Fig 7.2: Reconstruction of a bow drill handle



Detail from Wolley (1955:14).

Elliott (1991:35f) also notes that similar artefacts were found at LBA Megiddo and IA Tell al-Far'ah, which were manufactured from basaltic rock, which would have been an equally good material for drill caps, as it shares the necessary properties of diabase. It is therefore probable that the Miqne artefact was also a drill cap, although for a larger drill shaft than for the Ugarit artefacts.

Artefact 054 was a bowl manufactured from an intermediate igneous rock, shown in Plate 5. This sample was not analysed, as no data was available on potential source outcrops. However, it was thin sectioned, to more precisely identify the rock, as described below.

Tel Rehov

Tel Rehov is situated in the central Jordan Valley, 6 km west of the River Jordan and 5 km south of Beth Shean and is the largest sites in the area (Mazar 2001). The on-going excavations have so far focused on the Iron Age levels. The large IAI settlement shows considerable continuity from the LBA levels, but this was destroyed early in the IAII. After a period of abandonment the site was resettled on a smaller scale (Sumakai-Fink 2001; Panitz-Cohen 2001). All 10 of the samples collected date from the IAII. Six of these samples were analysed, as shown in Table 7.2. Unfortunately it was not possible to analyse any of the basaltic vessels which had been excavated.

Table 7.2: Artefacts analysed from Tel Rehov

ID	Artefact	Period
A089	Quern-stone	IAII
A092	Quern-stone	IAII
A093	Saddle quern	IAII
A094	Mortar	IAII
A095	Quern	IAII
A096	Saddle quern	IAII

Tel `Ain Zippori

Tel `Ain Zippori is situated in the Lower Galilee, next to one of the few perennial springs in the area. It was a relatively small village site, inhabited from the end of the MBA to the middle of the IAII (Reed 2000). 10 samples were received from Zippori of which 3 were analysed, as shown in Table 7.3. Again, it was not possible to analyse any of the excavated basaltic vessels.

Table 7.3: Artefacts analysed from Tel 'Ain Zippori

ID	Artefact	Period
A120	Pestle	LBA
A122	Handstone	LBA
A126	Handstone	LBA

Hazor

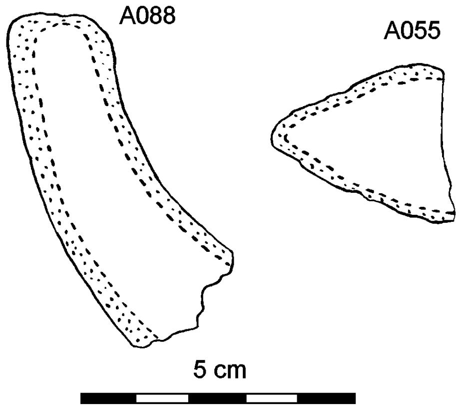
Hazor was a major settlement during the LBA and IA, not least as it was situated on a major north-south trade route to Phoenicia and Damascus (Herr 1997:127). 16 samples were collected, of which 8 were selected for analysis, as shown in Table 7.4.

Table 7.4: Artefacts analysed from Tel Hazor

ID	Artefact	Period
A078	Bowl	LBA
A081	Bowl	LBA
A082	Bowl	LBA
A083	Bowl	LBA
A075	Bowl	IA
A076	Quern-stone	IA
A080	Quern-stone	IA
A088	Bowl	IA

When the artefacts were examined, it was noted that A088 also had a visible weathering rind, 2 to 4 mm thick (Plate 6), similar to that of A055 and those noted on artefacts from Jericho and Hazor by Hunt (1991:343ff). A drawing of both the artefacts with weathering rinds was made so that they could be more clearly seen (Fig 7.3). Furthermore, given the thickness of the weathering rind on A088 and the size of the sample, it was possible to sample both the weathered and unweathered sections, which could then be analysed separately. Weathering rinds were not observed on any of the other artefacts. This suggests that the artefacts with weathering rinds had a different depositional history to the majority of the artefacts, possibly being exposed for longer. However, more work is required on this topic before any definite conclusions can be reached.

Fig 7.3: Artefacts with weathering rinds



Tell Iktanu

Tell Iktanu is situated about 10 km north-east of the Dead Sea, on the south side of the perennial Wadi Hesban. It was a large EBI settlement, consisting of mudbrick buildings with stone foundations, and possibly some cist burials, but was only occupied for a relatively short period (Prag 1989a:275f; Prag 1989b:33,39,45). 11 samples were received from Iktanu, of which 6 were analysed, as shown in Table 7.5. It was possible to analyse both bowls and utilitarian tools. Given Iktanu's location near both the Dead Sea and North Jordan Valley outcrops this may allow an examination of choices between basaltic outcrops for different categories of artefact.

Table 7.5: Artefacts analysed from Tell Iktanu

ID	Artefact	Period
A127	Bowl	EBI
A128	Bowl	EBI
A129	Pestle	EBI
A132	Handstone	EBI
A134	Bowl	EBI
A135	Bowl	EBI

Tell esh-Shuna

Shuna is located on the east bank of the Jordan Valley, at the foot of the northern uplands and was occupied during both the Chalcolithic and EBI (Baird and Philip 1994:111,131f). It was possible to analyse 6 samples of bowls from Shuna, as shown in Table 7.6.

Table 7.6: Artefacts analysed from Tell esh-Shuna

ID	Artefact	Period
A148	Bowl	Chalcolithic
A149	Bowl	EBI
A150	Bowl	EBI
A152	Bowl	EBI
A153	Bowl	EBI
A154	Bowl	EBA

Pella

Pella is located by a perennial spring in the foothills on the east side of the Jordan Valley, less than 30 km south of the Sea of Galilee. During the Chalcolithic Pella was a substantial settlement, with both stone and mudbrick buildings (Bourke 2001:117). Pella was also an important settlement during the LBA and IA. 19 samples of bowls were received from Pella, of which 8 were analysed, as shown in Table 7.7.

Table 7.7: Artefacts analysed from Pella

ID	Artefact	Period
A104	Fenestrated Bowl	L Chalcolithic
A106	Bowl	L Chalcolithic
A101	Bowl	LBI-II
A108	Bowl	IAI
A109	Bowl	IAI
A115	Bowl	IAI-II
A105	Bowl	IAI-II
A116	Bowl	IAII

Other samples

It was also possible to re-analyse four samples analysed by Philip and Williams-Thorpe (1993 and 2001). These had already been powdered, using a tungsten carbide mill (Williams-Thorpe pers. com. 2000), which introduces a small amount of trace element contamination of Nb and Ta (Ottley et al. in press:1). These samples are shown in Table 7.8, along with the original sample number assigned by Philip and Williams-Thorpe. It was also possible to analyse a further eight samples acquired by Philip and Williams-Thorpe, which they had been unable to powder or analyse, due to the large numbers of artefacts received. These are shown in Table 7.9. Both Tell Abu Matar and Bir es-Safadi are situated in southern Cisjordan (Fig 7.1), meaning that any basaltic artefact had to be imported over very long distances. For this reason, virtually all the basaltic artefacts on these sites are vessels.

Table 7.8: Re-analysed artefacts

ID	Sample	Site	Artefact	Period
A015	GP35	Sal	Bowl	Chalcolithic
A020	J2	Ghassul	Quern-stone	Chalcolithic
A023	J6	Ghassul	Fenestrated bowl	Chalcolithic
A046	J51	Safi	Bowl	EBI

Table 7.9: Additional analysed artefacts

ID	Site	Artefact	Period
A138	Abu Matar	Bowl	Chalcolithic
A139	Abu Matar	Bowl	Chalcolithic
A140	Abu Matar	Bowl	Chalcolithic
A141	Abu Matar	Bowl	Chalcolithic
A142	Bir es-Safadi	Bowl	Chalcolithic
A143	Bir es-Safadi	Bowl	Chalcolithic
A144	Bir es-Safadi	Bowl	Chalcolithic

Geological samples

As discussed in Chapter 4, the outcrops which most required additional samples were the Transjordanian outcrops, due to the general absence of published geochemical analyses, especially for the REE and HFSE. These were especially important as they were near settlements and therefore have a high probability of having been the source of the raw material for some of the artefacts. The sample locations are shown in Fig 7.4, below.

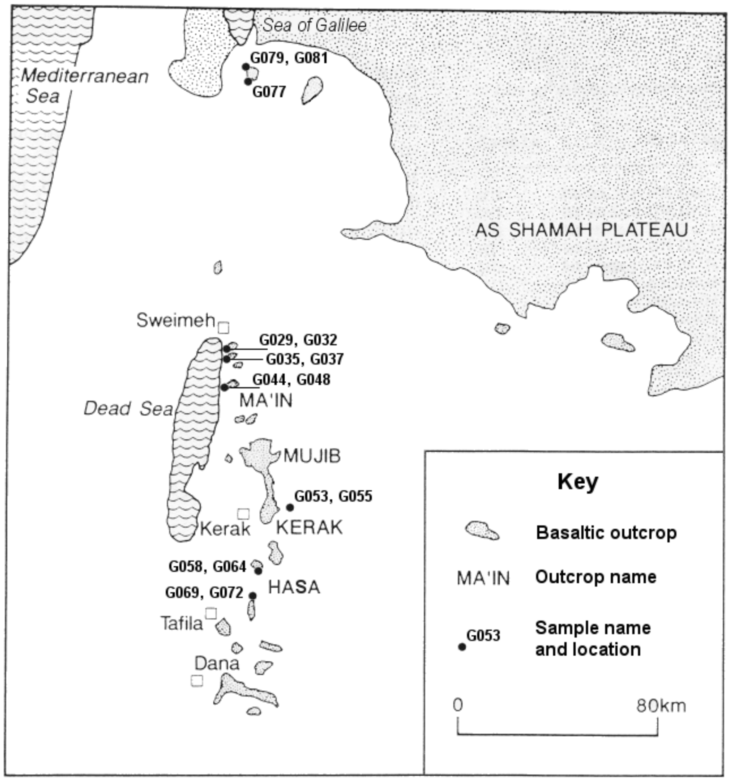
As noted in Chapter 4, there are two basaltic plugs situated in the Wadi al-Hasa, namely Jebel al-Dhakar and in the Wadi al-Khaymat (Plates 1 and 3). No geochemical data could be found for these two outcrops, so 10 samples were taken from Jebel al-Dhakar and 5 were taken from the smaller Wadi al-Khaymat outcrop. These outcrops were particularly important given their potential as sources of raw material, as discussed in Chapter 4.

Outcrops along the Dead Sea are also potential sources of raw material and were therefore sampled. The most prominent are the Sweimah outcrops and the Zarqa Ma'in outcrops. The Sweimah field (Plate 2) outcrops in two places close to the shores of the Dead Sea and so 5 samples were taken from each of these outcrops. The more extensive Zarqa Ma'in outcrops are inland, but there is a smaller outcrop close to the Dead Sea shore, as well as basaltic boulders which have been washed downstream by the Wadi Zarqa Ma'in. As wadi cobbles are a possible source of raw material 5 samples were taken from the wadi, in addition to 5 from the small Zarqa Ma'in outcrop.

A further 8 samples were taken from outcrops on the Kerak plateau, and a further 11 were taken from the Baqura outcrops, south of the Yarmouk River. The Baqura field also outcrops in two main locations, so samples were taken from both. These outcrops were again a potential source of raw material, given their high visibility (Plate 7) and proximity to past settlements.

The samples were broken from either the outcrops or, more usually, from boulders already detached from the outcrop. Although not geological best practice, which is concerned with obtaining the 'freshest' (most unweathered and unaltered) sample possible (Ramsey 1997:22), this approach was adopted to more accurately replicate the probable selection criteria of workers in the past (cf. Wilke and Quintero 1996). After collection, the samples were washed and examined, and a representative selection taken for further analysis (Fig 7.4 and Table 7.10).

Fig 7.4: Location of new geological samples



After Philip and Williams-Thorpe (1993:53).

Table 7.10: Analysed geological samples

Samples	Location	Outcrop
G077	North Jordan Valley	Al Baqura (1st outcrop)
G079, G081	North Jordan Valley	Al Baqura (2nd outcrop)
G029, G032	Dead Sea	Sweimah (1st outcrop)
G035, G037	Dead Sea	Sweimah (2nd outcrop)
G044	Dead Sea	Zarqa Ma'in
G048	Dead Sea	Wadi Zarqa Ma'in
G053, G055	Kerak Plateau	Al Lajjun
G058, G064	Wadi al-Hasa	Jebel al-Dhakar
G069, G072	Wadi al-Hasa	Wadi al-Khaymat

It was also possible to re-analyse 7 of the geological samples analysed by Philip and Williams-Thorpe (1993 and 2001), as shown in Table 7.11, along with the original sample number assigned by Philip and Williams-Thorpe. These had also been processed using a tungsten carbide mill. These samples were chosen to gain additional geochemical data on outcrops where no ICP-MS analyses had been carried out.

Table 7.11: Re-analysed geological samples

ID	Sample	Location	Outcrop
G001	GP2	Kerak Plateau	East of Kerak
G005	GP6	Eastern margin	Wadi Mujib
G008	GP9	Jordan Valley	Ghor al-Katar
G009	GP10	North Jordan Valley	Yarmouk
G018	GP31	Eastern margin	Dana Flow
G019	GP33	North Jordan Valley	Sal
G025	J22	North Jordan Valley	Wadi 'Arab

Sample preparation

Of the samples selected for analysis, all the geological samples and a significant number of the archaeological samples were sawn up using a diamond periphery Norton clipper to obtain a suitably sized block for preparation and analysis. Following standard geological practice, the weathered surfaces of the geological samples were also removed (Ramsey 1997:22). This was also done to ensure comparability between the present samples and the published data. However, two weathered sections (from G035 and G072) were also prepared for analysis, to examine the mobility of the trace elements. Any cut marks were removed using silicon carbide paper and all the samples were then rinsed using pure (MQ) water to remove any possible surface contaminants. A number of samples were also selected for thin sectioning to enable a petrographical description of the rocks.

All the samples were then crushed using a Fritsch Pulverette (Type 01-704) reciprocating rock crusher, with a manganese-steel jaw, to less than 0.5 cm^3. To minimise any possible source of contamination, the crusher was cleaned between each use using a wire brush and distilled (RO) water and dried, where necessary, using acetone. Furthermore, the first rock sample of each run that was crushed was not analysed to reduce any possibilities of cross-contamination between previous runs, which may have included rocks of very different compositions. Crushing using this equipment has been found to introduce only a minor amount of contamination for trace element analysis (J. Day 2001, pers. com.).

Once the samples had been crushed to gravel, they were split into aliquots (representative fractions), where necessary, and then milled to fine powder, using an agate Fritsch planetary ball mill. Agate is used as, although its low density requires longer crushing times, it also introduces “negligible” trace element contamination, usually only of Pb (Ramsey 1997:25). Prior to each milling run, the agate vials and balls were washed and dried and were then run with quartz sand for approximately five minutes, before being washed, rinsed with distilled water and dried again. This was to reduce the possibility of any cross-contamination between previous runs. The rock samples were then milled for 20-25 minutes, and the cleaning procedure repeated. Day (2001, unpublished data) has shown that the milling process is highly unlikely to result in any cross-contamination between samples, while the quartz sand is unlikely to contaminate the sample for any elements apart from Zr (<10 ppm) and SiO_2. Even this potential for contamination is very unlikely as the vials and balls were thoroughly washed between milling the sand and milling the sample. The larger samples were milled using four large agate vials, which took about 80g of sample and were milled for approximately 25 minutes, whilst the smaller samples were milled using eight small agate vials, which took up to 40g of sample and were milled for approximately 20 minutes. The fine powders were then bagged in readiness for chemical preparation for major and trace element analysis.

Sample analysis

The samples were analysed using the quadrupole ELAN 6000 ICP-MS at the Department of Geological Sciences, Durham. Samples were prepared and analysed using a routine technique developed at Durham for igneous rocks, described in Ottley et al. (in press). Digestion, dilution and analytical protocols ensured that the data generated were of high quality, with reproducibility of key elements and element ratios better than 5% at two standard deviations (ibid.). Twelve of the geological samples were also analysed using WDXRF at the Open University. The samples were analysed using fused discs on an ARL 8420 + dual goniometer, with a Rh anode 3 kw X-ray tube, using the analytical procedure described in Ramsey et al. (1995:3f). These major elements were required to classify the geological samples using the TAS diagram for comparability with the other geological samples.

Accuracy of results

As discussed in Chapter 3, the accuracy of geochemical data is determined by measuring the precision (%RSD) and bias (%bias) of the results, by analysing standards with known abundances. For the XRF measurements both international standards (WS-E) and internal standards (OUG94) were analysed. From Table 7.12 it can be seen that both the average %RSDs and the average %bias of the measurements for all the major elements are generally low. The figures for the individual major elements can be found in Appendix 2. It can therefore be concluded that these measurements have a high level of precision.

Table 7.12: Average precision and bias of XRF analyses of the major elements

	Average %RSD	Average %Bias
WS-E	0.44	0.89
OUG94	0.45	0.86

The ICP-MS measurements were determined over 4 runs. The precision and bias of the analyses were again checked by analysing a number of international standards. On the longer analytical runs a number of the standards were analysed twice, while one standard was analysed several times during the run. This was NBS688 for Run 2, while sample G009 was used as an internal standard for Runs 3 and 4. As discussed in Chapter 3, the elements most useful for provenancing artefacts are the REE and HFSE, with 13 of these elements selected for the provenance analyses, as will be discussed below. The %RSD and %bias of these elements across all of the runs are shown in Tables 7.13 and 7.14, whilst the figures for individual runs are given in Appendix 2. It can be seen that the measurements have a high level of precision and a reasonably low bias.

Table 7.13: %RSD of ICP-MS analyses for selected elements

	NBS688	G009	B-EN	BHVO-1	AGV-1	Root Mean Sq
Y	1.53	4.05	1.43	1.10	2.11	**2.05**
Zr	1.04	4.12	1.12	0.79	1.41	**1.70**
Nb	0.92	3.64	0.86	0.72	1.59	**1.55**
La	1.98	3.84	2.01	1.43	1.78	**2.21**
Ce	2.02	4.04	1.77	1.52	1.74	**2.22**
Nd	2.04	4.22	2.18	1.78	2.16	**2.48**
Sm	2.00	4.37	2.07	1.49	1.62	**2.31**
Tb	2.64	4.64	0.70	1.08	1.49	**2.11**
Yb	2.06	4.97	0.66	0.56	0.54	**1.76**
Lu	3.72	6.21	1.25	0.83	1.37	**2.68**
Hf	2.64	5.41	1.13	0.55	0.53	**2.05**
Ta	5.05	3.19	3.42	1.58	3.94	**3.44**
Th	2.91	3.56	1.27	0.84	1.36	**1.99**
Root Mean Sq	**2.54**	**4.37**	**1.57**	**1.13**	**1.65**	***2.25***

Table 7.14: %bias of ICP-MS analyses for selected elements

	B-EN	BHVO-1	AGV-1	Root Mean Sq
Y	2.47	1.49	1.50	**1.82**
Zr	4.12	2.11	1.33	**2.52**
Nb	18.21	2.07	3.02	**7.77**
La	1.46	3.23	1.14	**1.94**
Ce	2.48	4.20	1.07	**2.58**
Nd	1.33	4.45	1.64	**2.47**
Sm	3.31	1.28	0.99	**1.86**
Tb	1.33	1.74	3.93	**2.33**
Yb	2.94	0.91	3.41	**2.42**
Lu	12.69	4.31	0.93	**5.98**
Hf	6.54	1.11	0.40	**2.68**
Ta	9.27	4.15	2.26	**5.23**
Th	2.57	13.55	1.79	**5.97**
Root Mean Sq	**5.65**	**3.73**	**1.87**	***3.75***

These figures show that the overall accuracy of the ICP-MS analyses are good. As the analyses were measured over four separate runs, it is also necessary to examine the amount of difference between the individual runs. This is known as the reproducibility and can be measured by analysing the same sample in each of the different runs and examining the variation between the measured values (Gill and Ramsey 1997:8). This was done by calculating the overall average measurements for each of the selected elements and then calculating the %RSD between the overall average and the results from each of the four runs (Table 7.15; Appendix 2).

Table 7.15: Reproducibility (measured using %RSD) of ICP-MS analyses for selected elements

	NBS688	G009	B-EN	BHVO-1	AGV-1	Root Mean Sq
Y	0.29	1.86	0.71	0.32	0.97	**0.83**
Zr	0.12	1.88	0.60	0.23	0.62	**0.69**
Nb	0.99	1.71	0.68	0.23	0.69	**0.86**
La	0.89	1.67	0.84	0.40	0.68	**0.90**
Ce	0.73	1.75	0.51	0.47	0.67	**0.83**
Nd	0.70	1.78	0.85	0.61	0.78	**0.95**
Sm	0.47	1.83	1.03	0.54	0.60	**0.89**
Tb	0.32	2.12	0.51	0.57	0.92	**0.89**
Yb	0.43	2.26	0.40	0.22	0.21	**0.70**
Lu	0.99	3.00	0.69	0.29	0.63	**1.12**
Hf	0.63	2.58	0.50	0.19	0.26	**0.83**
Ta	0.71	1.41	2.02	0.62	1.87	**1.33**
Th	0.66	1.73	0.91	0.15	0.39	**0.77**
Root Mean Sq	**0.68**	**1.99**	**0.81**	**0.39**	**0.70**	***0.91***

As can be seen, the reproducibility of the analyses is generally good, showing that there are no serious problems with the analytical methodology and that the data from the different analytical runs can be combined.

Comparability of results

Two further issues that require discussion are the comparability of the XRF and ICP-MS data, and the possible affects that weathering has on the trace element abundances of samples, especially when comparing archaeological and geological samples.

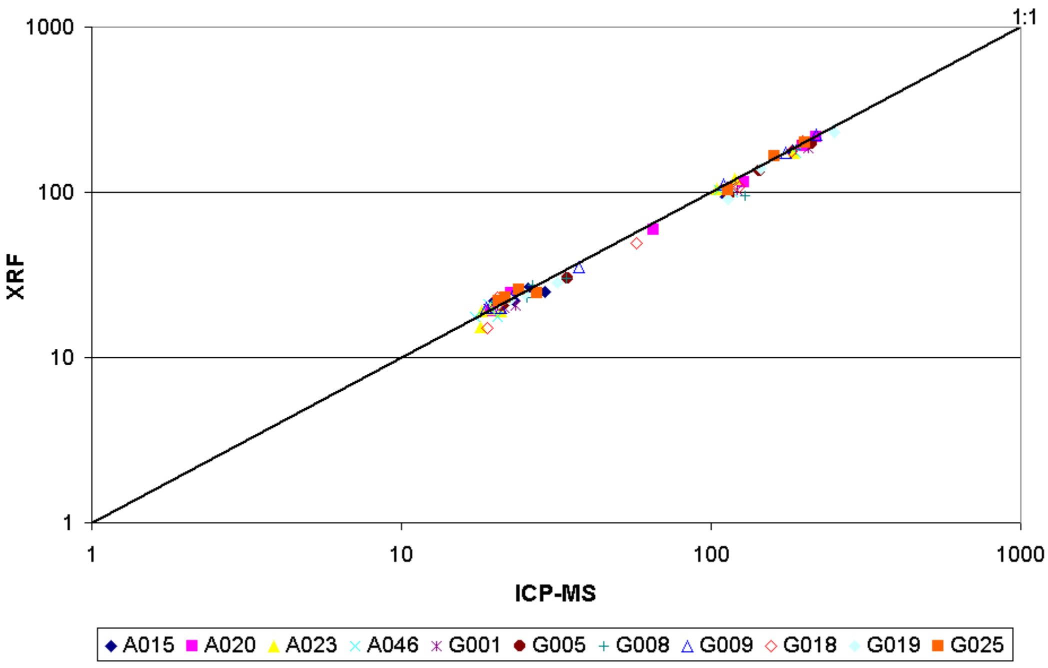
Comparison of XRF and ICP-MS data

The XRF data presented by Philip and Williams-Thorpe (1993 and 2001) and the ICP-MS data of this study for the same samples were compared for the 7 elements used for provenancing the XRF-analysed artefacts, as will be discussed below. These elements are Nb, Zr, V, Zn, Ga, Y and Sc; the amount of variation is shown in Fig 7.5, overleaf. On this plot the abundances of the element as reported by ICP-MS and XRF were taken as the two co-ordinates for each point. This means that if there was no variation between these two values, the point would fall directly on the 1 to 1 line shown on the graph. It can be seen that there is a generally good level of agreement between the two data-sets. This is also shown in Table 7.16, which reports the %RSD of each of 7 elements for each of the samples (for more detail see Appendix 3). The limited variation that does exist can in part be explained by the differing levels of accuracy and precision of the two techniques for different elements and may in part be due to natural sample heterogeneity. As the levels of variation are generally low, it can be concluded that it is possible to use both XRF and ICP-MS data in provenancing studies. As discussed in Chapter 5, this is important to avoid "argu[ing] endlessly about the alleged relative merits of isolated and non-comparable data sets" (Knapp and Cherry 1994:36).

Table 7.16: %RSD between XRF and ICP-MS analyses for the selected elements

	A015	A020	A023	A046	G008	G009	G018	G025	G001	G005	G019	Root Mean Sq
Sc	3.50	1.85	7.08	0.94	6.91	3.23	16.27	4.07	0.09	1.85	2.96	**4.43**
V	4.16	1.75	4.35	5.79	2.41	1.50	1.85	0.04	7.61	5.22	5.69	**3.67**
Zn	12.37	7.26	0.33	11.02	20.66	1.70	9.64	6.24	11.34	12.32	15.77	**9.88**
Ga	7.14	2.48	2.94	6.47	0.10	4.37	1.44	4.69	5.33	0.27	0.03	**3.20**
Y	1.98	5.96	0.92	1.83	2.22	6.49	8.36	5.11	2.07	1.22	2.30	**3.50**
Zr	0.98	1.21	1.05	1.38	2.02	0.02	1.98	2.65	4.79	3.78	2.39	**2.02**
Nb	10.42	6.73	11.71	10.33	9.11	3.88	10.75	7.36	8.48	8.66	8.30	**8.70**
Root Mean Sq	**5.79**	**3.89**	**4.05**	**5.39**	**6.21**	**3.03**	**7.18**	**4.31**	**5.67**	**4.76**	**5.35**	***5.06***

Fig 7.5: Comparison of ICP-MS and XRF analyses of Nb, Zr, V, Zn, Ga, Y and Sc



Comparison of archaeological and geological samples

As discussed in Chapters 3 and 4, there does not appear to be a serious problem with the post-manufacture weathering of artefacts, which would alter the chemical signature of the artefact and thereby confound attempts to provenance it. This is especially the case if only the immobile elements are used, including the REE and HFSE. However, it is standard geological practice to remove all weathered surfaces from rock samples prior to analysis in order to avoid the possibility of any alteration (Ramsey 1997:22).

However, when preparing the samples for analysis it was not usually possible to remove the weathered sections from the archaeological samples, given their generally small size. This introduced the prospect that it would not be possible to match artefacts to their original source, if post-manufacture weathering had significantly altered their trace element concentrations or if the artefact originated from a more weathered section of rock than was subsequently sampled. Furthermore, as noted in Chapter 3, more work is required to confirm the absence of post-manufacture weathering. To examine this, the weathered sections from the two geological samples and the weathering rind from A088 were analysed. Using the same procedure as used in Fig 7.5, the abundances for the weathered and unweathered samples were plotted against each other (Fig 7.6). As can be seen, this shows that there is very little variation between the weathered and unweathered samples. This is also shown by the root mean square of the %RSD of the 13 selected elements between the weathered and unweathered samples (Table 7.17).

Fig 7.6: Comparison of unweathered and weathered samples for selected elements

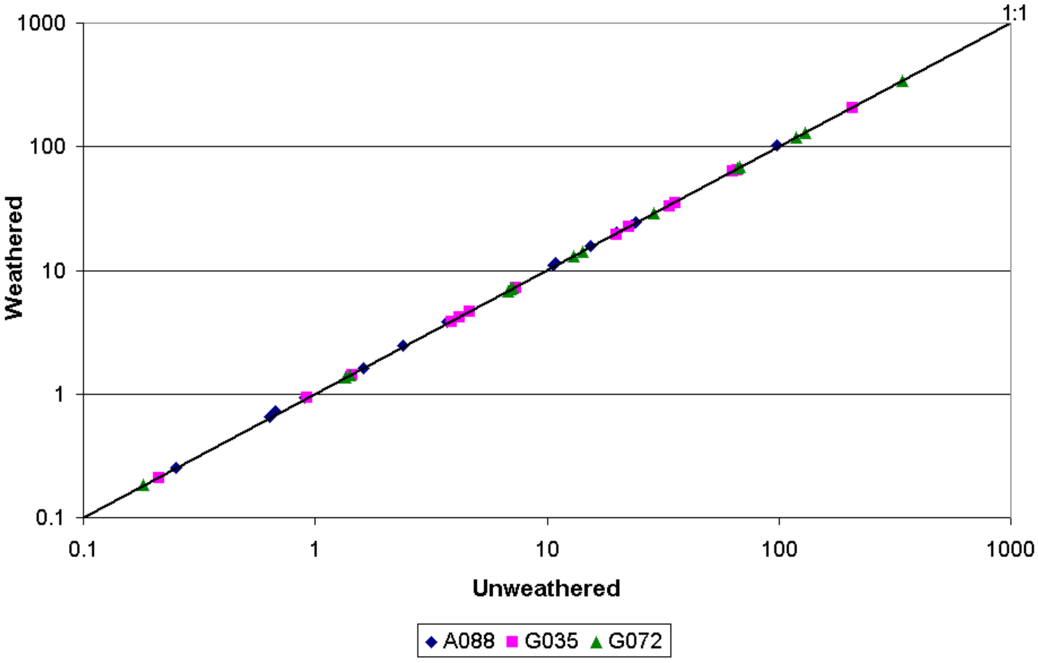


Table 7.17: Root mean square of the %RSD between weathered and unweathered samples for selected elements

Sample	Root Mean Sq
G035	0.86
G072	0.59
A088	2.14

As can be seen, the amount of variation is insignificant, being less than the variation due to analytical error (see Table 7.13). The amount of variation between the unweathered artefact and its weathering rind is higher than for the geological samples, although it is still less than analytical error. Although no generalisations can be made on the basis of these samples, the higher level of variation, coupled with the difference in colour (with the weathering lighter in the geological samples and darker in the artefact), raises the possibility that there is some difference in the weathering processes. Further work is required to examine this, but this observation could help in the understanding of the artefact's use-life and the taphonomic processes involved in the artefact's deposition.

The low levels of variation in the REE and HFSE between the weathered and unweathered samples confirms that the observation that these elements are essentially immobile (Rollinson 1993:137) holds true in archaeological situations. This therefore confirms the usefulness of these elements for provenance studies and further demonstrates the usefulness of ICP-MS, which enables the low levels of REE and HFSE present in most mafic rocks to be measured at high precision. This is especially the case as only a limited number of REE can be routinely determined by XRF (Jarvis 1997:183). Furthermore, it also demonstrates that the data of Weinstein (2000) can be used in the provenance study. As noted in Chapter 4, Weinstein (2000:870) reports that the calcite and zeolite amygdales were removed before the analysis of his samples. This was not done for the new samples analysed in this study and is not reported as having been done for the other geological studies. Therefore, the comparability of Weinstein's (2000) data with the other geochemical data was questionable. However, as only the immobile REE and HFSE will be used to attempt to provenance artefacts this should not be problematic.

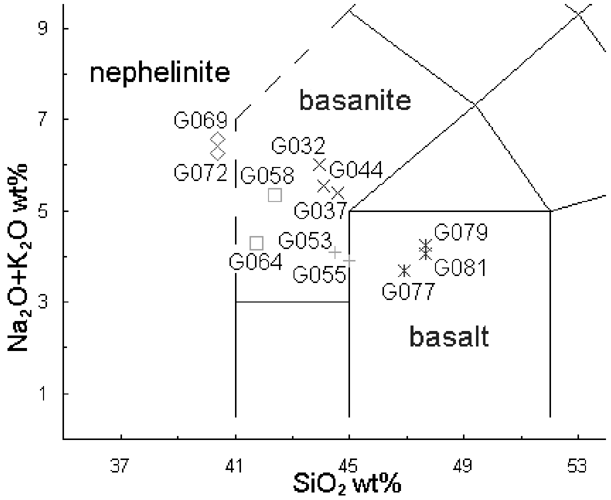
Sample classification

As discussed in Chapter 3, the two main methods of classifying igneous rocks are using either thin sections or the TAS diagram. Both of these methods were used, not least to demonstrate their advantages and disadvantages. The geological samples analysed by XRF were classified using the TAS diagram and the norm, by inputting the major element data into SINCLAS. The results are shown below (Table 7.18) and are shown plotted on the TAS diagram (Fig 7.7).

Table 7.18: Classification of geological samples

Samples	Outcrop	Classification
G077, G079, G081	Al Baqura	Alkali basalt
G032, G037	Sweimah	Basanite
G044	Zarqa Ma'in	Basanite
G053, G055	Al Lajjun	Basanite
G058, G064	Jebel al-Dhakar	Melanephelinite
G069, G072	Wadi al-Khaymat	Nephelinite

Fig 7.7: Samples plotted on the TAS diagram



It can be seen from Table 7.18 that, despite plotting in the basanite field of the TAS diagram (Fig 7.7), G058 and G064 are actually classified by SINCLAS as foidites, namely melanephelinite. This is also indicated by these samples having the highest levels of MgO and is in line with the problem noted in Chapter 3 that the TAS diagram cannot properly classify all foidites. The classification of the different samples conforms with the classifications, where they exist, of previous studies of the same outcrops, as discussed in Chapter 4. This classification also enabled the new geological samples to be compared with the existing samples.

Thin sections were also taken from a representative selection of the geological samples and also from some of the artefactual samples. Not all of the artefacts could have thin sections taken, given their small size, but the ones chosen were as representative as possible, given this limitation. Thin sections were taken to provide basic information on the types of mafic rock that could be found at the various outcrops or sites. The petrographic descriptions made from these thin sections can be found in Appendix 4. For the geological samples, these concurred with the rock classifications made using the major element data. Representative photographs of these samples can also be seen (Plates 8 to 10). For the artefactual samples, most were manufactured from basalt, although the sample taken from Tel Rehov (A091) was manufactured from basanite (Plates 11 and 12). A thin section was also taken of A054 from Miqne, which had been identified as being manufactured from an intermediate igneous rock. Using the thin section, it was possible to identify this sample as being manufactured from granodiorite (Plate 13). The nearest outcrops of this rock appear to be in southern Cisjordan, Cyprus, and the northern Levant. Unfortunately, as no data had been collected from these outcrops a more precise identification is currently impossible. Although, as Hunt (1991) demonstrated, petrographic analysis cannot be used to provenance artefacts, it can be seen that it is a useful initial step for identifying the raw material used. Its main limitation is that a relatively large part of the sample has to be removed, thereby limiting its applicability.

Physical properties

As discussed in Chapter 5, the various rock types have varying physical properties, while Tite et al. (2001) were able to show that consumers were aware of the varying physical properties of pottery vessels, which influenced their choice of vessel. Furthermore, Stol (1979:85) argued that the varying physical properties of mafic rocks were recognised in the past, as reflected by the variety of words used to describe them. However, most of the work undertaken on this subject has been too generalised for the present purposes (cf. Chapter 3). Therefore, six samples were analysed by the School of Engineering, University of Durham, for density and uniaxial compressive strength (UCS; see Chapter 3), as summarised in Table 7.19, overleaf.

Unfortunately, the samples had not been collected specifically for the UCS test, meaning they were too small for it to be carried out properly, as 5 separate cores are required from each sample for an average UCS value to be derived (McEleavey pers. com. 2002). As can be seen from Table 7.19, it was only possible to take between one and three cores from each sample. However, even this limited and partial data reveals a number of interesting features. Despite being compositionally similar and with similar average densities, the different rock types vary significantly in strength. The large differences in average UCS and density between the two alkali basalt samples is probably due to the more vesicular and weathered nature of G080. Unfortunately porosity was not measured, meaning that this observation cannot be quantified, but this is in line with the observations discussed in Chapter 5 and would also have been noticeable by a craft worker.

Table 7.19: Physical properties

ID	Rock Type	Core Number	UCS (MPa)	Average UCS (MPa)	Average Density (Mg/m^3)
G040	Basanite	1 2	131.4 146.7	**139.1**	**2.72**
G059	Melanephelinite	1 2 3	279.6 250.5 244.4	**258.2**	**3.04**
G068	Nephelinite	1	201.6	**201.6**	**2.98**
G072	Nephelinite	1 2	339.4 170.7	**255.1**	**2.99**
G080	Alkali basalt (vesicular)	1	46.6	**46.6**	**2.27**
G083	Alkali basalt (non-vesicular)	1 2 3	278.3 254.8 233.1	**255.4**	**2.90**

A potential difficulty with working nephelinite is shown by G072, with the large amount of difference in the strength of the two cores. The lower value was due to a "possible fault in the core" (McEleavey pers. com. 2002), suggesting that the potentially higher strength and unpredictable fracturing of nephelinite could have made it unattractive to craft workers. The one sample taken from each of the basanite and melanephelinite rocks suggests that these would have been as attractive to work as alkali basalt, although more samples are required to confirm this statement.

Although very preliminary in nature, these tests show that our understanding of raw material choice could be enhanced by the more widespread testing of samples. Furthermore, it suggests that the testing of archaeological samples could reveal interesting data, if, for example, they were found to be manufactured from a narrower range of strengths than that available at the source outcrop. As most artefacts would not be suitable for UCS testing, given the large sample sizes required, it may be possible to test them using the point-load test. This is faster, cheaper and requires smaller samples than the UCS test; it also indirectly measures the UCS, with the point-load strength being about 20 times less than the UCS (Farnoudi 1998:29,32). Portable point-load testing machines are also available (Farnoudi 1998:76), thereby enabling tests to be more easily carried out. Point-load tests have the further advantage of more directly quantifying the level of strength experienced by the craft worker attempting to work mafic rock. Unfortunately, no data could be found on the point-load strength of mafic rocks.

Sample database

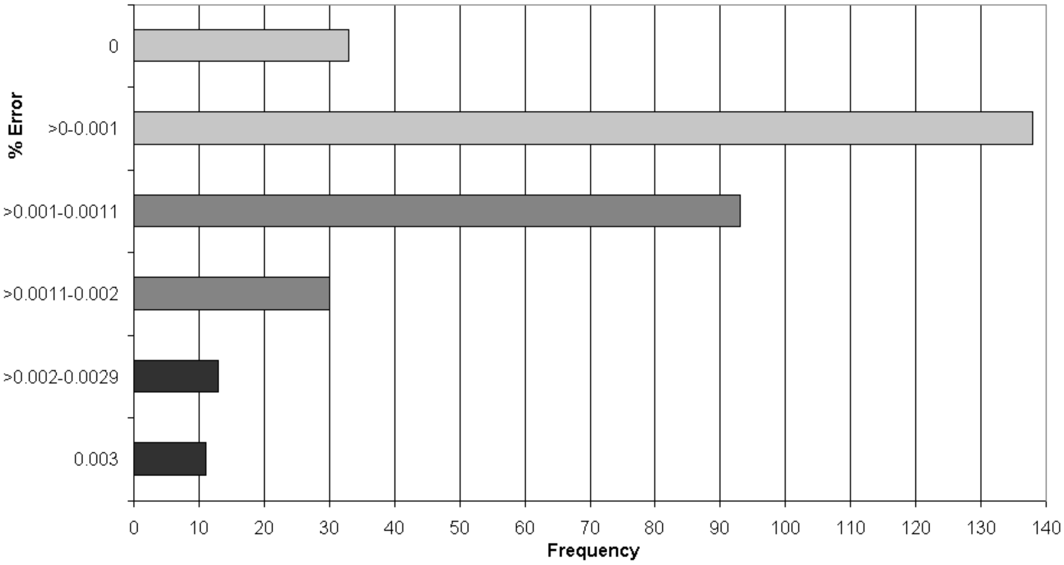
As discussed in Chapter 4, the 344 analyses of geological samples (or averages of samples) collected from the literature were inputted into a relational database, using MS Access 97. The analyses of artefacts reported by Philip and Williams-Thorpe (1993 and 2001) and Williams-Thorpe (n.d.) and all the new analyses discussed above were also added. The database consists of a number of different tables, to enable the data to be easily and flexibly retrieved, using the ‘queries’ function. The tables are “Artefacts”, “Geological”, “MajorAnal”, “Norms”, “TraceAnal”, and “Link” (a printed version can be found in Appendix 7; the database is also contained on the accompanying disk). The first two tables contain the basic information on the samples, including where they were published. A unique number is assigned to each of the samples, with the prefix “A” for archaeological samples and “G” for geological samples. These identifiers are then used in the other tables, which provide the analytical data on each of the samples. The final table, “Link” is a bridging table to enable data from both “Artefacts” and “Geological” to be easily combined with data from the other tables (Farnoudi 1998:51).

All of the data in “TraceAnal” are taken directly from the literature, although reported values of zero were omitted, for the ease of further analysis. A blank cell therefore generally means either that the element was not measured or was not detected. However, a small number of reported abundances were not included in the database, either because they were most probably erroneous, or because negative values were reported (excluding LOI). The values reported by Duffield et al. (1988) for Mn ranged from 1,280 to 1,350 ppm, whilst the other 22 geological samples for which Mn abundance is reported range in value from 0.15 to 0.2 ppm. Saffarini et al (1987) reported the abundance of Sr in one sample (G289) as being 10,896 ppm, with the second highest abundance in their samples being 1,203 ppm, and the highest abundance of the other 349 samples with reported Sr values being 2,051 ppm. Laws (1997) reported negative values of La for G137, Sc for G105, and Sc and V for G144. None of these values were included as they would affect the subsequent analysis of the data, which could limit the effectiveness of the provenance study.

Most of the data in “MajorAnal” was taken directly from the literature, with the exception that, where possible, the Fe_2O_3 and FeO abundances were re-calculated using Middlemost's (1989) method. The magnesium number was always re-calculated using SINCLAS, to ensure comparability. All the data in “Norms” were calculated using SINCLAS, whether or not CIPW norms had been calculated in the literature. This was to ensure comparability, as there are a number of slightly differing procedures for calculating the norm (Middlemost 1989:25).

As discussed in Chapter 3, Middlemost (1989:25) recommended that the sum of the oxides (after adjustment for the volatiles) and the sum of the normative minerals should not differ by more than 0.001% when calculated using a computer program. Verma et al. (2002:713) reported that the observed accuracy of SINCLAS is generally better than 0.002%. As SINCLAS automatically calculates and reports this difference, it was therefore possible to easily evaluate the accuracy of the program. A total of 318 samples (including the 12 new samples, discussed above) had been analysed for the major elements and so were classified using SINCLAS. The reported accuracies for the samples are summarised in Fig 7.8. As can be seen, the largest difference between the sum of the oxides and the sum of the normative minerals was 0.003%, which occurred in 11 samples (3.46% of the total). 171 samples (53.78%) fulfil Middlemost's recommendation by differing by 0.001% or less, whilst a further 93 samples (29.25%) differed by 0.0011% or less. Only 24 samples (7.55%) differed by greater than 0.002%. This analysis of the errors therefore confirms the generally good accuracy of SINCLAS and supports the observations of Verma et al. (ibid.).

Fig 7.8: Percentage difference between oxides and SINCLAS-calculated normative minerals



% Error	0	>0-0.001	>0.001-0.0011	>0.0011-0.002	>0.002-0.0029	0.003
Percentage	10.38	43.40	29.25	9.43	4.09	3.46

Furthermore, the rock type was also re-classified using SINCLAS. As discussed in Chapter 4, SINCLAS sometimes classifies rocks differently to their published rock types. There are two main reasons for this. First, SINCLAS re-calculates the elements to 100 wt%, on a volatile free basis. Despite being recommended by Le Maitre (2002:34), this procedure was not always followed in the literature. This can lead to differences in the classification, if the samples are near the boundaries of the rock types on the TAS diagram. Second, some of the criteria of Le Maitre (2002), as discussed in Chapter 3, have only recently been adopted, and so have not always been used in other studies. Therefore, to ensure comparability, the classifications of SINCLAS were usually adopted. The one exception to this was that SINCLAS occasionally misclassified nephelinite or basanite rocks as melanephelinite. As noted in Chapter 3, Le Maitre (2002:36) recommends that if a sample falls in the foidite or tephrite/basanite field and "if normative *ne* < 20% and *ab* is present but is < 5% the rock is a **melanephelinite**." However, SINCLAS classifies a rock as a melanephelinite if the normative nepheline is less than 20%

even when there is no albite present. It is therefore necessary to manually check the norms if SINCLAS classifies the rock as melanephelinite. However, this is the only classification error that was encountered when using SINCLAS.

Sample provenancing

The above assessment of the data and the creation of a database therefore enables the provenancing of artefacts to be undertaken and shows that the data will enable a meaningful provenance study to be undertaken. A further criterion for the provenancing of the artefacts was that it must be easily repeatable, as this will enable examination of the provenancing and, more importantly, it will enable further samples, both geological and artefactual to be easily included. This will enable future work to be easily incorporated into the provenance study (cf. Chapter 3). Element plots were therefore used to provenance the artefacts, as they best fulfil these criteria.

Analysis of geochemical data

As a pre-cursor to provenancing the artefacts, it was necessary to examine the geochemical analyses of the outcrop themselves. First, these analyses were grouped manually, based on their geographical location. These groups were then plotted using Zr/Nb against Y/Nb. This plot was used for a number of reasons. First, it utilises element ratios, thereby making cross-study and cross-technique comparisons more robust and reducing still further the problems of any weathering or intra-outcrop fractional crystallisation, as discussed in Chapter 3 and above. Second, the three elements used are HFSEs, which, as already discussed, are generally immobile during weathering. These element ratios are also routinely used in geochemical analysis (discussed in Chapter 3; Rollinson 1993:171ff), whilst Philip and Williams-Thorpe (2000:1382; 2001:23) report that these three elements were useful in discriminating between outcrops.

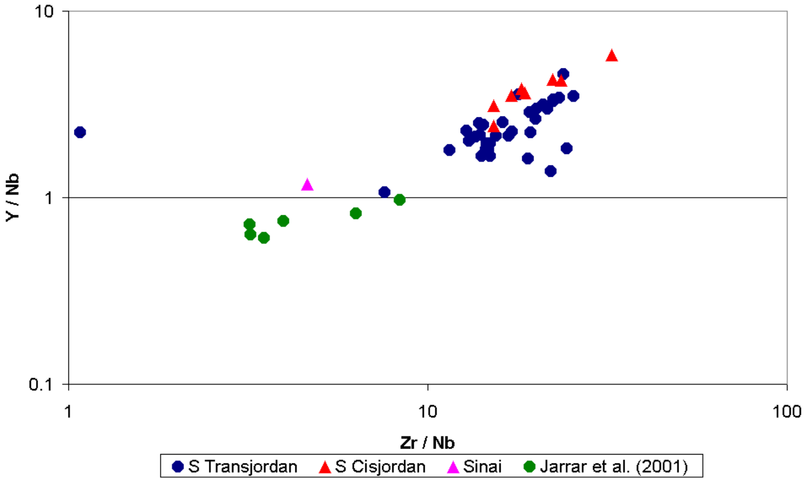
Two main problems were encountered when constructing these plots. First, as mentioned in Chapter 4, the data were unevenly distributed among the geographical areas (Table 7.20; most locations shown in Fig 7.1; all are shown in the figures in Chapter 4). Second, none of the geochemical data for the southern Cisjordan area (all of which was from the Roded suite and reported by Bogoch et al. 1993) included analyses for Nb. This was the only area for which no data for Nb was reported. Therefore, rather than disregard this location or change the elements used an attempt was made to determine the likely value of Nb from the reported geochemical data (cf. Rollinson 1993:182f). Therefore, as geochemical data for Ta was reported by Bogoch et al. (1993) and as Rollinson (1993:183) reports an Nb/Ta ratio of 16, the Nb concentrations were reconstructed by multiplying the reported Ta concentrations by 16. These reconstructed values are subject to relatively large error limits, due to the approximate nature of the ratio and the low tantalum abundances, and so can only provide an approximation of the actual Nb values, making their general use inappropriate. However, they are probably valid, given their observed overlap with the southern Transjordan field (Fig 7.9), as anticipated (cf. Jarrar et al. 2001). Furthermore, as will be discussed below, the reconstructed values served to confirm that no artefact sample plotted near to the Cisjordan outcrops. The reconstructed values are included in brackets in Tables 7.20 and 7.21.

Table 7.20: Analyses divided by geographical location

Region	Samples analysed for Y, Zr and Nb	Total number of analyses
Dead Sea	12	*13*
ESE Mafraq	12	*12*
Galilee	63	*66*
Golan	16	*54*
Harrat Ash Shaam	22	*24*
Eastern Margin	21	*21*
Jordan Valley	5	*5*
Kerak Plateau	9	*9*
Ma'in	11	*13*
Mt Carmel	4	*4*
Mt Hermon	49	*49*
North Jordan Valley	21	*21*
Ramon	16	*16*
S Cisjordan	0 (8)	*8*
Sinai	1	*1*
S Transjordan	40	*43*
Total	***302 (310)***	***359***

Fig 7.9, overleaf, shows the Zr/Nb-Y/Nb plot of samples from the southern Cisjordan, southern Transjordan and Sinai areas. As mentioned above, there is an overlap between the southern Cisjordan and the majority of the southern Transjordan samples. The smaller group of Transjordanian samples are mostly those of Jarrar et al. (2001), shown in green. These are the averages of analyses from dykes in the area (see Chapter 4) and appear to be different in composition from the other samples. The one other sample in this cluster was from Jarrar et al. (1992), who included analyses of some dykes. However, they do not provide sufficient information to determine the location of this sample (G240). There is also one outlier (G248) at the far left of the plot, but this is almost certainly due to an erroneously reported Zr abundance, which is published as 14 ppm, whilst the abundances of the other samples range from 112 to 437 ppm. If the Zr abundance for G248 is reconstructed as 140-149 ppm it plots at the edge of the main group. However, this cannot be proven, and so it will not be included in future plots.

Fig 7.9: Zr/Nb-Y/Nb plot for southern Cis- and Transjordan



From Fig 7.10 it can be seen that there is a wide range of compositions from Maktesh Ramon, which are partially discriminated on the basis of the specific outcrop within the crater. There are no obvious outliers or problems with the data, all of which is from Laws (1997).

Fig 7.10: Zr/Nb-Y/Nb plot for Maktesh Ramon

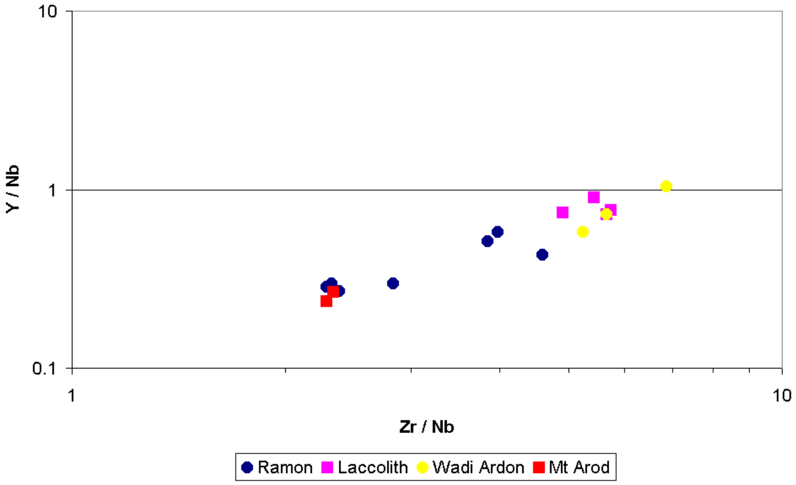
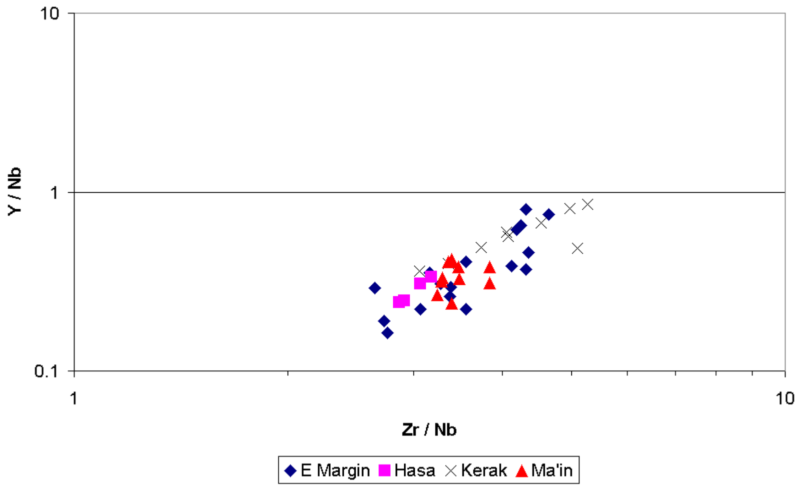


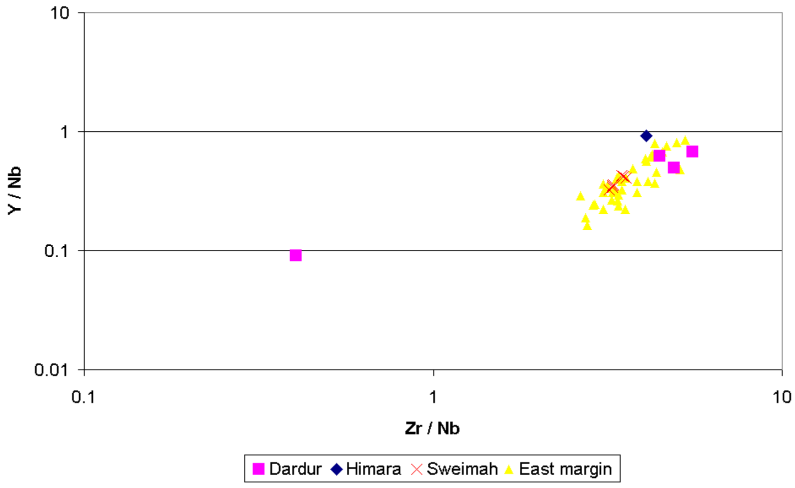
Fig 7.11 shows that the various outcrops which make up the eastern margin group have similar, overlapping ranges. These samples are from a variety of different studies and there are no obvious outliers or problems with the data. Given the amount of overlap between the different outcrops, these samples will be combined into one Eastern Margin group.

Fig 7.11: Zr/Nb-Y/Nb plot for the Transjordan eastern margin outcrops



The Dead Sea outcrops (Fig 7.12) can be largely discriminated from each other. The Sweimah samples cluster very tightly together, which is especially notable, as they are a combination of Duffield et al. (1988), Philip and Williams-Thorpe (1993) and the present study. The one Wadi Dardur outlier (G297) has a high Nb abundance, but is within the range of abundances from other outcrops. Without more samples it cannot be determined whether this sample reflects the compositional range of this outcrop, or whether it has somehow been contaminated.

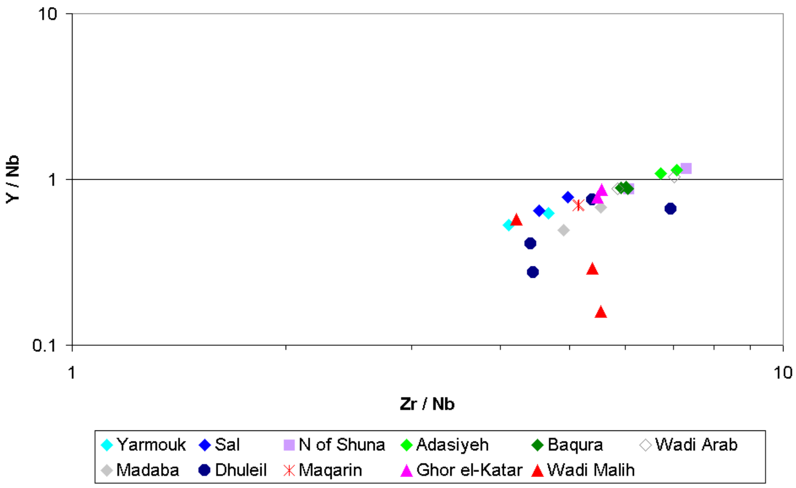
Fig 7.12: Zr/Nb-Y/Nb plot for the Dead Sea outcrops



Furthermore, there is a significant amount of overlap between the Dead Sea and eastern margin outcrops (shown as yellow triangles in Fig 7.12), making it impossible to discriminate between these geographically proximal outcrops, using the Zr/Nb against Y/Nb plot.

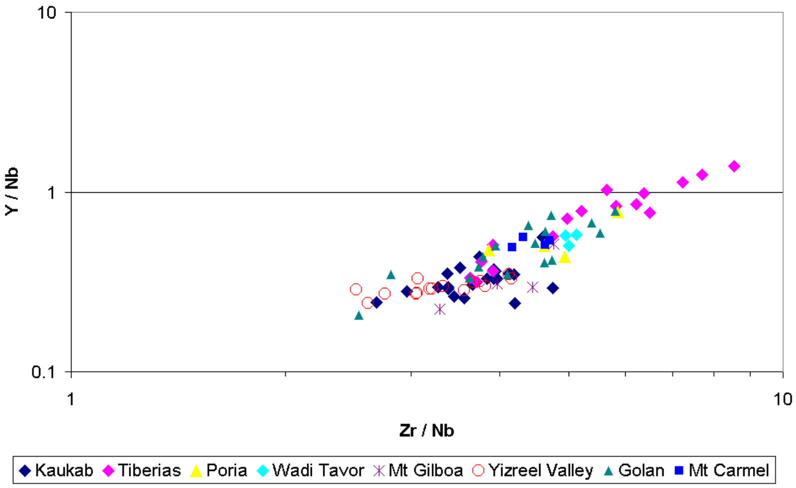
The plot of the various outcrops in the Jordan Valley (Fig 7.13) shows that there is only a partial discrimination on the basis of outcrop, with a number of outcrops having overlapping compositions. This includes the outcrops of Ghor al-Katar and Wadi Malih from the central section of the Jordan Valley, which partially overlap with the outcrops of the North Jordan Valley. One note of caution is that there are only two samples for the majority of outcrops, meaning that not all of the outcrop variability may be revealed. This is supported by those outcrops where there are more samples, most notably Dhuleil and Wadi Malih. These both have two samples which are close to each other and other samples whose element ratios are significantly different. Therefore more samples are required to examine this possibility. For the purposes of this study, the North Jordan Valley outcrops will be grouped together, as will those from the central Jordan Valley.

Fig 7.13: Zr/Nb-Y/Nb plot for the Jordan Valley outcrops



Using Fig 7.14, it is not possible to discriminate between the Golan and Galilee outcrops, while there is a certain amount of overlap between individual Galilee outcrops.

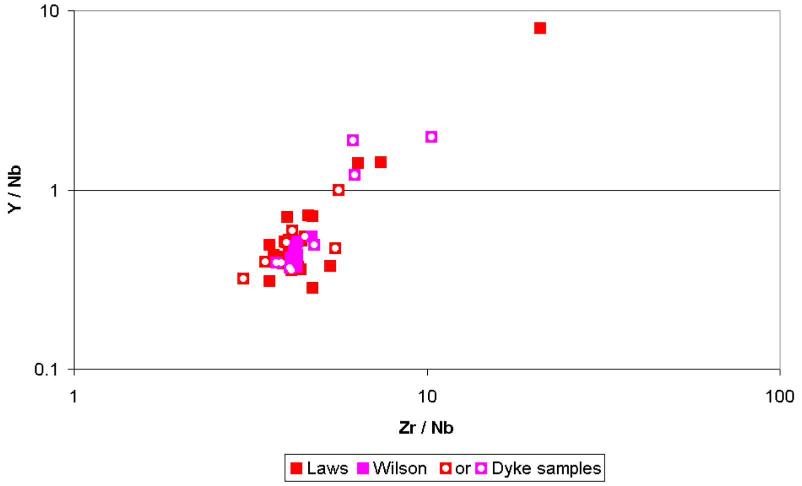
Fig 7.14: Zr/Nb-Y/Nb plot for the Galilee and Golan outcrops



There are also no obvious outliers between the various Galilee outcrops, while, although the Golan samples are widely spread, there does not appear to be any problems with the data. The few samples from Mount Carmel are also plotted on Fig 7.14, and cluster tightly together, although they cannot be separated from the other outcrops simply using this plot.

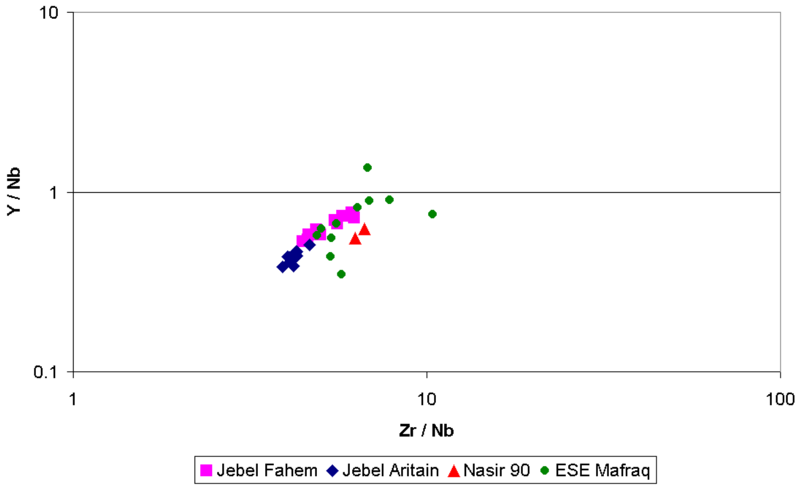
Fig 7.15 shows the Zr/Nb-Y/Nb plot of samples from the Mount Hermon outcrops, which divide into a main group and a smaller group. However, there is no clear basis for this division, which is not divided by study, geographically, or by type of magmatic feature (extrusive flows or intrusive dykes). The extreme outlier (G137) at the top edge of the plot has anomously low reported abundances for all three elements. This is also the sample which reported a negative value for La, discussed above. This therefore raises the possibility that this sample is in some way contaminated or that there was a problem with the analysis. As it is impossible to evaluate this further, G137 will not be used any further in this study.

Fig 7.15: Zr/Nb-Y/Nb plot for the Mt Hermon outcrops



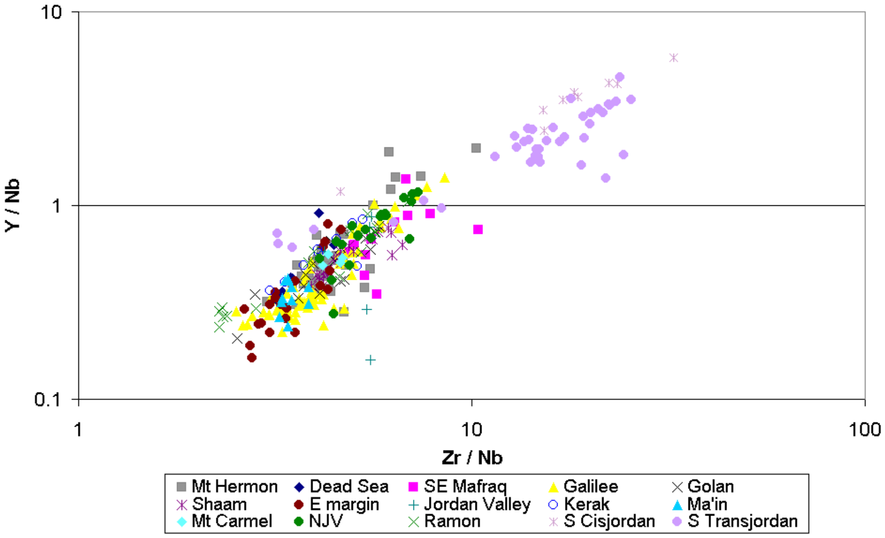
The plot of the samples from Harrat Ash Shaam (Fig 7.16, overleaf) shows that the various groups plot closely together, or overlap. The two samples from Nasir (1990) are averages of a number of samples, meaning that the individual samples may well overlap with those from Jebel Fahem. It can also be seen that the samples from ESE Mafraq also overlap with the samples from the northern part of the Harrat Ash Shaam. Although more samples are required to properly investigate the variability of the Shaam plateau, the fact that the elemental ratios overlap suggests that there is a relatively limited amount of variability.

Fig 7.16: Zr/Nb-Y/Nb plot for Harrat Ash Shaam and ESE Mafraq



One general problem encountered, which reduces the effectiveness of the Zr/Nb against Y/Nb plot to provenance artefacts alone, is that many of the outcrops are internally variable and overlap in composition with other outcrops (Fig 7.17; cf. Philip and Williams-Thorpe 2001:27). As discussed in Chapter 4, this is probably because, although the tectonic history of the region is complex, most of the outcrops are magmatically related. As discussed in Chapter 3, within-plate eruptive settings usually have Zr/Nb ratios of between 4 and 8 (but occasionally go up to 10), whilst subduction settings have ratios higher than 12 (Williams-Thorpe and Thorpe 1993:281). Virtually all the southern Levantine samples have ratios below 8, except G282 (10.4), G158 (10.3) and G381 (8.5) and the southern Cis/Transjordan outcrops, which mostly have ratios of between 11.5 and 32.5. However, the data of Jarrar et al. (2001), the averages of analyses from dykes in southern Transjordan, have Zr/Nb ratios of 8.3 or below.

Fig 7.17: Zr/Nb-Y/Nb plot for all southern Levantine outcrops



However, the Zr/Nb against Y/Nb plots have enabled an examination of the individual groups and the recognition of a number of samples with erroneous abundances. Nonetheless, given the usefulness of the REE plots (discussed in Chapter 3), the plot for measuring the amount of REE fractionation, La/Yb against Yb (Rollinson 1993:137), was used to examine whether or not these overlaps were merely artefacts of the Zr/Nb against Y/Nb plot.

One problem encountered when attempting to use the REE plot, was the limited number of analyses where the abundances of La and Yb were reported. There were even less analyses where Y, Zr, Nb, La and Yb were all reported (Table 7.21), thereby limiting the amount of direct comparability between the two plots. It can also be seen from Table 7.21 that the number of analyses reporting the abundances of any two REE is more than double the number reporting both La and Yb. However, the highest number of analyses report La and Ce (the first two REE), thereby limiting the possibilities of examining differences due to fractionation trends.

Table 7.21: Analyses reporting the REE and HFSE

Region	REE (2+)	La and Ce	Also with Y, Zr & Nb	La and Yb	Also with Y, Zr & Nb	Total analyses
Dead Sea	6	6	5	6	5	*13*
ESE Mafraq	9	9	9	0	0	*12*
Galilee	30	30	27	30	27	*66*
Golan	47	47	9	4	4	*54*
Harrat Ash Shaam	4	4	2	2	0	*24*
Eastern Margin	20	20	20	6	6	*21*
Jordan Valley	3	3	3	3	3	*5*
Kerak Plateau	5	5	5	3	3	*9*
Ma'in	9	9	7	4	2	*13*
Mt Carmel	4	4	4	2	2	*4*
Mt Hermon	42	41	41	22	22	*49*
N Jordan Valley	11	11	11	7	7	*21*
Ramon	14	14	14	6	6	*16*
S Cisjordan	8	8	0 (8)	8	0 (8)	*8*
Sinai	1	1	1	1	1	*1*
S Transjordan	3	3	0	3	0	*43*
Total	***216***	***215***	***158 (166)***	***107***	***87 (96)***	***359***

Nonetheless, these plots will now be examined in more detail. Fig 7.18, overleaf, shows that the REE plot of the southern outcrops enables most of the samples from Maktesh Ramon to be discriminated. The three southern Transjordanian samples are dykes from Jarrar et al. (2001). It is therefore surprising that there is an overlap between these samples and the samples from the southern Cisjordan, given the amount of separation on Fig 7.9. The one Sinai sample is again separate.

Fig 7.18: REE fractionation plot for southern outcrops

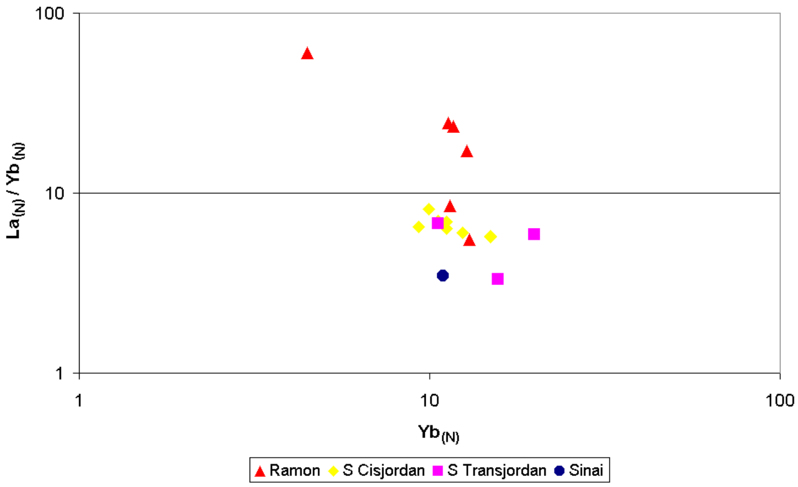
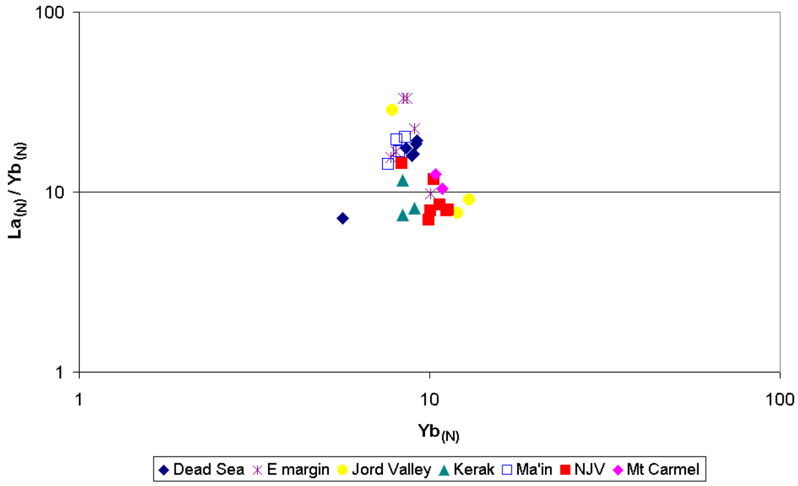


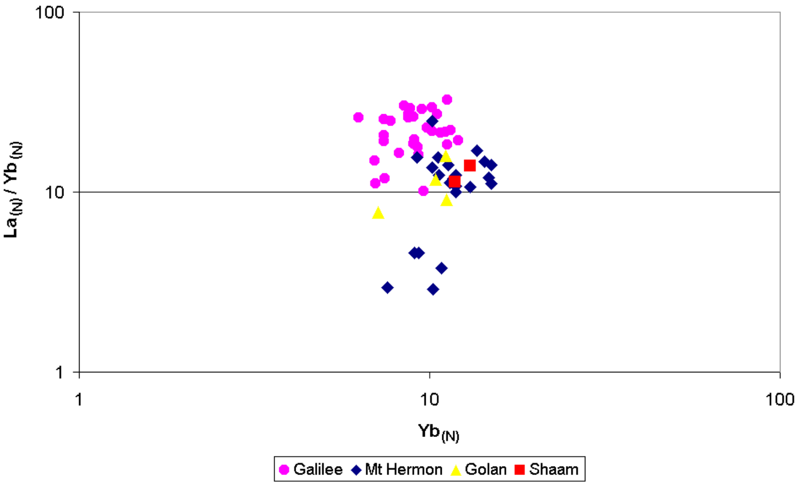
Fig 7.19 shows that the central outcrop samples overlap to a limited extent. The Sweimah samples cluster together, whilst the Dead Sea outlier is the only sample from Wadi Himra. Two of the central Jordan Valley samples group closely together, of which one is from Ghor al-Katar, whilst the other, and the outlier, are from Wadi Malih. Without more samples it cannot be determined whether one of the Malih samples is an outlier, or whether this outcrop is very variable. This illustrates the problems with only having a small number of samples from any individual outcrop.

Fig 7.19: REE fractionation plot for central outcrops



From Fig 7.20 it can be seen that the Galilee and Golan samples only partially overlap, unlike the Zr/Nb against Y/Nb plot (Fig 7.14) where they completely overlap. The Mafraq samples could not be plotted, as none were analysed for ytterbium. It can also be seen that the Mount Hermon samples again divide into two groups. These groups consist of the same samples, with the smaller group consisting of G116, G131, G158, G159 and G160 (with G125 not having any REE data) in both plots. This clearly demonstrates that these two independent plots can reveal the same groups, thereby supporting their use for provenance studies.

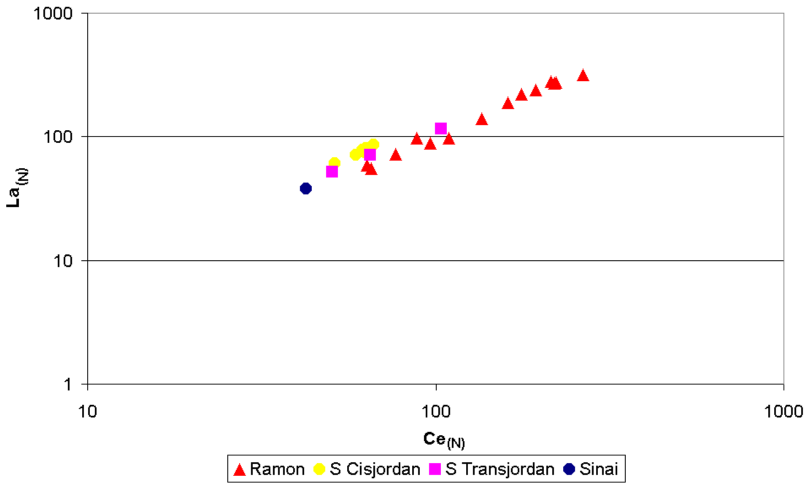
Fig 7.20: REE fractionation plot for northern outcrops



From the above examination and discussion of these two different types of plot it can be seen that they both enable discrimination between certain outcrops, although neither of them offer total discrimination of all the outcrops. This was also encountered by Philip and Williams-Thorpe (2001:27) who comment on the “within-source variation and between source overlaps” in the southern Levant. However, they can be used in combination to reduce the number of potential sources from which an artefact could originate. The following procedure will therefore be adopted for the provenancing of the artefacts. First, artefact samples will be plotted on both of the plots. Ideally, only geological samples which plotted close to the artefacts on both of these plots would be further examined. However, as Table 7.21 shows, this would dramatically reduce the number of potential samples, and so, until more samples can be analysed, samples which plot close to artefacts on either of the two plots will be considered a potential source. Indeed, the very choice of La and Yb significantly reduces the number of samples, whilst La and Ce have been analysed in many more samples, significantly more of which have also been analysed for Y, Zr and Nb (Table 7.21). Therefore, although not a standard geological plot, the samples were plotted on a La against Ce plot to determine whether it was possible to identify the same trends as shown on the more standard La/Yb against Yb plot.

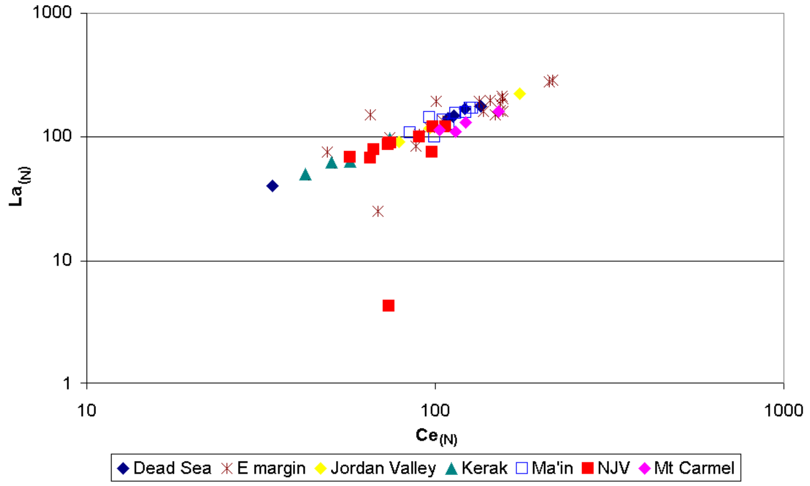
The samples were again plotted by area. A comparison of the southern outcrop plots of Fig 7.18 and Fig 7.21, overleaf, shows that the same patterns are evident in both. The Ramon samples are again largely separate, whilst the southern Cisjordan and Transjordan samples partially overlap on both the plots.

Fig 7.21: La against Ce plot for southern outcrops



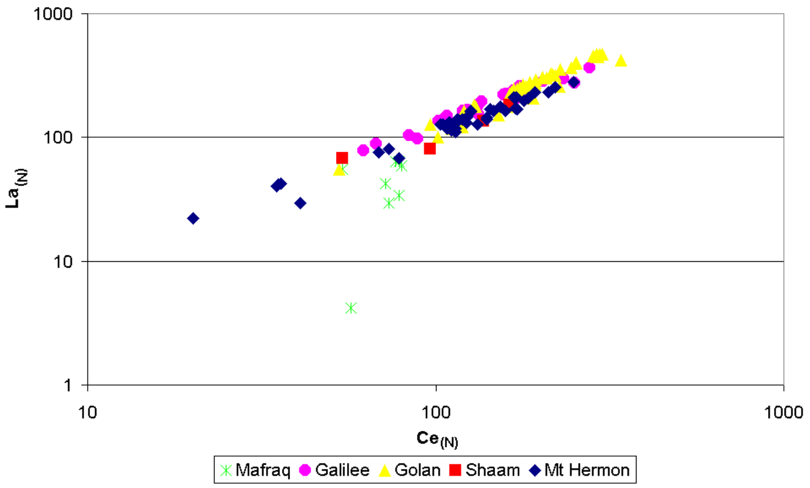
The patterns for the central outcrops are also the same using both La/Yb against Yb (Fig 7.19) and for La against Ce (Fig 7.22), although this latter plot contains considerably more samples. The North Jordan Valley outlier (G273) is due to the reported La abundance being 1 ppm. The next lowest reported abundance for the North Jordan Valley outcrops is 16 ppm, whilst the lowest abundance for all other samples is 5.3 ppm. This is therefore most probably an erroneous value, and so was subsequently deleted from the database. The eastern margin outlier (G290) has a reported La abundance of 6 ppm, whilst the next lowest abundance for the eastern margin is 18 ppm. Again, this sample is probably erroneous and so was not included in subsequent plots.

Fig 7.22: La against Ce plot for central outcrops



A comparison of Fig 7.19 with Fig 7.23 shows that the general patterns identified using the La/Yb against Yb plot are also shown in the La against Ce plot. The lanthanum-cerium plot also enables the plotting of samples from ESE Mafraq, which plot between the two Harrat Ash Shaam samples. However, a number of these samples have anomalously low lanthanum values, especially G279, with a reported abundance of 1 ppm which was again deleted. G281, G276 and G285 also had low reported La abundances which were therefore not subsequently used. It is also notable that this plot more clearly divides the Mount Hermon samples into three groups, with one outlier. The outlier is G158, the next group consists of G131, G159 and G160, whilst the small group nearest the main group of samples consists of G125, G140 and G141 (the last two samples did not have data for ytterbium). This plot therefore potentially enables better discrimination for the Mount Hermon outcrop than the other plots.

Fig 7.23: La against Ce plot for northern outcrops



This brief examination of the La against Ce plots shows that they generally enable the same groupings of the samples to be identified as was possible with the La/Yb against Yb plot. One disadvantage of the former plot is that it does not use element ratios, but, given that more samples can be examined using this plot, it will be utilised until more samples are analysed for ytterbium.

Therefore, a combination of these plots will be used to identify individual geological samples which seem to closely match the abundances of artefactual samples. These samples will then be compared more closely, using spidergrams. As discussed in Chapters 2 and 3, multi-element plots (spidergrams) allow the examination of geological trends and have been used in previous provenance studies with good results, most notably by Lease et al. (1998 and 2001). Ideally, this examination would be undertaken by utilising both HFSE and REE plots. This would allow comparison between the two plots to cross-check the conclusions. Again, however, this is not practicable given the general absence of REE data. Therefore, one spidergram, utilising both the REE and HFSE will be used, with the 13 elements that are included shown in Table 7.22.

Table 7.22: Elements used in the spidergrams

Name	Symbol
Thorium	Th
Niobium	Nb
Tantalum	Ta
Lanthanum	La
Cerium	Ce
Neodymium	Nd
Samarium	Sm
Zirconium	Zr
Hafnium	Hf
Terbium	Tb
Yttrium	Y
Ytterbium	Yb
Lutetium	Lu

To more clearly show the amount of variation between the geological samples and the artefact on the spidergram, the geological samples will be normalised against the artefactual sample. Therefore, a geological sample which completely matched the artefact would plot as a horizontal line. None of the previous studies discussed in Chapters 1 and 2 have used this approach, instead relying on visual examination and comparison between abundances or plots. To quantify this approach, the Euclidean distance between the samples was calculated. This is a multivariate statistical technique which measures the amount of difference between two data-sets (Shennan 1997:223ff; Baxter 1994:63f). The smaller the Euclidean distance measurement, the more similar the data-sets are to each other (Shennan 1997:224). Therefore, for the purposes of this study a Euclidean distance measurement of ≤25 between the artefact and the geological sample will be used as the limit at which artefacts will be accepted as having originated from the same outcrop as the geological sample. However, given the uneven distribution of the samples, a measurement of ≤50 will be accepted as an indication of the probable source of the artefact. Although these levels are somewhat arbitrary, some cut-off point is required for the interpretation of the data (cf. Shennan 1997:53f; Gould 1996:106).

That this approach will provide valid results is also indicated by the low level of variation between the unweathered and weathered samples, discussed above (Table 7.16). To further demonstrate the applicability of the methodology for provenancing, the three weathered samples were plotted on both the Zr/Nb against Y/Nb and La against Ce plots, and all the geological samples that plotted near to the weathered samples were identified and recorded. The spidergrams of these samples were then normalised to the weathered sample, and the Euclidean distance between the geological samples and the weathered sample for the 13 selected elements was calculated, as shown in Table 7.23 (where ED stands for Euclidean distance).

Table 7.23: Comparison of weathered and unweathered samples using the selected elements

A088W		G035W		G072W	
Sample	**ED**	**Sample**	**ED**	**Sample**	**ED**
G131	32.88	G029	12.12	G069	5.74
A083	21.80	G035	5.12	G072	3.62
A088	12.26	G037	14.46	G314	32.29
A150	47.38	A020	10.87		

As can be seen, the sample with the lowest Euclidean distance was in all three cases the unweathered sample taken from the same rock. However, it should be noted that the nearest sample to A088W on the Zr/Nb against Y/Nb plot is A083, not A088. This demonstrates the importance of comparing the Euclidean distances and not simply relying on the visual inspection of certain plots for provenancing.

Artefactual samples

These results can be taken as a positive indication that the methodology described above is valid and so will be used to attempt to provenance the artefactual samples. When the artefacts are plotted on the Zr/Nb against Y/Nb, and the La against Ce plots (Figs 7.24 and 7.25) they reveal a narrower range of values than those for the outcrop samples. This suggests that not all of the outcrops were utilised for the production of artefacts. Philip and Williams-Thorpe (1993:58) report that their artefacts had a Zr/Nb ratio of between 3.4 and 7.7, whilst the ratio of the artefacts analysed by Philip and Williams-Thorpe (2001) was between 3.5 and 10.2. The Zr/Nb ratio for the artefacts analysed by Williams-Thorpe (n.d.) ranged from 4.9 to 7.9, whilst the ratio for the artefacts analysed in this study ranges between 3.3 and 9.1. As discussed in Chapter 3, this probably indicates that all of the artefacts analysed originate from within-plate basalts. Most notably, the majority of the southern Cis/Transjordan samples do not plot near any of the artefactual samples, as these outcrops generally had a Zr/Nb ratio of greater than 10 (Fig 7.9), and so are ruled out as probable sources. Therefore, the Zr/Nb axis was set to a maximum of 10 as this allows the clustering of the artefacts into two main groups to be clearly observed.

Fig 7.24: Zr/Nb-Y/Nb plot of artefactual and geological samples

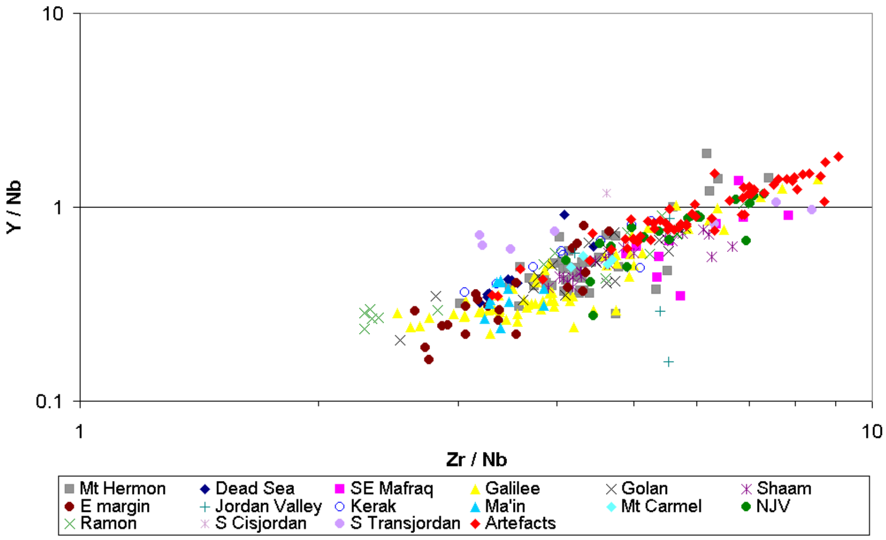
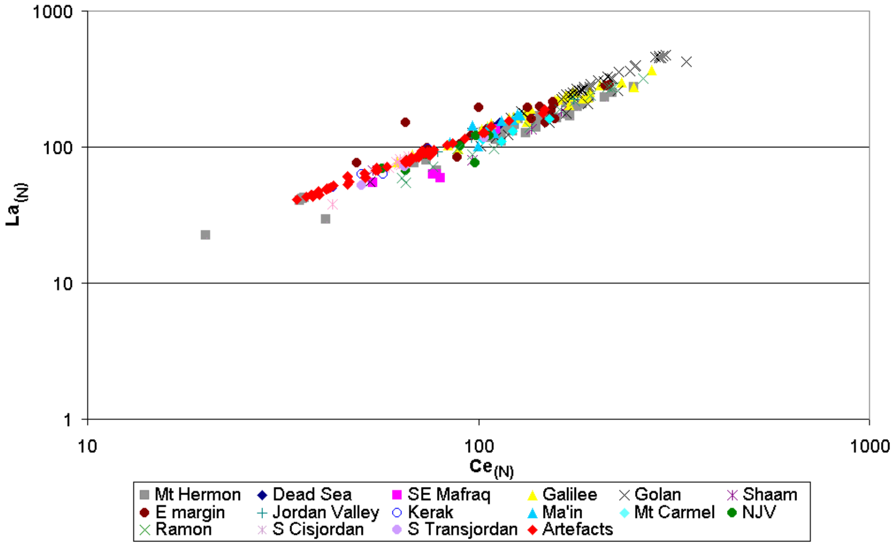


Fig 7.25: La against Ce plot of artefactual and geological samples



It can also be seen that some of the artefacts do not plot close to any of the geological samples, thereby indicating that either the source outcrop is not represented or, more probably, that there is a greater degree of variability within the outcrops than is currently represented by the geological samples. There is also considerable overlap in the compositions of the different outcrops, showing why the plots by themselves cannot be used to positively identify the source outcrop. Therefore, all the individual samples that plotted near to each artefact were identified. The artefact-normalised spidergrams were then plotted for each of these samples and the Euclidean distances calculated. Two examples of the spidergram plots are shown overleaf.

Fig 7.26: Spidergram of geological samples normalised to A020

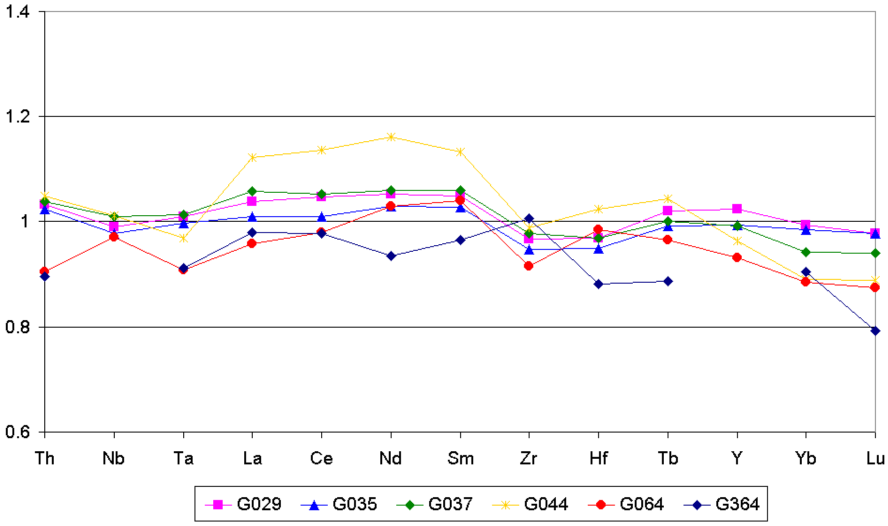
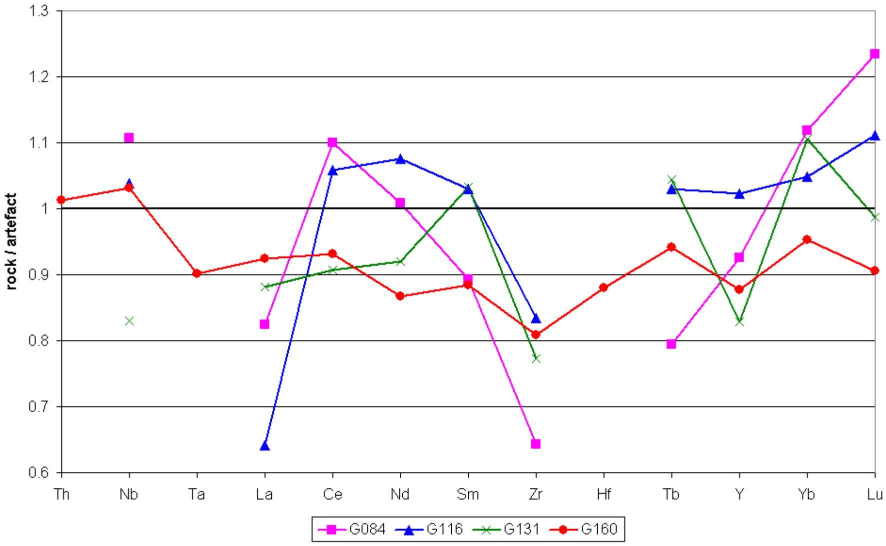


Fig 7.27: Spidergram of geological samples normalised to A071



These figures have been slightly simplified by not including the geological samples which were identified as plotting close to the artefact, but which had a greater Euclidean distance than the samples shown. The results of the calculation of the Euclidean distances are also given (Table 7.24). From both the plots and the data it can be seen that there is a great deal of variation between the composition of the artefact and individual geological samples, despite plotting near to each other on the element and element ratio plots. However, there are also positive correlations, especially for A020, with the lowest Euclidean distance being 9.48. To put this into context, it is worth noting that the Euclidean distance between A088 and A088W is 12.26 (Table 7.23).

Table 7.24: Euclidean distances of geological samples from the artefacts

A020			A071		
ID	**Location**	**ED**	**ID**	**Location**	**ED**
G029	Dead Sea	11.67	G084	Sinai	55.56
G035	Dead Sea	9.48	G116	Mt Hermon	42.90
G037	Dead Sea	15.20	G131	Mt Hermon	39.13
G044	Ma'in	32.98	G160	Mt Hermon	36.52
G064	Eastern margin	25.50			
G364	Ma’in	32.24			

One problem highlighted by Figs 7.26 and 7.27 is that not all of the geological samples were analysed for all of the 13 elements used in the spidergrams. The Euclidean distances were therefore calculated using the available elements, meaning that not all of the distances are directly comparable. This potentially reduces the accuracy of the provenance study, as the addition of the missing elemental abundances could either increase or decrease the overall Euclidean distance. Therefore, if two geological samples had low Euclidean distances, but only on the basis of a limited number of elements, the Euclidean distance would be recalculated using the elements that the two samples had in common, to indicate which sample was more probably the source of the artefact. For example, for A066, G125 had an Euclidean distance of 26.93, while G079 had an Euclidean distance of 32.62. However, G125 was only analysed for Nb, La, Ce, Nd, Zr and Y, so an Euclidean distance for G081 was calculated using just these elements. This new figure was 21.55, meaning that, with the available evidence, G079 can be regarded as the most probable source of A081.

The Euclidean distances were calculated for every analysed artefact, as given in Appendix 5 and summarised below (Table 7.25). Where re-calculations, such as that required for A066, were undertaken these are shown in an additional column in Appendix 5. With the available geological samples it was possible to identify the likely location of 82.5% (47) of the 57 artefacts analysed using ICP-MS. Five of the artefacts could not be sourced to an outcrop with any degree of certainty, whilst for a further two it was not possible to determine which of two potential source outcrops was the most likely origin of the artefact (Table 7.26). This uncertainty was largely due to the problem, noted above, of samples not being analysed for all 13 elements. However, unlike the example of A066, different combinations of elements gave contradictory lowest Euclidean distances, making it impossible to determine the probable source. These problems illustrate the limitations of using an incomplete data-set.

Table 7.25: Euclidean distances for the artefacts

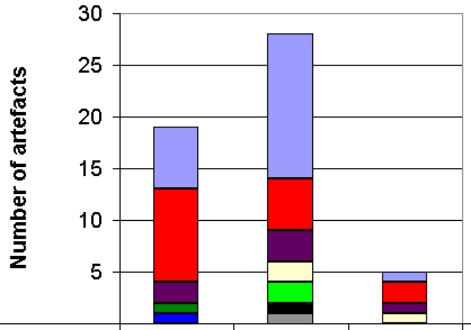
ED	Number	Percentage
≤ 25	19	**33.3**
25.01 - 49.99	28	**49.1**
Multiple	2	**3.5**
≥50	5	**8.8**
No match	3	**5.3**

Table 7.26: Artefacts with two potential sources

Artefact	Potential sources	
A015	Galilee	NJV
A095	NJV	Golan

The identification of the most probable outcrop of origin for the analysed artefacts is summarised in Fig 7.28. From this it can be seen that the vast majority of the artefacts originate from the Mount Hermon or North Jordan Valley outcrops, whilst the Kerak outcrops were the origin of a smaller number of the analysed artefacts. The identification of the North Jordan Valley and the Kerak plateau as important centres of artefact production is in line with the conclusions of Philip and Williams-Thorpe (2001). However, Mount Hermon has not previously been identified as a potential source of artefacts. The large number of artefacts from this area which have an Euclidean distance of between 25.01 and 49.99 indicates that the exact location has not been sampled, but does give a general indication that this is the correct locality. This is further strengthened by the observation that 14 of the 21 artefacts (66.7%) are most similar to sample G160. This sample was in the group of outliers, as discussed above. Moreover, it was taken from a dyke and is described as being dolerite (i.e. a medium-grained basalt). Therefore, while this sample cannot directly represent the actual source of these artefacts, it strongly suggests that extrusive rocks with similar geochemical characteristics will be found.

Fig 7.28: Distribution of artefacts by source and amount of variation



ED Sources	≤ 25	25.01 - 49.99	≥50	Total
🟦 Mt Hermon	6	14	1	21
🟥 NJV	9	5	2	16
🟪 Kerak	2	3	1	6
🟨 Galilee	0	2	1	3
🟩 Jordan Valley	0	2	0	2
⬛ E margin	0	1	0	1
🟩 Golan	1	0	0	1
🟦 Dead Sea	1	0	0	1
■ Ma'in	0	1	0	1

Another striking feature of the identified sources is the virtual absence of both the Golan and Galilee outcrops as potential sources. Both of these areas were identified as one of the potential sources for one each of the artefacts with two potential sources (Table 7.26), whilst the Golan was identified as the probable source of one artefact, with an Euclidean distance under 25. The Galilee was the closest match to two artefacts where the Euclidean distance was over 25 and one where the Euclidean distance was over 50. These results are especially notable, given that more analyses were available from these two areas than any of the other potential locations (Table 7.21). Although there is still a need for even more samples from these areas, these results suggest that these outcrops were not heavily exploited, at least for the sites and periods examined in this study.

As discussed above, it was possible to re-analyse, using ICP-MS, four of the artefacts analysed by Philip and Williams-Thorpe (1993 and 2001), using XRF. After the artefacts had been assigned to a source, this was compared to Philip and Williams-Thorpe's assignments. These assignments are compared in Table 7.27.

Table 7.27: Comparison of sources assigned to artefacts

ID	Previous assignment	Current assignment
A015	Outcrop near Sal	Galilee or NJV
A020	Sweimah or Ma'in	Sweimah
A023	Unknown	Mount Hermon
A046	Wadi Yarmouk	Kerak

Only one of the four assignments (A020) concurs with the source of the artefact. As discussed above, it was possible to positively match this artefact to the Sweimah outcrop, with the lowest Euclidean distance for a sample being 9.48%. It was also possible to rule out Ma'in as a source, with the lowest Euclidean distance for a Ma'in sample being 32.24 (see Table 7.24). For A015, it was not possible to determine whether the source was the Galilee or the North Jordan Valley. The lowest Euclidean distance was 20.45 for G378 (Galilee), which only reported the abundances for Th, Nb, Zr and Y. When the Euclidean distances of the geological samples from the artefact were recalculated using only Nb, Zr and Y, the distance for G378 dropped to 9.78, but the Euclidean distance for G025 (Wadi 'Arab in the North Jordan Valley) dropped from 37.90 to 15.65. Although the most likely source therefore remains the Galilee, given the small number of elements involved in the calculation, it is possible that the source is actually the North Jordan Valley. A similar problem exists for A095 (see Table 7.26) between G390 (Golan) and G025. For A015 it is also worth noting that the two analyses from the outcrop near Sal give Euclidean distances of 69.24 (G019) and 71.51 (G020), thereby ruling it out as a potential source.

For A046, the lowest Euclidean distance is 8.77, for a Kerak sample (G055). The Wadi Yarmouk samples give Euclidean distances of 243.24 (G009) and 356.95 (G010), unequivocally ruling it out as a potential source. For A023 the artefact is provisionally assigned to a source, Mount Hermon, for which Philip and Williams-Thorpe (2001) had no outcrop data. The lowest Euclidean distance is 55.34 for G160. The limitations of this sample have already been discussed, but it remains a possibility that Mount Hermon is the correct source. In conclusion, this methodology is capable of successfully provenancing artefacts, and has the advantage over previous methodologies of enabling the amount of variation between an artefact and potential sources to be quantified.

Reanalysis

Given this success and the modifications made to the original assignments of Philip and Williams-Thorpe (1993 and 2001), an attempt was made to re-provenance these artefacts, especially as they were not able to identify the source of them all. It was also possible to attempt to re-provenance the artefacts analysed by Williams-Thorpe (n.d.).

However, modifications had to be made to the methodology described above, due to differences in the elements analysed. As all of these artefacts had been analysed by XRF and not ICP-MS, no REE data was reported. This meant that REE plots could not be used to group the artefacts, and limited the number of elements in the spidergram to Th, Nb, Zr, and Y. Furthermore, thorium could not be used, as for many of the analyses the amount was only reported as less than a certain abundance (eg "<4 ppm"), due to it being at the XRF detection level. Given the very few elements that would therefore make up the spidergram, the transition elements of Sc, V and Zn and also Ga were included. However, scandium and vanadium abundances were not analysed by Williams-Thorpe (n.d.), making attempts to re-provenance these samples even more problematic. These elements were chosen as being the least likely to have been affected by alteration processes among those elements which had actually been analysed (cf. Rollinson 1993:104f). These limitations could therefore reduce the effectiveness of the method.

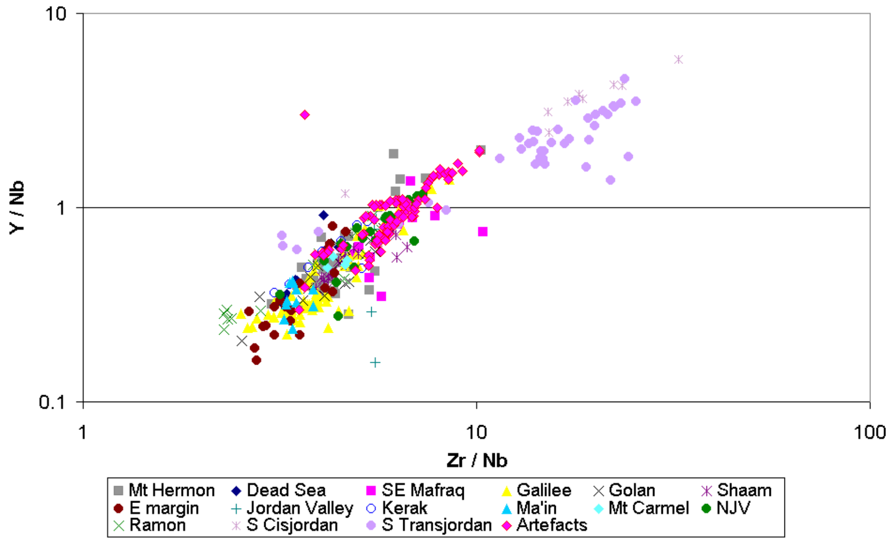
To check that this alternative methodology was capable of generating meaningful and consistent assignments, the original XRF data of the four artefacts which had been reanalysed and reassigned was examined. These four artefacts were assigned using the revised methodology, and the assignments were then compared with those made using the ICP-MS data and methodology (Table 7.28). Although there are differences in the Euclidean distances and differences for three of the artefacts in which geological sample the artefact most closely matched, it is notable that the outcrop identified as the most probable source of the artefact remains the same. This therefore gives some degree of confidence that alternative methodology will at least provide a positive indication of the source outcrop.

Table 7.28: Comparison of assignments using XRF and ICP-MS methodologies

Artefact	**ICP-MS**		**XRF**	
	Source	*Euclidean Distance*	*Source*	*Euclidean Distance*
A015	G378(Galilee) or G025 (NJV)	**20.45 or 37.90**	G079 (NJV)	**24.65**
A020	G035 (Dead Sea)	**9.48**	G029 (Dead Sea)	**12.01**
A023	G160 (Mt Hermon)	**55.34**	G160 (Mt Hermon)	**34.00**
A046	G055 (Kerak)	**8.77**	G055 (Kerak)	**28.03**

The artefacts were therefore plotted using the Zr/Nb against Y/Nb plot (Fig 7.29). It can be seen that, as two of the artefacts had Zr/Nb ratios that were greater than 10, it was not initially possible to set the axis below 100. However, once these two artefacts had been assigned the axis was re-set to 10, to enable the other artefacts to be more easily assigned.

Fig 7.29: Zr/Nb against Y/Nb plot of artefacts analysed by XRF



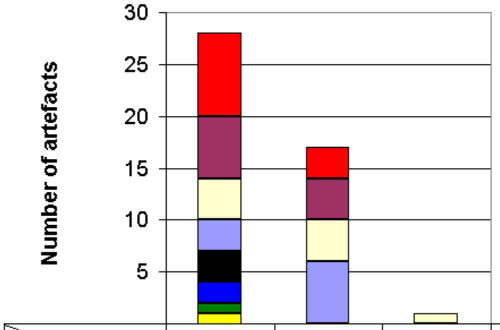
The Euclidean distances were again calculated for every artefact analysed (given in Appendix 5). For the artefacts analysed by Philip and Williams-Thorpe (1993 and 2001), excluding the reanalysed artefacts, the re-provenancing was able to identify the likely location of 95.7% (45) of the 47 artefacts (Table 7.29). One of the artefacts (A022) could not be sourced to an outcrop with any degree of certainty, while for another artefact (A006) it was not possible to determine which of two potential outcrops (Kerak or the Jordanian eastern margin) was its most likely source.

Table 7.29: Euclidean distances for Philip and Williams-Thorpe's (1993 and 2001) artefacts

ED	Number	Percentage
≤ 25	30	**63.8**
25.01 - 49.99	15	**31.9**
Multiple	1	**2.1**
≥50	1	**2.1**

The identification of the most probable originating outcrop for the analysed artefacts is summarised in Fig 7.30. In broad terms, it can be seen that the same sources have been identified as for the artefacts analysed using ICP-MS, despite the analysis of different artefacts, sometimes from different sites. This gives further credence to the argument that these two methodologies are consistent with each other. Four main sources of material were identified, namely the North Jordan Valley, the Galilee, the Kerak plateau and Mount Hermon. All of the nine artefacts definitely or provisionally identified as originating from Mount Hermon were most similar to G160. The main difference from the ICP-MS-analysed artefacts is the identification of the Galilee area as the second most important source of material.

Fig 7.30: Distribution of Philip and Williams-Thorpe's (1993 and 2001) artefacts by source and amount of variation



ED Sources	≤ 25	25.01 - 49.99	≥50	Total
🟥 NJV	8	3	0	11
🟫 Kerak	6	4	0	10
⬜ Galilee	4	4	1	9
🟪 Mt Hermon	3	6	0	9
⬛ E margin	3	0	0	3
🟦 Dead Sea	2	0	0	2
🟩 Golan	1	0	0	1
🟨 Jordan Valley	1	0	0	1

These assignments can now be compared with the original assignments of Philip and Williams-Thorpe (1993 and 2001), as shown in Appendix 6. Fifty-one artefacts, including the four reanalysed artefacts, were originally analysed by Philip and Williams-Thorpe. Of these, they were able to assign 27 to one or two individual outcrops. They identified a further 11 artefacts as originating from one of the northern Cis/Transjordanian outcrops and a further 4 as possibly originating from the Galilee area. The source of the remaining 9 artefacts could not be identified. When these assignments are compared to those of the present study, 16 of the assignments match, while there is disagreement in 15 cases. For the 11 artefacts identified simply as being from a northern Cis/Transjordanian outcrop, all could be identified as originating from outcrops in this general region. The 4 artefacts identified as possibly originating from the Galilee area, were all identified as originating from the North Jordan Valley. It was also possible to identify the possible origin of the 9 artefacts which could not be sourced by Philip and Williams-Thorpe, with 6 of these being identified as originating from Mount Hermon and the other 3 from the North Jordan Valley.

As discussed in Chapter 6, of the 36 Tel Miqne artefacts analysed by Williams-Thorpe (n.d.), 35 were basalt and one was gabbro. As discussed above, these artefacts do not have reported abundances for scandium or vanadium, making it necessary to check whether the assignments generated with the remaining elements were consistent with the previous assignments. Therefore, the artefacts from Table 7.28 were reassigned, excluding the Sc and V abundances.

The results are shown in Table 7.30, and it can be seen that the assignments differ for A015 and A020. These differences are somewhat worrying, with the lowest Euclidean distance for A015 being to Mount Hermon (G125) and the lowest for A020 being to Ma'in (G017). These results contradict the results given using the other methodologies and therefore suggest that there could well be a problem with mis-assigning the artefacts analysed by Williams-Thorpe (n.d.).

Table 7.30: Comparison of assignments with and without Sc and V

Artefact	**With Sc and V**		**Without Sc and V**	
	Source	*Euclidean Distance*	*Source*	*Euclidean Distance*
A015	G079 (NJV)	**24.65**	G125 (Mt Hermon)	**19.46**
A020	G029 (Dead Sea)	**12.01**	G017 (Ma'in)	**10.44**
A023	G160 (Mt Hermon)	**34.00**	G116 (Mt Hermon)	**21.96**
A046	G055 (Kerak)	**28.03**	G055 (Kerak)	**22.42**

Due to this problem, a number of other artefacts were also reassigned using this methodology. While most of the provenances agreed with their previous assignments, there were a number where either a Harrat Ash Shaam sample or a Makhtesh Ramon sample were identified as the probable source. In these cases, the Shaam or Ramon samples were identified as the source of the artefacts, but only with the methodology excluding scandium and vanadium. This is illustrated in Table 7.31, where G160 is a sample from the Mount Hermon outcrops and G357 is a sample from the Harrat Ash Shaam outcrops. This is therefore a serious limitation on using this methodology to attempt to provenance artefacts.

Table 7.31: Changing assignments with changes in methodology for A080

ICP-MS		**XRF**		**No Sc and V**	
Sample	ED	Sample	ED	Sample	ED
G160	***40.68***	*G160*	***32.54***	G160	**27.57**
G285	**585.60**	G285	**41.01**	*G285*	***22.24***

However, until the artefacts can be re-analysed, an attempt will be made to provenance them using the current data, but any results can only be regarded as provisional. To take into account the observed problems of mis-assignment, those artefacts which gave the lowest Euclidean distance to either a Harrat Ash Shaam or Makhtesh Ramon sample were assigned to the outcrop with the next lowest Euclidean distance. This can be justified as none of the artefacts provenanced using the other two methodologies have positively identified any artefact as originating from these two locations.

With these caveats, the artefacts were examined using the Zr/Nb against Y/Nb plot (Fig 7.29). As the artefact manufactured from gabbro did not plot anywhere near any of the geological (or artefactual) samples it was excluded from the subsequent analysis. Of the remaining 35 artefacts, it was possible to determine the likely source of all 35, as summarised in Table 7.32. The data for the individual artefacts can again be found in Appendix 5.

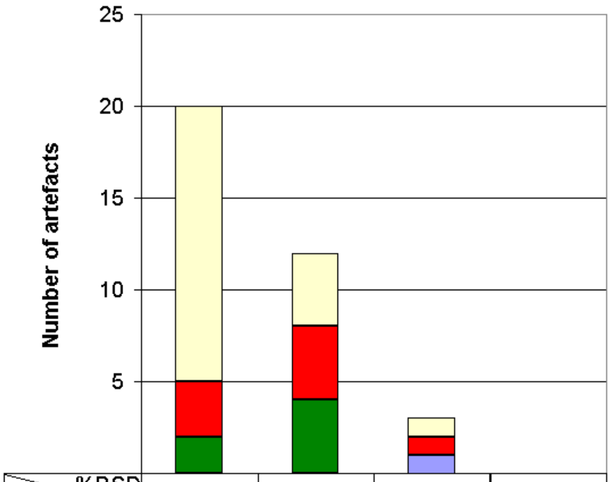
Table 7.32: Euclidean distances for Williams-Thorpe's (n.d.) artefacts

ED	Number	Percentage
≤ 25	25	**71.4**
25.01 - 49.99	10	**28.6**

Of these artefacts, 15 had their sources reassigned from either a Shaam sample (13) or a Ramon sample (2), with 13 of the artefacts reassigned to a Galilee sample, and one each reassigned to a Golan and Mount Hermon sample. As no artefacts were identified as originating from the Ma'in outcrops, and only one as possibly originating from the Mount Hermon outcrops, the other problems, identified in Table 7.30, can be safely discounted. The identified sources are therefore shown in Fig 7.31.

Williams-Thorpe (n.d.:10f) reported that the most likely source for the majority of the artefacts were the Galilee outcrops, and this has been provisionally confirmed with 20 (57.1%) of the artefacts identified as probably originating from these outcrops. However, both the North Jordan Valley and the Golan were also identified as being the origin of a significant minority of the artefacts, while one artefact probably originated from the Mount Hermon outcrops. Although these identifications are only provisional, they can probably be regarded as broadly correct, until they can be confirmed by reanalysis.

Fig 7.31: Distribution of Williams-Thorpe's (n.d.) artefacts by source and amount of variation

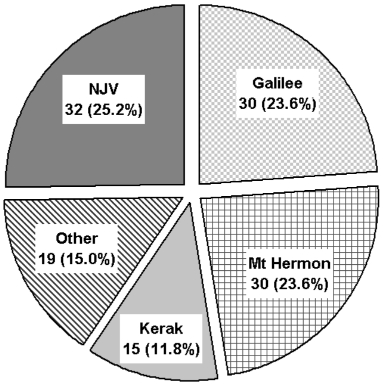


%RSD / Sources	≤ 5	5.01 - 9.99	≥10	Total No
□ Galilee	15	4	1	20
🟥 NJV	3	4	1	8
🟩 Golan	2	4	0	6
🟦 Mt Hermon	0	0	1	1

Conclusion

This provenance study has used 359 analyses of geological samples to examine the likely location of a total of 139 artefacts. Using the three different methodologies described above, it has been possible to positively identify the source of 74 of these (53.2%), with Euclidean distances ≤25 between the artefact and geological sample. It has also been able to indicate the probable source of a further 53 (38.1%) artefacts, with Euclidean distances ≤50. From these 127 artefacts, four major sources of raw material have been identified, as shown in Fig 7.32.

Fig 7.32: Identified sources of the analysed artefacts



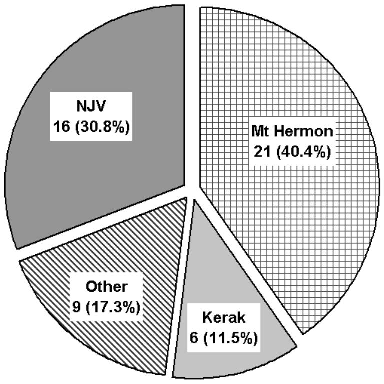
The North Jordan Valley, Kerak Plateau and the Galilee area have already been identified as probable sources of basaltic artefacts, whilst the identification of Mount Hermon as an important source has not previously been made. Of the remaining 12 artefacts, 3 could only be identified as potentially originating from one of two source outcrops, 6 could only be matched to a sample with an Euclidean distance of between 50 and 75 and three could not even be matched at this level.

It is also notable which outcrops do not appear to have been utilised, at least to any great degree. No artefacts were found to originate from the Wadi al-Hasa outcrops, despite their proximity to a number of the sites, and the fact that the Wadi al-Hasa is the only perennial wadi in southern Transjordan. The Golan, with its extensive outcrops and location between Mount Hermon and the rest of the southern Levant, was identified as the source for 9 artefacts, of which 6 were analysed by Williams-Thorpe (n.d.), meaning their identification is less secure.

Of the 57 artefacts analysed by ICP-MS, it was possible to identify the source of 19 of these (33.3%) with Euclidean distances of ≤25, and to indicate the probable source of a further 28 (49.1%) artefacts, with Euclidean distances ≤50. Two main sources were identified, namely Mount Hermon and the North Jordan Valley, while the Kerak Plateau was identified as a minor, but significant source (Fig 7.33). The proportions of artefacts provenanced are lower than for the artefacts analysed by XRF, where 55 (67.1 %) and 25 (30.5 %) could be provenanced with

Euclidean distances of ≤25 and ≤50, respectively. However, given the cross-checking possible with the additional elements reported by ICP-MS these assignments can be regarded as more secure than those by XRF in general and much more secure than those from Williams-Thorpe (n.d.), given the narrow range of elements available.

Fig 7.33: Identified sources of the ICP-MS-analysed artefacts



As discussed in Chapter 5, it is not enough to simply identify the likely sources for the raw materials used to manufacture artefacts. For the scientific work to be properly meaningful it is necessary to relate it to the general archaeological understanding of the periods in question (summarised in Chapter 6). This will be the subject of the next chapter.

Chapter 8: Archaeological significance of the data

"Science is rooted in creative interpretation. Numbers suggest, constrain, and refute; they do not, by themselves, specify the content of scientific theories. Theories are built upon the interpretation of numbers." (Gould 1996:106)

Chapter 7 was able to specify the most likely provenance of the basaltic artefacts, with four major sources of raw material identified. As already discussed, and as the opening quotation makes clear, the next stage must be to examine the archaeological implications of the provenance study. This should enable a better understanding of how the basaltic-rock procurement systems operated.

Provenance of artefacts by site

The clustering of the artefacts into a relatively small number of groups seems to indicate the deliberate choice of particular outcrops (cf. Philip and Williams-Thorpe 2001:20), despite the availability of alternative sources. To examine this, the provenance of the artefacts will be examined on a site-by-site basis, moving from south to north for Cisjordan and then Transjordan (see Fig 7.1 for locations). The tables from Chapter 7 showing the analysed artefacts will be used, with the addition of three columns, showing the analytical technique, the probable source area, and the Euclidean distances between the artefact and the geological sample. The Euclidean distances will be summarised as ≤25 (shown in bold), ≤50 (shown in italics), ≤75, or "no match"; where ≤25 is taken as indicating a securely provenanced sample, ≤50 as indicating the possible location and ≤75 as indicating the best match with the available samples. Where artefacts have two potential sources, no level of variation is given, due to the inherent ambiguity present. Artefacts from different periods at a single site are again separated by a double line. Where applicable in individual tables, artefacts analysed by ICP-MS as part of this study are listed first, followed by artefacts previously analysed by XRF.

Bir es-Safadi

Bir es-Safadi is situated in southern Cisjordan, on the southern bank of the Nahal Beersheva. It was an extensive Chalcolithic settlement and, given its close proximity and identical occupational sequences and assemblages, is probably part of the same Chalcolithic settlement represented by Abu Matar on the northern bank of the Nahal Beersheva (see below; Shugar 2000:32f). Given Safadi's location, any basaltic artefact had to be imported over very long distances. It was possible to analyse three artefacts, and reassign four previously analysed artefacts, with the results given in Table 8.1, overleaf.

Table 8.1: Provenance of artefacts analysed from Bir es-Safadi

ID	Artefact	Period	Method	Source	ED
A142	Bowl	Chalcolithic	ICP-MS	*Jordan Valley*	*≤50*
A143	Bowl	Chalcolithic	ICP-MS	**Mt Hermon**	**≤25**
A144	Bowl	Chalcolithic	ICP-MS	*Mt Hermon*	*≤50*
A041	?Bowl	Chalcolithic	XRF	**Galilee**	**≤25**
A042	?Bowl	Chalcolithic	XRF	*NJV*	*≤50*
A043	?Bowl	Chalcolithic	XRF	***NJV***	**≤25**
A044	?Bowl	Chalcolithic	XRF	*NJV*	*≤50*

From Table 8.1, it is notable that there appears to be a distinction in sources based on the analytical technique used. This therefore requires further investigation to determine whether this distinction is real or simply due to problems with the methodologies. First, the three artefacts analysed using ICP-MS were reassigned using the XRF methodology, to check whether there was any variations in assignments between the two methods used, as shown in Table 8.2. Although there was a variation in source for A142, both of the outcrops in question were different from those identified as sources for the other artefacts. However, to further examine the artefacts, the Euclidean distances were calculated between the ICP-MS-analysed artefacts and the geological samples which most closely matched the XRF-analysed artefacts (G022, G023, G079 and G380), using the XRF methodology. As can be seen (Table 8.3), the artefacts do not appear to match these samples, increasing the likelihood that the artefacts do originate from a variety of different outcrops.

Table 8.2: Comparison of assignments using ICP-MS and XRF methodologies

Artefact	**ICP-MS**		**XRF**	
	Source	*Euclidean distances*	*Source*	*Euclidean distances*
A142	G008 (Jordan Valley)	**29.28**	G005 (E margin)	**21.44**
A143	G160 (Mt Hermon)	**20.95**	G160 (Mt Hermon)	**23.48**
A144	G160 (Mt Hermon)	**39.13**	G160 (Mt Hermon)	**52.88**

Table 8.3: Euclidean distances between ICP-MS-analysed artefacts and identified sources of the XRF-analysed artefacts for the elements Nb, Zr, V, Zn, Ga, Y and Sc

	G022	**G023**	**G079**	**G380**
A142	39.49	38.33	26.72	35.86
A143	91.06	93.78	106.97	181.74
A144	77.86	76.80	86.54	152.34

As a final test, the Euclidean distance was calculated between the artefacts (Table 8.4), which showed that the level of variation between the XRF- and ICP-MS-analysed artefacts is always greater than 25, again indicating that they originate from different outcrops. This therefore strengthens the probability that the above assignments of the XRF-analysed artefacts are correct.

Table 8.4: Euclidean distances between artefacts from Safadi for the elements Nb, Zr, V, Zn, Ga, Y and Sc

	A142	**A143**	**A144**
A041	28.37	193.28	160.84
A042	44.66	74.43	70.53
A043	41.05	81.35	73.91
A044	42.28	80.63	74.69

The results therefore indicate that at least three distinct outcrops were being exploited, which could well have been acquired by different procurement systems. This will be discussed below.

Tell Abu Matar

As mentioned above, Abu Matar is situated on the northern bank of the Nahal Beersheva and is probably part of the same settlement as Safadi (Shugar 2000:32f). Abu Matar has been identified as possibly the most important Chalcolithic copper smelting site in the southern Levant (Shugar 2000:28,45), demonstrating the importance of procurement systems to the inhabitants of this site. Both Safadi and Abu Matar were only occupied during the Chalcolithic (Shugar 2000:40). Four artefacts were analysed and a further four were reassigned (Table 8.5).

Table 8.5: Provenance of artefacts analysed from Abu Matar

ID	**Artefact**	**Period**	**Method**	**Source**	**ED**
A138	Bowl	Chalcolithic	ICP-MS	*Mt Hermon*	*≤50*
A139	Bowl	Chalcolithic	ICP-MS	*Mt Hermon*	*≤50*
A140	Bowl	Chalcolithic	ICP-MS	**Mt Hermon**	**≤25**
A141	Bowl	Chalcolithic	ICP-MS	*Mt Hermon*	*≤50*
A037	?Bowl	Chalcolithic	XRF	*Galilee*	*≤50*
A038	?Bowl	Chalcolithic	XRF	*Galilee*	*≤50*
A039	?Bowl	Chalcolithic	XRF	**Galilee**	**≤25**
A040	?Bowl	Chalcolithic	XRF	**NJV**	**≤25**

From Table 8.5, it can be seen that there again appears to be a distinction between the artefacts analysed by ICP-MS and those analysed by XRF. As for the artefacts from Safadi, the Euclidean distances between the artefacts were calculated (Table 8.6), which showed that the level of variation between the XRF- and ICP-MS-analysed artefacts is always greater than 25, indicating that the artefacts do originate from different outcrops.

Table 8.6: Euclidean distances between artefacts from Abu Matar for the elements Nb, Zr, V, Zn, Ga, Y and Sc

	A138	**A139**	**A140**	**A141**
A037	39.15	30.24	66.31	31.70
A038	46.89	35.36	54.93	37.25
A039	45.06	28.69	62.46	40.53
A040	67.29	54.87	47.80	58.12

Therefore, the results shown in Table 8.5 should be accepted as broadly correct, although it should be noted that, as 5 of the artefacts have only been matched to samples with an Euclidean distance of ≤50, meaning that more samples are required to provenance the artefacts to samples with an Euclidean distance of ≤25. Nonetheless, the results again indicate that three distinct outcrops were being exploited. Furthermore the examples of Abu Matar and Safadi also illustrate the problems of small sample sizes, where the addition of more samples can significantly alter our understanding of operation of the procurement systems.

Tell Erani

Tell Erani is situated in central Cisjordan, on the south-east coastal plain. Only a few Chalcolithic artefacts have been found and only in later contexts, but these include pottery cornets and basaltic fenestrated vessels (Kempinski and Gilead 1991:186). During the EBI many locally-made Egyptian-style artefacts and buildings in Egyptian architectural styles have been found. This is interpreted as Erani being a centre of the Egyptian colonisation and control of the region, especially as it was situated on a major north-south road (Kempinski and Gilead 1991:187,166). Kempinski and Gilead (1991:189) argue that Erani became one of the major economic centres of the region during the EBI.

Philip and Williams-Thorpe (2001) analysed 4 bowls from Tell Erani. After reassignment (Table 8.7), it can be seen that the sources are the same as those for the sites of Abu Matar and Safadi, and do not include the more proximal sources of Kerak and Mujib. This was also observed by Philip and Williams-Thorpe (2001:26). Although more samples are required to confirm this observation, as this pattern of procurement has been observed on three independent sites it should be regarded as fairly secure.

Table 8.7: Provenance of artefacts analysed from Tell Erani

ID	Artefact	Period	Method	Source	ED
A028	Pedestal bowl	Chalcolithic	XRF	**Galilee**	**≤25**
A029	Bowl	EBI	XRF	**NJV**	**≤25**
A030	Bowl	EBI	XRF	**NJV**	**≤25**
A031	Four handled bowl	EBI	XRF	*Mt Hermon*	*≤50*

Tel Miqne

Miqne is situated on the western edge of the inner coastal plain in central Cisjordan, 20 km east of the Mediterranean (Gitin 1998:1). In addition to the 9 artefacts analysed as part of this study, all 35 of the basaltic artefacts analysed by Williams-Thorpe (n.d.) were from Miqne. However, although Williams-Thorpe (n.d.:1) reports that a wide range of artefact types were analysed, this information is not given in the unpublished report. She only explicitly mentions the type of artefact for three of the samples, but from her discussion it is possible to infer the likely artefact type of the rest of the artefacts (Williams-Thorpe n.d.:7). These artefact types are therefore prefixed with a question mark. Furthermore, although Williams-Thorpe sampled artefacts from both the IAI and IAII, this information is not given, so all artefacts are simply classified as "Iron Age".

The provenance of all the artefacts from Miqne are summarised in Table 8.8, overleaf. As discussed in Chapter 7, there were a few problems with the reassignment of the artefacts analysed by Williams-Thorpe (n.d.), with a number of artefacts erroneously assigned to samples from the Shaam or Ramon outcrops. These artefacts were reassigned to the next lowest source, which is given in brackets, with round brackets indicating a reassignment from the Shaam outcrops and square brackets from the Ramon outcrops. It can be seen that there are a variety of sources used, with no real correlation between the type of artefact and the source.

It is notable that the provenance of both the EBI bowls is from Mount Hermon, whilst only one artefact from the later periods possibly originates from this source. Although more artefacts need to be analysed before this identification is secure, this possibly indicates a shift in the procurement system, as will be discussed below. The two major sources which appear to have supplied the basaltic artefacts to IA Miqne were the North Jordan Valley and the Galilee area, while the Golan appears to have been a minor source of material. The two main sources provided both bowls and tools, while the Golan appears to have only supplied tools. Only two artefacts appear to have originated from the Kerak Plateau, both of which were tools.

While both bowls and quern-stones appear to have originated from the same sources, with the available data it cannot be determined whether they were procured using the same mechanisms. Nonetheless, as both the Kerak plateau and the Golan area appear to have only supplied tools to Tel Miqne, this strengthens the possibility that separate procurement systems were operating for the different categories of artefact. These procurement systems also appear to cut across the cultural boundaries which have been identified during the IA. This will again be discussed below.

Table 8.8: Provenance of artefacts analysed from Tel Miqne

ID	Artefact	Period	Method	Source	ED
A071	Bowl	EBI	ICP-MS	*Mt Hermon*	*≤50*
A072	4 handled bowl	EBI	ICP-MS	*Mt Hermon*	*≤50*
A060	Quern	LBA	ICP-MS	Kerak	≤75
A055	Bowl	IAI	ICP-MS	NJV	≤75
A066	Pestle	IAI	ICP-MS	*NJV*	*≤50*
A067	Pestle	IAI	ICP-MS	**Kerak**	**≤25**
A068	Rubbing stone	IAI	ICP-MS	**NJV**	**≤25**
A061	Bowl	IAII	ICP-MS	*Galilee*	*≤50*
A062	Drill cap	IAII	ICP-MS	No match	-
A156	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A157	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A158	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A159	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A160	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A161	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A162	Bowl	IA	XRF	**(Galilee)**	**≤25**
A163	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A164	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A165	?Bowl	IA	XRF	*NJV*	*≤50*
A166	?Bowl	IA	XRF	*NJV*	*≤50*
A167	?Bowl	IA	XRF	**NJV**	**≤25**
A168	Mortar	IA	XRF	**NJV**	**≤25**
A169	?Bowl	IA	XRF	*(Mt Hermon)*	*≤50*
A170	?Bowl	IA	XRF	*Galilee*	*≤50*
A171	Altar	IA	XRF	*NJV*	*≤50*
A172	?Bowl	IA	XRF	**Galilee**	**≤25**
A173	?Bowl	IA	XRF	*(Galilee)*	*≤50*
A174	?Quern-stone	IA	XRF	*Golan*	*≤50*
A175	?Quern-stone	IA	XRF	**Golan**	**≤25**
A176	?Quern-stone	IA	XRF	*(Galilee)*	*≤50*
A177	?Quern-stone	IA	XRF	**Golan**	**≤25**
A178	?Quern-stone	IA	XRF	**Golan**	**≤25**
A179	?Quern-stone	IA	XRF	**NJV**	**≤25**
A180	?Quern-stone	IA	XRF	**Golan**	**≤25**
A181	?Quern-stone	IA	XRF	**Golan**	**≤25**
A182	?Quern-stone	IA	XRF	**[Galilee]**	**≤25**
A183	?Quern-stone	IA	XRF	*[NJV]*	*≤50*
A184	?Quern-stone	IA	XRF	**Galilee**	**≤25**
A185	?Quern-stone	IA	XRF	**Galilee**	**≤25**
A186	?Quern-stone	IA	XRF	**Galilee**	**≤25**
A187	?Quern-stone	IA	XRF	**(Galilee)**	**≤25**
A188	?Quern-stone	IA	XRF	**Golan**	**≤25**
A189	?Quern-stone	IA	XRF	**Galilee**	**≤25**
A190	?Quern-stone	IA	XRF	*Galilee*	*≤50*

Tel Rehov

Tel Rehov is one of the largest sites in the central Jordan Valley, and is situated 6 km west of the River Jordan (Mazar 2001) and close to the Galilee and North Jordan Valley outcrops. Six artefacts were analysed, all of which were processing tools. Despite this, a variety of sources have been identified (Table 8.9). Unsurprisingly, a number of the artefacts probably originate from the North Jordan Valley outcrops. One of the tools appears to originate from the nearby outcrop of Ghor al-Katar, although as the Euclidean distance is only ≤50, more samples are required before this assignment can be regarded as secure. If this is confirmed, it will contradict Wright et al. (in press, p.11) who stated that this outcrop was too eroded to have been workable. It is also surprising that none of the, admittedly small, sample of tools appears to originate from the Galilee outcrops, whilst one of the artefacts originates from the Mount Hermon outcrops.

Table 8.9: Provenance of artefacts analysed from Tel Rehov

ID	Artefact	Period	Method	Source	ED
A089	Quern-stone	IAII	ICP-MS	*NJV*	*≤50*
A092	Quern-stone	IAII	ICP-MS	**Mt Hermon**	**≤25**
A093	Saddle quern	IAII	ICP-MS	*Ghor al-Katar*	*≤50*
A094	Mortar	IAII	ICP-MS	**NJV**	**≤25**
A095	Quern	IAII	ICP-MS	NJV/Golan	-
A096	Saddle quern	IAII	ICP-MS	**NJV**	**≤25**

These results therefore seem to indicate that even for basaltic tools the most proximal outcrops were not necessarily or exclusively the source of the raw material. Why this is the case will be discussed further, below.

Tel ‘Ain Zippori

Tel ‘Ain Zippori is situated in the Lower Galilee and was a village site, occupied between the end of the MBA and the middle IAII (Reed 2000). Like Rehov, the sources of the raw material for the basaltic tools are not exclusively the most proximal, with the North Jordan Valley and Mount Hermon, as well as the Galilee, being identified as probable sources (Table 8.10). As it was only possible to analyse a small number of samples the only safe conclusion currently possible is that a number of sources were again used for seemingly utilitarian tools.

Table 8.10: Provenance of artefacts analysed from Tel 'Ain Zippori

ID	Artefact	Period	Method	Source	Variation
A120	Pestle	LBA	ICP-MS	**Mt Hermon**	**≤25**
A122	Handstone	LBA	ICP-MS	*Galilee*	*≤50*
A126	Handstone	LBA	ICP-MS	*NJV*	*≤50*

Hazor

Hazor is situated above the Hula Valley, to the north of the Galilee and Golan outcrops and to the south of the Mount Hermon outcrops and was a major settlement during the LBA and IA (Herr 1997:127). A variety of sources seem to have been exploited (Table 8.11), despite the close proximity of the Mount Hermon outcrops, with the North Jordan Valley supplying two artefacts and the Golan supplying a quern-stone.

Table 8.11: Provenance of artefacts analysed from Tel Hazor

ID	Artefact	Period	Method	Source	Variation
A078	Bowl	LBA	ICP-MS	**Mt Hermon**	**≤25**
A081	Bowl	LBA	ICP-MS	**NJV**	**≤25**
A082	Bowl	LBA	ICP-MS	*Mt Hermon*	*≤50*
A083	Bowl	LBA	ICP-MS	*Mt Hermon*	*≤50*
A075	Bowl	IA	ICP-MS	**NJV**	**≤25**
A076	Quern-stone	IA	ICP-MS	**Golan**	**≤25**
A080	Quern-stone	IA	ICP-MS	*Mt Hermon*	*≤50*
A088	Bowl	IA	ICP-MS	*Mt Hermon*	*≤50*

Wadi Faynan

Philip and Williams-Thorpe (1993 and 2001) were able to analyse 5 samples from sites in the Wadi Faynan area, all dating to the EBI. These sites are associated with copper production, with the major settlement being that of Wadi Faynan 100 (Barker et al. 1999). After reassignment (Table 8.12) it was notable that the Faynan sites appear to have derived most of their bowls from the Kerak plateau. However, these sites also appear to have participated in the wider procurement systems, as reflected by one of the bowls, which has been matched with a Euclidean distance of ≤25 to the North Jordan Valley outcrops.

Table 8.12: Provenance of artefacts analysed from the Faynan area

ID	Site	Artefact	Period	Method	Source	ED
A012	Faynan	Bowl	EBI	XRF	*Kerak*	*≤50*
A013	Faynan	Bowl	EBI	XRF	**NJV**	**≤25**
A025	W. Fidan 4	Mortar	EBI	XRF	**E margin**	**≤25**
A026	W. Faynan 100	Bowl	EBI	XRF	**Kerak**	**≤25**
A027	W. Faynan 100	Rubber	EBI	XRF	*Kerak*	*≤50*

Despite the close proximity of the Wadi al-Hasa outcrops and the other Eastern Margin outcrops, it is notable that only one of the artefacts was manufactured from these sources. This was also noted by Philip and Williams-Thorpe (2001:24) and will be discussed below.

Safi

Safi is situated on a ridge on the south side of the Wadi al-Hasa, south of the Dead Sea(MacDonald 1992:61). The site consists of a large number of cist graves, dating from the EBI, many of which have been disturbed. Finds include, pottery, bones and a number of basaltic bowls (MacDonald 1992:61,64). Seven samples, all of bowls, were analysed by Philip and Williams-Thorpe (1993 and 2001), of which one was re-analysed using ICP-MS. The assignments for these artefacts (Table 8.13), all but one of which vary have Euclidean distances of ≤25, again differ notably from sites in other areas of the southern Levant, with four of the artefacts matching samples from the Kerak plateau and one originating from the Wadi Mujib outcrops.

Table 8.13: Provenance of artefacts analysed from Safi

ID	Artefact	Period	Method	Source	ED
A046	Bowl	EBI	ICP-MS	**Kerak**	**≤25**
A010	Bowl	EBI	XRF	*Kerak*	*≤50*
A011	Bowl	EBI	XRF	**Golan**	**≤25**
A047	Bowl	EBI	XRF	**Galilee**	**≤25**
A048	Bowl	EBI	XRF	**Kerak**	**≤25**
A049	Bowl	EBI	XRF	**Kerak**	**≤25**
A050	Bowl	EBI	XRF	**W Mujib**	**≤25**

This re-analysis of the data therefore supports the general conclusion of Philip and Williams-Thorpe (2001:26) that there was a spatially restricted procurement system for EBI basaltic vessels which operated only in the southern Transjordan. However, there is now evidence that, despite the operation of this localised procurement system, there was still some contact with the broader procurement system, with one bowl appearing to originate from the Golan outcrops and one from the Galilee outcrops, both matched with Euclidean distances of ≤25. This will be discussed below.

Bab edh-Dhra’

Bab edh-Dhra’ is situated on the east shore of the Dead Sea and consists of an EBI cemetery and settlement (Rast 1999:166). Philip and Williams-Thorpe (1993) analysed 9 bowls from this site. Although it was not possible to re-analyse any of these using ICP-MS, they were all reassigned, (Table 8.14); the results of which broadly confirm the original assignments of Philip and Williams-Thorpe (1993:59). One difference is the assignment of three of the samples to the Mount Hermon outcrops. This is therefore more evidence that the local basaltic bowl procurement system was not completely exclusive.

Table 8.14: Provenance of artefacts analysed from Bab edh-Dhra’

ID	Artefact	Period	Method	Source	ED
A001	Bowl	EBI	XRF	**Kerak**	**≤25**
A002	?Bowl	EBI	XRF	**Mt Hermon**	**≤25**
A003	Bowl	EBI	XRF	**Mt Hermon**	**≤25**
A004	Bowl	EBI	XRF	*Kerak*	*≤50*
A005	Bowl	EBI	XRF	**W Mujib**	**≤25**
A006	Bowl	EBI	XRF	Kerak/W Mujib	-
A007	Bowl	EBI	XRF	**Mt Hermon**	**≤25**
A008	Bowl	EBI	XRF	**Kerak**	**≤25**
A009	Bowl	EBI	XRF	**Kerak**	**≤25**

Teleilat Ghassul

Ghassul is situated about 5 km north-east of the Dead Sea and was one of the largest permanent Chalcolithic settlements (Hennessy 1989:230,232). Six samples, three quern-stones and three vessels were analysed by Philip and Williams-Thorpe (2001), of which two were re-analysed using ICP-MS. The three quern-stones could all be matched with Euclidean distances of ≤25 to the local Sweimah outcrops, whilst two of the bowls probably originate from Mount Hermon, whilst one may originate from Galilee, although more geological samples are required to confirm these assignments (Table 8.15).

Table 8.15: Provenance of artefacts analysed from Ghassul

ID	Artefact	Period	Method	Source	ED
A020	Quern-stone	Chalcolithic	ICP-MS	**Sweimah**	**≤25**
A023	Fenestrated bowl	Chalcolithic	ICP-MS	Mt Hermon	≤75
A019	Quern-stone	Chalcolithic	XRF	**Sweimah**	**≤25**
A021	Quern-stone	Chalcolithic	XRF	**Sweimah**	**≤25**
A022	Fenestrated bowl	Chalcolithic	XRF	Galilee	≤75
A045	Fenestrated bowl	Chalcolithic	XRF	*Mt Hermon*	*≤50*

These assignments confirmed those made by Philip and Williams-Thorpe (2001:24), who noted the “clear distinction” between the origin of the tools from local outcrops, and the bowls from non-local sources, including one phosphorite bowl. This dichotomy of sources will be further discussed below.

Tell Iktanu

Tell Iktanu was a large EBI settlement and is situated about 10 km north-east of the Dead Sea (Prag 1989a:275f). It is notable that, despite the small sample size, all four of the bowls appear to originate from the North Jordan Valley outcrops (although the assignments for A127 and especially A128 are not secure), while the two tools probably originate from the Ma’in and Kerak outcrops. There therefore appears to be a distinction between the sources used for the two main artefact categories (cf. Philip and Williams-Thorpe 2001:24), although further samples are required to test this hypothesis.

Table 8.16: Provenance of artefacts analysed from Tell Iktanu

ID	Artefact	Period	Method	Source	ED
A127	Bowl	EBI	ICP-MS	*NJV*	*≤50*
A128	Bowl	EBI	ICP-MS	NJV	≤75
A129	Pestle	EBI	ICP-MS	*Ma’in*	*≤50*
A132	Handstone	EBI	ICP-MS	*Kerak*	*≤50*
A134	Bowl	EBI	ICP-MS	**NJV**	**≤25**
A135	Bowl	EBI	ICP-MS	**NJV**	**≤25**

Pella

Pella is located by a perennial spring in the foothills on the east side of the Jordan Valley, less than 30 km south of the Sea of Galilee (Bourke 2001:117). Eight samples were analysed, from a number of periods (Table 8.17). Each of the periods appears to only have exploited a single source for their bowls, but this is probably due more to the small sample size than to any correspondence with reality. The procurement of artefacts from the North Jordan Valley is unsurprising given the close proximity of these sources to the site, although the probable use of Kerak as a source for bowls during the IAI had not previously been suspected.

Table 8.17: Provenance of artefacts analysed from Pella

ID	Artefact	Period	Method	Source	ED
A104	Fenestrated Bowl	L Chalcolithic	ICP-MS	**NJV**	**≤25**
A106	Bowl	L Chalcolithic	ICP-MS	*NJV*	*≤50*
A101	Bowl	LBI-II	ICP-MS	**NJV**	**≤25**
A108	Bowl	IAI	ICP-MS	*Kerak*	*≤50*
A109	Bowl	IAI	ICP-MS	*Kerak*	*≤50*
A105	Bowl	IAI-II	ICP-MS	Galilee	≤75
A115	Bowl	IAI-II	ICP-MS	No match	-
A116	Bowl	IAII	ICP-MS	No match	-

The inability to source any of the IAI-II or IAII artefacts with any degree of certainty shows the need for further analyses of the basaltic outcrops in the region. It is also worth noting that these three samples also do not correspond closely to each other, thereby probably indicating that they originate from distinct outcrops.

Tell esh-Shuna

Shuna is located on the east bank of the Jordan Valley, at the foot of the northern uplands and was occupied during both the Chalcolithic and EBI (Baird and Philip 1994:111,131f). Six new samples were analysed, whilst 8 samples had been analysed by Philip and Williams-Thorpe and were reassigned, as shown in Table 8.18. Despite the close proximity of the North Jordan Valley, a substantial number of the EBI bowls were probably procured from the Mount Hermon outcrops. Although there are only four Chalcolithic samples, only one of these even possibly originates from the Mount Hermon outcrops. This could indicate a shift in procurement systems away from more proximal outcrops, although more samples are required to test this suggestion.

Table 8.18: Provenance of artefacts analysed from Tell esh-Shuna

ID	Artefact	Period	Method	Source	ED
A148	Bowl	Chalcolithic	ICP-MS	*E Margin*	*≤50*
A149	Bowl	EBI	ICP-MS	**Mt Hermon**	**≤25**
A150	Bowl	EBI	ICP-MS	*Mt Hermon*	*≤50*
A152	Bowl	EBI	ICP-MS	*Mt Hermon*	*≤50*
A153	Bowl	EBI	ICP-MS	*Mt Hermon*	*≤50*
A154	Bowl	EBA	ICP-MS	*Mt Hermon*	*≤50*
A033	Bowl	Chalcolithic	XRF	*Mt Hermon*	*≤50*
A034	Bowl	Chalcolithic	XRF	*NJV*	*≤50*
A036	Mortar	Chalcolithic	XRF	**NJV**	**≤25**
A035	Bowl	EBI	XRF	**NJV**	**≤25**
A032	Bowl	EBI	XRF	*Mt Hermon*	*≤50*
A051	Bowl	EBI	XRF	**NJV**	**≤25**
A052	Bowl	EBI	XRF	*Mt Hermon*	*≤50*
A053	Bowl	EBI	XRF	*Mt Hermon*	*≤50*

Sal

Sal is situated in northern Transjordan, south of the Harrat ash Shaam plateau. It is an extensive, unexcavated Chalcolithic site, with a large surface scatter of artefacts (Philip and Williams-Thorpe 1993:54). Three samples were analysed by Philip and Williams-Thorpe (1993), whilst one was re-analysed using ICP-MS. Despite the proximity to the North Jordan Valley outcrops, at least one of the samples is from the Galilee outcrops, whilst neither of the two North Jordan Valley samples that are the probable or potential sources derive from the most proximal outcrops. A017 most closely resembles a sample taken from the Adasiyeh outcrop and A015 could originate from the Wadi ‘Arab outcrop, both of which are situated near the Jordan Valley, east of Sal.

Table 8.19: Provenance of artefacts analysed from Sal

ID	Artefact	Period	Method	Source	ED
A015	Bowl	Chalcolithic	ICP-MS	Galilee/NJV	-
A017	Bowl	Chalcolithic	XRF	**NJV**	**≤25**
A018	Bowl	Chalcolithic	XRF	**Galilee**	**≤25**

Maadi

Philip and Williams-Thorpe (2001) were also able to analyse one sample, a spindle whorl, from the Egyptian delta site of Maadi, contemporary in date with the Levantine Chalcolithic (Philip and Williams-Thorpe 2001:26). When reassigned, this artefact (A024) could be matched, with a Euclidean distance of 18.27, to a sample from the Galilee outcrops. This concurs with the original assignment (ibid.).

Procurement systems

The above discussion of the provenance of the analysed artefacts on a site-by-site basis has revealed that all of the sites appear to have procured their basaltic artefacts from a variety of different outcrops, not necessarily, or indeed usually, the most proximal sources. This observation raises the question of why the most proximal source was not always used. To answer this, two main reasons can be suggested. The first is that a more distant source has superior physical properties (cf. Chapter 5) which are sufficient to justify the extra effort required to procure this material. The second is that social factors, such as a lack of appropriate skill, knowledge and technology, or a desire to maintain contacts with another group, or some perceived difference between the local and exotic source, renders it socially inappropriate or impossible to utilise the local source (cf. Bradley and Edmonds 1993:205f). These reasons are by no means mutually exclusive, not least as value-judgements about what constitute ‘superior properties’ and what level of extra effort ‘justifies’ the use of a non-local source are themselves at least partially social constructs.

An obvious place to start attempting to determine which of these reasons were the most important in the present cases is an examination of the physical properties of the various outcrops. As discussed in Chapters 6 and 7, there is very little data on the physical properties of the different mafic rock types. The tests undertaken as part of this thesis (discussed in Chapter 7) suggest that nephelinite would have been noticeably harder and more prone to unpredictable fractures than the other rock types, making it more difficult to work. This may well help to explain the observation, made by both this study and Philip and Williams-Thorpe (2001:24), that the closest (nephelinite) outcrops to the Faynan area were not exploited, despite their ready availability. There were not enough samples to determine the merits or demerits of the other rock types, but it was notable that the vesicular basalt sample was significantly weaker than the non-vesicular basalt. However, vesicular basalt could well be prone to more unpredictable fracture due to the vesicles, making it more difficult to work. Nonetheless, some bowls were manufactured from vesicular basalt (cf. Chapter 6). More thorough testing of the physical properties of the different rock types is required, which may well give a better understanding of the technological choices involved in the manufacture of the different artefact types. Nevertheless, the preliminary data suggests that, for most sites, the varying physical properties of the rocks would not have been a primary factor in choosing a more distant outcrop over the most proximal outcrop.

Therefore, to examine the operation of the procurement systems more clearly and to attempt to identify any diachronic or synchronic differences, the data discussed above will now be summarised by period and area.

Chalcolithic

In the southern Cisjordan, a large number of the Chalcolithic artefacts from Safadi and Abu Matar appear to originate from the Mount Hermon outcrops. This probably indicates a predominately maritime procurement system, given the other evidence for this (Philip 2002:223) and the bulky nature of basaltic rock. However, there are also artefacts which probably originate from the North Jordan Valley and Galilee, especially for the XRF-analysed artefacts. Whether these artefacts were transported exclusively overland or using a mixture of land and seaborne transport is impossible to determine. The circumstantial evidence is also somewhat ambiguous. Only one Chalcolithic artefact was analysed (using XRF) from both Tell Erani in central Cisjordan and Maadi in the Egyptian Delta. Both of these artefacts originate from the Galilee outcrops, which could suggest the partial seaborne transport of the artefacts between the outcrops and the Delta. However, both Shuna and Ghassul in the Jordan Valley have bowls originating from Mount Hermon, thereby suggesting an overland system from this outcrop. This possibility is strengthened as the southern Cisjordan sites are situated inland and by the evidence for the overland transport of phosphorite artefacts in the area, reaching as far as

Ghassul (discussed in Chapter 6). To attempt a more comprehensive answer to this question requires the examination of the number and frequency of basaltic artefacts on these sites. From this it should be possible to examine the fall-off curves and determine the most likely direction and type of procurement system. However, as has been frequently reiterated, this data is not currently available.

As already briefly discussed, the majority of the Chalcolithic bowls analysed from the site of Ghassul appear to originate from the Mount Hermon outcrops, while the quern-stones originate from the local outcrops of Sweimah. This is clear evidence for the existence of separate procurement systems, with direct procurement operating for the quern-stones and some form of indirect procurement operating for the bowls. This therefore raises the question of why the bowls were being transported approximately 100 km from their source to a site situated less than 5 km from outcrops of useable basaltic rock! The main reason for this is almost certainly the desire to maintain social relations with the other individuals or groups involved in the exchange network which must have operated, as was also observed by Bradley and Edmonds (1993:205f) in their study of British Neolithic stone axes. A secondary reason may have to do with the potentially superior physical properties of the basalt available at the non-local outcrops compared to the basanite available at the local outcrops. However, this is somewhat speculative and is unlikely to have been a major factor, especially as the basanite was worked to produce quern-stones.

In northern Transjordan, it was possible to analyse basaltic artefacts dating from the Chalcolithic from the sites of Pella, Shuna and Sal. The majority of these appear to originate from the North Jordan Valley outcrops, although one XRF-analysed bowl from Sal originates from the Galilee outcrops, whilst from Shuna one (ICP-MS-analysed) bowl probably originated from the Eastern margin outcrops and one (XRF-analysed) bowl appears to originate from the Mount Hermon outcrops. Therefore, even for sites situated near outcrops which supplied the raw material for artefacts found throughout the southern Levant, basaltic artefacts were imported. This is again clear evidence that social factors were important in the operation of basaltic procurement systems.

Early Bronze I

Unfortunately, no EBI artefacts have so far been analysed from the southern Cisjordan sites, but from the central Cisjordan site of Tell Miqne two bowls have been analysed, both of which appear to originate from Mount Hermon. Three artefacts were also analysed (by XRF) from Tell Erani, one of which appears to originate from Mount Hermon, whilst the other two are from the North Jordan Valley outcrops. This seems to suggest a basic continuity in the procurement systems to central and southern Cisjordan, with a significant maritime component probably remaining important.

It was possible to analyse a number of artefacts from sites in the Faynan area of southern Transjordan. Two of the XRF-analysed bowls and a handstone probably originate from the Kerak plateau outcrops, while a mortar is from the local eastern margin outcrops. This artefact most closely matches G287, a melanephelinite sample, and is described by Philip and Williams-Thorpe (2001:23) as a "mortar-type vessel with curved sides". This shows that melanephelinite could be successfully worked, although only experimental work can demonstrate how easily this was undertaken. Whether the workability of the local outcrops was the main factor in the choice to procure vessels from Kerak is debatable, but experimental and rock property studies could demonstrate if this was a contributing factor, by providing more data on whether, as suspected, there was a significant difference between the rock properties of these outcrops.

One bowl appears to originate from the North Jordan Valley, which contradicts Philip and Williams-Thorpe's (2001:24) suggestion that the sites in southern Transjordan did not participate in the wider basaltic procurement system. However, the data does support the general conclusion of Philip and Williams-Thorpe (2001:26) that there was a spatially restricted procurement system for EBI basaltic vessels that operated only in the southern Transjordan. This is also shown by the sites of Safi and Bab edh-Dhra', where, although most of the bowls appear to originate from Kerak or the Wadi Mujib, a number of XRF-analysed bowls probably originate from the Mount Hermon outcrops, with one probably originating from the Galilee outcrops and one from the Golan outcrops.

Again, this shows that the regional procurement system from Kerak predominated, but that there was also a limited amount of contact with the procurement systems which operated throughout the rest of the southern Levant. Two explanations for the relative isolation of these sites (at least in terms of basaltic-rock procurement systems) are either widespread import-substitution or the preferential operation of a local, exclusionary procurement system. To investigate these possibilities contextual and typological data are required. If artefacts from more distant sources were preferentially treated or are only found in higher-status contexts, then the import substitution of artefacts for the local sub-elites becomes more likely. If stylistic differences between the Kerak-produced bowls and the other bowls could be demonstrated, and these locally produced styles were preferentially acquired, then the preferential operation of a local procurement system becomes more likely. If there is no difference between the Kerak-produced and other artefacts, either contextually or stylistically, the most likely explanation is that all of the artefacts were procured by the same mechanism (with freelance traders, possibly as part of seasonal movement, being the most probable source) and that the maintenance of this mechanism was more important that the origin of the artefacts. Unfortunately, the required data is not currently available.

In central Transjordan, EBI basaltic artefacts were analysed from Iktanu, with all four of the bowls appearing to originate from the North Jordan Valley outcrops, whilst a pestle probably originated from the Ma'in outcrops and a handstone probably came from the Kerak plateau. Although the sample size is only small, it appears to indicate the general exploitation of the local outcrops, and some exploitation of the outcrops to the south. However, it is notable that even the tools do not appear to originate from the most proximal outcrops, despite the Chalcolithic exploitation of the Sweimah outcrops for quern-stones. If these patterns are confirmed when more artefacts are analysed, this suggests that even for seemingly utilitarian tools the creation and maintenance of social relations through procurement systems was more important than the 'economic' manufacture and procurement of tools.

In northern Transjordan, EBI basaltic artefacts were analysed from Shuna, where the vast majority of bowls appear to originate from Mount Hermon, while two XRF-analysed artefacts appear to originate from the North Jordan Valley outcrops. This seems to indicate a shift in emphasis from the Chalcolithic procurement of local artefacts to more long-range contacts with the Mount Hermon area. This is in contrast to the procurement patterns tentatively identified from EBI Iktanu.

Late Bronze Age

Only a few artefacts have so far been analysed dating to the LBA, making it even more difficult to determine any trends in the data. From Miqne, central Cisjordan, one quern was analysed, which possibly originates from the Kerak outcrops, although this has not been securely provenanced.

In northern Cisjordan, artefacts were analysed from the sites of Zippori and Hazor. From Zippori, one pestle originates from the Mount Hermon outcrops, whilst one handstone probably originated from the North Jordan Valley and another probably from the local Galilee outcrops. From Hazor, three of the four bowls probably originate from the local Mount Hermon outcrops, whilst one has been sourced to the North Jordan Valley outcrops. In northern Transjordan, only one LBA bowl from the site of Pella has been analysed, which originates from the North Jordan Valley outcrops. These observations again show the exploitation of a mixture of local and non-local sources for all the sites.

Iron Age

From central Cisjordan, a number of artefacts from Miqne were analysed using ICP-MS, with both a bowl and tools probably originating from the North Jordan Valley and one pestle seeming to originate from the Kerak plateau. One bowl also may have originated from the Galilee outcrops. As discussed previously, the provenance of the artefacts analysed by Williams-Thorpe (n.d.) is less secure than the other artefacts examined in this thesis, but most of these artefacts appear to originate from either the North Jordan Valley or Galilee outcrops. This appears to be a shift in procurement systems, with very few artefacts originating from Mount Hermon, especially as the artefacts analysed by Williams-Thorpe (n.d.:1) were spread throughout the IA.

As indicated above, clear cultural boundaries have been identified during the IA between the Philistine and other polities in the southern Levant (Dothan and Gitin 1997:30) Despite this, half of the ceramic repertoire at these sites consists of the local Levantine forms (Stager 1995:334). It is therefore unsurprising that the basaltic procurement systems, as shown from Miqne, also cut across these boundaries, especially as the southern Levant was a major exporter of basaltic quern-stones from the LBA onwards (Chapter 2; Williams-Thorpe et al. 1991;1993). It is therefore probable that basaltic artefacts were not used as inter-cultural markers (cf. Jones 1997:114f,128), but were used as some form of status symbol, given their exotic origin and superior physical qualities. These qualities would have made even basaltic quern-stones a desirable commodity and therefore a potential status marker, as quern-stones were still routinely manufactured from local rock types (cf. Chapter 6).

From northern Cisjordan, IA artefacts were analysed from Hazor and Rehov. From Rehov, the analysed quern-stones and mortar mostly came from the North Jordan Valley with one appearing to originate from the Jordan Valley outcrop of Ghor al-Katar, and one originating from Mount Hermon. If the source of one of the quern-stones is confirmed as Ghor al-Katar then this could well be evidence for the local exploitation of an inferior source of material (cf. Wright et al. in press, p.11). From Hazor, a bowl and a quern-stone probably originated from Mount Hermon, one quern-stone came from the Golan outcrops and one bowl originated from the North Jordan Valley. This again shows the use of both local and non-local sources.

For northern Transjordan, artefacts were analysed from Pella, with two bowls possibly originating from the Kerak outcrops, and one possibly originating from the Galilee outcrops. Two of the bowls did not match any of the available geological samples. As the two bowls from Kerak are IAI in date and the others are from the IAII this could suggest a shift in procurement systems, but this is more probably due to the small sample size.

Summary

The examination of the element ratio and element plots in Chapter 7 showed that most of the artefacts clustered into groups, whilst their compositional range was significantly narrower than that of the basaltic outcrops. The observations made in Chapter 7 and in this chapter strongly indicate the deliberate choice of certain outcrops (also observed by Philip and Williams-Thorpe 2001:20). As Philip and Williams-Thorpe (2001:26f) also found, there is no real correlation between the location of the site and the source of the basaltic artefacts, even for tools such as quern-stones and pestles. Whilst some of these may be broken and re-worked bowls, the provenances of these artefacts is probably indicative of more complex procurement systems, even for seemingly utilitarian artefacts, than has been previously envisaged.

Figs 8.1 and 8.2, below, show the range of sources identified as being used for the Chalcolithic and EBI artefacts. It can be seen that, overall, there is a good level of agreement between the ICP-MS and XRF-analysed artefacts, both of which indicate that only a limited number of source outcrops were used during these periods. The identification of the Galilee as a significant source for the XRF-analysed artefacts is probably a genuine difference in the artefacts analysed, rather than a misidentification due to the differing methodologies.

Fig 8.1: Identified sources of the Chalcolithic and EBI ICP-MS-analysed artefacts

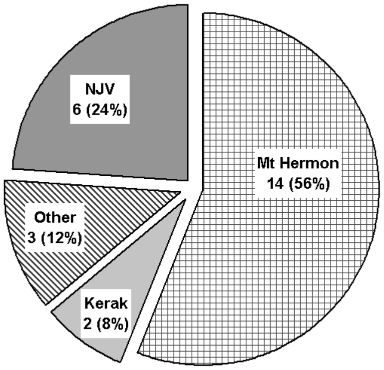
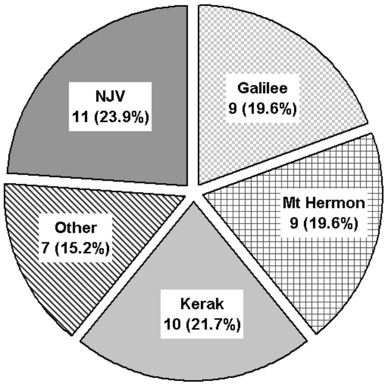


Fig 8.2: Identified sources of Philip and Williams-Thorpe's (1993 and 2001) artefacts



Sites in central and southern Cisjordan probably received most of their basaltic vessels via seaborne transport. There is considerable evidence for merchant ships operating along the Levantine seaboard and to the Egyptian Delta (Philip 2002:223) which could have also transported basaltic artefacts. The artefacts could then have been moved inland, probably using donkey trains. This hypothesis could be examined by a calculation of the quantities and relative proportions (to similar, but non-basaltic, stone artefacts) of these objects. If this examination was coupled with provenance analyses, it could reveal whether the basaltic rock from the different outcrops was procured in the same way. For example, if the Mount Hermon artefacts (some 200 km north of the sites) were transported by sea, while the Galilee and North Jordan Valley artefacts were transported overland, then different proportions of artefacts from these sources should be expected at the coastal and inland sites. If artefacts from all three outcrops were transported either overland or by sea, then the proportions should be roughly consistent, but the fall-off curves should be indicative of the route taken. Unfortunately, a much larger quantity of samples is required before such an examination could be undertaken.

For sites in southern Transjordan, the outcrops of the Kerak plateau were preferred as the source of the basaltic artefacts, both for bowls and tools, but more local outcrops were also used to provide tools, and there is also some evidence for the limited participation of these sites in the wider basaltic procurement systems.

Sites in the rest of the southern Levant, regardless of their proximity to useable basaltic outcrops, generally participated in complex procurement systems, acquiring their basaltic artefacts from a variety of sources. This was almost certainly due to a desire to maintain social relations with other groups. The alternatives, that there were problems with either the physical properties of the rocks at the more proximal outcrops or a lack of suitably skilled craft workers, can be disregarded, as many of the sites were close to outcrops that were also being exploited.

Figs 8.3 and 8.4 show the range of sources identified as being used for the LBA and IA artefacts. There are significant differences between the sources identified from the ICP-MS-analysed artefacts from a range of sites, and the XRF-analysed artefacts from IA Tel Miqne.

Fig 8.3: Identified sources of the LBA and IA ICP-MS-analysed artefacts

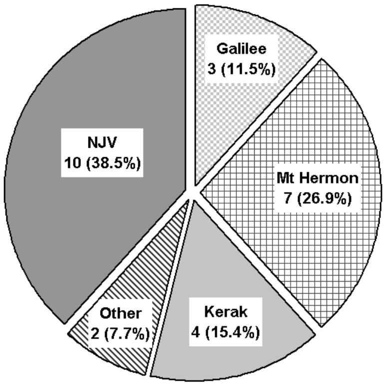
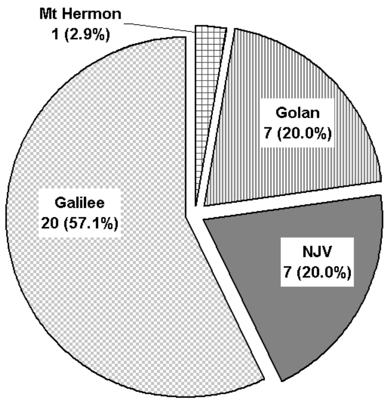


Fig 8.4: Identified sources of Williams-Thorpe's (n.d.) artefacts



When comparing the sources identified for the ICP-MS-analysed artefacts from the Chalcolithic-EBI and LBA-IA it is noticeable that, although a few more sources were used, there appears to be a basic continuity in the exploitation of certain sources. This is contradicted by the XRF-analysed artefacts from IA Tel Miqne (Fig 8.4). As discussed in Chapter 7, it is currently unclear whether this is due to the large number of artefacts analysed from one site revealing a more complex picture of acquisition from different sources, or whether there are misidentifications due to the limited number of elements analysed by Williams-Thorpe (n.d.). This can only be resolved by the re-analysis of these artefacts or the analysis of more samples.

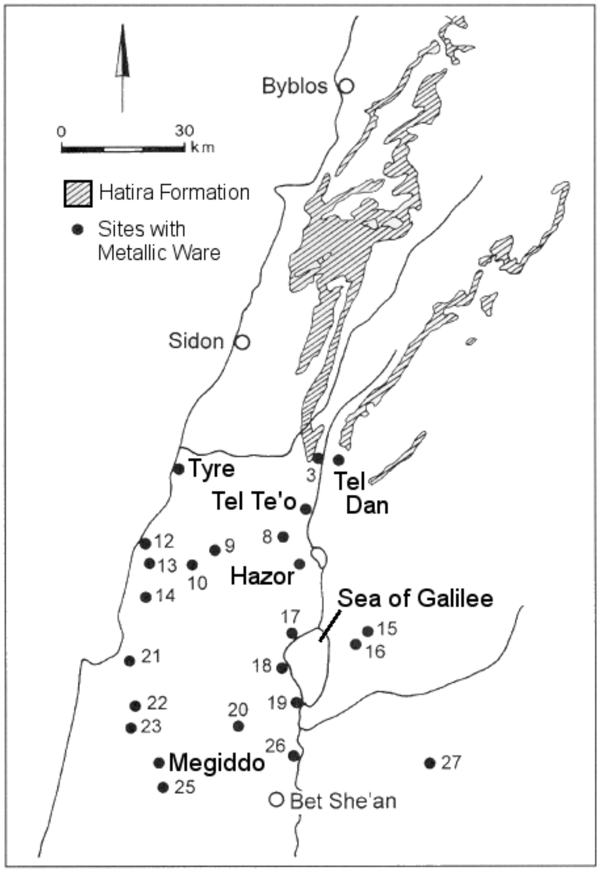
Nonetheless, during the LBA and IA, for Miqne in central Cisjordan there appears to be a shift in procurement systems away from the Mount Hermon outcrops and towards the North Jordan Valley and Galilee outcrops. This possibly represents a shift from a maritime to an overland system, perhaps due to the decreasing costs of donkey trains which enabled a variety of goods to be more easily transported (cf. Monroe 2000:78; Petit 2001). It is notable that, away from the basaltic outcrops, quern-stones were still predominately manufactured from local rock types (see Chapter 6), showing that the transport costs of basaltic quern-stones were still too high for them to be widely distributed.

The northern Cisjordan sites procured artefacts from the Mount Hermon outcrops (showing that these were still exploited) and the North Jordan Valley outcrops. The Kerak outcrops appear to have been more widely exploited, with artefacts from both Miqne and Pella provenanced to this location. Although it was possible to only analyse a limited number of samples from these periods, the results show that further analysis would be rewarding, as there is again no clear correlation between site location and the outcrops exploited.

The Mount Hermon outcrops

The identification of Mount Hermon as a source of basaltic artefacts was previously unsuspected, not least due to its remote location from the rest of the southern Levant and the limited number of sites in the area during the Chalcolithic and EBI (Greenberg 2002:73f). Furthermore, the role of this area in procurement systems is particularly interesting, as it was also the source of two unusually widespread pottery traditions, namely the Metallic Ware of the EBII and the Chocolate-on-White Ware of the MBII to LBIB. These two pottery types are petrographically identical and were manufactured from the distinctive clay of the Lower Cretaceous Hatira Formation, whose southernmost outcrops are on the southern slopes of Mount Hermon (Fig 8.5; Fischer 1999:23; Greenberg 2002:48).

Fig 8.5: Outcrops of the Hatira Formation and southern Levantine EBII sites with Metallic Ware



After Greenberg and Porat (1996:11).

Metallic Ware is unusual in that it occurs in large quantities (from 50% to over 85% of the total assemblage) at many sites in the Galilee, the Hula valley, northern Transjordan and southern Lebanon areas during the EBII period (Fig 8.5; Greenberg and Porat 1996:5). Greenberg and Porat (1996:18) report on the results of petrographic analysis of the pottery, which shows the most likely source area was the southern slopes of Mount Hermon, exactly the same area which appears to have been used for the manufacture of basaltic artefacts. Greenberg and Porat (1996:18) argue that groups using the Mount Hermon area would have pursued craft specialisation, due to the limited amount of agricultural land available. Furthermore, Dar (1993:1) notes that the climatic conditions are different to most areas of the southern Levant with "excessive cold, rainfall, snow, fog, and fierce winds", thereby providing a further encouragement for non-agricultural specialisation. Greenberg and Porat (1996:19f) go on to argue that this specialisation only started with an influx of settlers to the area in EBII. They also acknowledge that this does not explain the monopolisation of ceramic production over such a wide area, although Dessel and Joffe (2000:43) argue that the distribution of Metallic Ware is probably due to a mutually reinforcing ceramic and commodity exchange system.

However, Dar (1993:11) reports that Chalcolithic sites have been recognised in the Beq'a Valley, on the northwest side of Mount Hermon and also reports that one Chalcolithic site (Jebel Shaq al-Arus) has been identified on the southern slopes of Mount Hermon. This site was dated primarily by a pillar figurine, resembling those discovered in the Golan and therefore suggesting contact between these areas. Shaq al-Arus is a few hundred metres north of Tel Dan (Fig 8.5) and a few kilometres west of the basaltic outcrops, as shown in Plate 14. This is part of the Israeli archaeological survey map of the area, overlain by Wilson et al's (2000:56) map of the basaltic outcrops (Fig 4.8). On this map, location 116 is the sample location of G160, which is the nearest, most accessible outcrop to Shaq al-Arus, being only about 5 km distant. Furthermore, Greenberg (2002:73f) reports that 19 EBI occupation sites and at least 5 Chalcolithic sites have also been identified in the area. Greenberg (2002:86) argues that the only evidence of external contacts is that of Grey Burnished Ware (cf. Chapter 6), with one vessel being provenanced to the central Jordan Valley. To this evidence of contact should be added the pillar figurine and, more extensively, the widespread evidence of basaltic artefacts originating from Mount Hermon.

Therefore, contrary to Greenberg and Porat, it can be argued that there is evidence for the (at least part-time) specialist manufacture of basaltic artefacts during the preceding Chalcolithic and EBI. Greenberg (2002:45) reports that the manufacture of Metallic Ware started during the Late EBI in a few limited forms, but also reports that his survey shows that there was a rapid decline in settlement in the Mount Hermon area during this same period (Greenberg 2002:87). This is the same period when there was also a decline in the production of basaltic vessels throughout the southern Levant (see Chapter 6). Whether these two events are linked and, if so, which caused the other cannot be determined with the available data, and is outside the scope of this study. However, it is possible to speculate that with the decline in the demand for basaltic vessels people either left the area or switched to pottery production, possibly attempting to exploit the pre-existing exchange network and maintain their social and economic relations with other groups (cf. Dessel and Joffe 2000:43). The growth in demand for Metallic Ware then encouraged a resettlement of the valley, allowing more Metallic Ware to be produced and distributed. This could help to explain how the mutually reinforcing exchange system (Dessel and Joffe 2000:43) began to function and so explain the unusually widespread adoption of Metallic Ware. Whether or not this hypothesis is proven to be correct, the discussion illustrates the greater understanding of the past provided by provenance studies.

This evidence for the participation of the Mount Hermon settlements in long-term, inter-area procurement systems is further strengthened by Fischer's (1999) analysis of Chocolate-on-White Ware. This was widely distributed in the southern Levant between the MBII and LBIB. Fischer concluded that much of the Chocolate-on-White Ware originated from the Mount Hermon area (with another source being in the Jordan Valley) and utilised the same clay as that used to manufacture the much earlier Metallic Ware. He concluded that the provenance of Metallic Ware and Chocolate-on-White Ware was evidence for the "intense, enduring trade" between Mount Hermon and the Jordan Valley (Fischer 1999:23).

Furthermore, Fischer (1999:22) reported that there were few examples of Chocolate-on-White Ware in the northern Levant, despite the close proximity of the Mount Hermon area. He (Fischer 1999:23) also commented that it is unclear how this exclusive product could have been afforded by the consumers, and what was given in exchange for the pottery. These questions and observations also apply to basaltic artefacts.

Nonetheless, the identification of the relatively remote area of Mount Hermon as a major source of artefacts is by no means unique. As was discussed in Chapter 2, both the obsidian workshop of Kaletepe (Binder and Balkan-Atli 2001) and the stone axe workshops of the Greater Langdale (Bradley and Edmonds 1993) provide parallels. Bradley and Edmonds (1993:206) argue that a significant factor in the continuing importance of the Greater Langdale as a source of stone axes was precisely its remote location, whilst two of the other important Neolithic stone axes sources (Graig Lwyd and Rathlin Island) could only be reached by boat (Bradley and Edmonds 1993:42). It therefore seems that the fact that exchange was occurring was almost as important as what goods were actually being exchanged. In turn, this raises the question of how this procurement system actually operated.

Procurement mechanisms

This question is not confined to the Mount Hermon area, but applies across to all the sites for which artefacts have been analysed. As noted by Philip and Williams-Thorpe (2001:27) and discussed above, different categories of basaltic artefacts would probably be procured by different mechanisms. This is especially the case for sites closer to outcrops, where direct procurement as well as exchange was possible. Therefore, a range of procurement mechanisms will have operated simultaneously.

Philip and Williams-Thorpe (2000:1387) argued that the procurement of Chalcolithic and EBI basaltic vessels should be seen as part of the creation and maintenance of long-range social and political connections. Furthermore, as discussed in Chapter 5, as gift-giving creates and maintains relations with other groups, exchange of other goods can be more easily undertaken. Furthermore, successful external relations can enhance the prestige and power of an individual within their own group (Lewis 1985:201,204). This web of social, political and economic motives can help explain the otherwise seemingly bizarre situation of sites near to vessel-producing outcrops procuring basaltic vessels from hundreds of kilometres away. This is especially the case given the widespread nature of the basaltic vessels and the virtual absence of basaltic quern-stones and other tools from sites not in close proximity to the outcrops. It can also help explain why continuing links with the Mount Hermon area were desirable, despite a shift from Chalcolithic and EBI rock vessels to EBII pottery vessels, with the acquisition of exotic artefacts being more important than the exact nature of the exotica acquired (cf. Bradley and Edmonds 1993:206).

As also discussed in Chapter 5, people from many sectors of society may have acquired valued artefacts (by a variety of means), which were commensurate with their (socially-constructed) means and desires. This understanding could help explain the widespread distribution of a seemingly valuable class of artefacts such as basaltic vessels. The literature reviewed in Chapter 5 suggests two potential mechanisms which could have operated to produce the observed distribution of basaltic vessels. Either, the bowls were originally acquired by the local elites, before losing some of their value (perhaps through over-production), and so being acquired by the sub-elites of the society. This is especially applicable to basaltic artefacts, given their durability. Alternatively, the basaltic bowls were acquired directly by the sub-elites in emulation of the societal elites who were participating in the exchange of other categories of goods. If the EBI was heterarchical (Philip 2001:189), then these two mechanisms could still operate, but with different sectors of society involved, rather than elites and sub-elites. To determine which, if either, of these mechanisms was actually operating requires analysis of the contexts in which the bowls are found, and an examination of whether these alter through time.

Whether quern-stones were procured through gift-giving or some other means of exchange is currently unclear. It is possible that basaltic tools, especially quern-stones, could have been gifts, given that their rarity and superior physical properties would have enhanced an individual’s social standing, thereby making a basaltic quern-stone a suitable gift (possibly as part of a dowry?). This suggestion is strengthened by the later textual evidence for this practice (Chapter 6; Wright 2000:115). A wider variety of procurement mechanisms probably operated synchronically for the acquisition of basaltic tools, depending on the site and individual in question. For example, the evidence from Ghassul seems to indicate the direct procurement (or intra-site exchange) of tools from the local outcrops. Evidence from the Faynan sites seems to suggest that even some tools were preferentially procured from the Kerak outcrops, rather than from more proximal outcrops.

As discussed in Chapter 6, during the LBA and IA there was wide-scale inter-regional procurement of basaltic artefacts, mostly, although by no means exclusively, through economic mechanisms (Williams-Thorpe and Thorpe 1993; Petit 2001). It is therefore probable that this was also the case in the intra-regional procurement of basaltic artefacts. Basaltic artefacts appear to have still been valued, given this long-distance trade and their inclusion in temple and mortuary contexts. Gift exchange, including in dowries, also operated, as shown in the available texts from these periods (Wright 2000:115). Given the continuing value of the artefacts, atypical procurement strategies (such as gambling; DeBoer 2001) may also have been utilised during any or all the periods in question. These reasons can also help explain why the most proximal outcrop of basaltic rock was not exclusively exploited. Furthermore, it is probable that a number of specialist workshops existed which produced basaltic artefacts, which, coupled with the ready availability of donkey trains (Monroe 2000:78), would probably have reduced the transport costs to levels where factors other than distance became more important.

‘Life cycles’ of artefacts

This provenance study has been able to reveal the likely source outcrop for a considerable number of the analysed basaltic artefacts. Unfortunately, it has not been able to determine with any certainty the mechanism by which they were distributed. Furthermore, as discussed in Chapter 5, distribution is only one aspect of the complex web of actions and choices which makes up the ‘life cycle’ of an artefact (Fig 5.4). However, most of the contextual and quantitative data necessary to understand this history, including distribution, is not currently available for basaltic artefacts. Given the durability of basaltic rock and the value placed on at least some of the artefacts, it is likely that they were curated for a considerable period of time, which could well have involved the redistribution of an individual artefact several times before its eventual deposition. This may well confound attempts to fully understand how the procurement systems operated. Nonetheless, this study has shown that a relatively few basaltic outcrops were preferentially exploited for long periods of time. This provides a much reduced area within which to conduct detailed investigations in order to locate the quarries and primary workshops which produced the artefacts. This would greatly aid the understanding of how the production and distribution of basaltic artefacts was organised.

Goren and Zuckerman (2000:176) speculate that Grey Burnished Ware was used more for decorative or social purposes than for everyday use and suggest that it was used only on special occasions, to reinforce the significance of a social event. As discussed in Chapter 6, it is probable that the EBI Grey Burnished Ware appropriated some of the functions of basaltic vessels, so these artefacts were probably used for similar functions, both in the Chalcolithic and EBI. It is even possible that basaltic vessels and Grey Burnished Ware vessels were used in conjunction during the EBI. This could also help explain the inclusion of both of these artefact types in mortuary contexts.

Experimental studies

As discussed in previous chapters, experimental and ethnoarchaeological data can aid interpretations of likely artefact usage. Although such studies were largely outside the scope of this study, one very small-scale experiment was attempted. Epstein (1998:17) reported that basaltic rock and soil quickly turn bright red when burnt and that the basaltic hearth stones were a pinkish colour, but did not discuss this observation any further. This offered the potential for determining whether or not any of the artefacts had been in a fire and, more speculatively, the possibility of whether any of the artefacts had been used as an incense burner.

To investigate this possibility, one of the unanalysed geological samples (G074) was selected for testing. G074 was selected as it was a slightly vesicular alkali basalt sample from the North Jordan Valley outcrops, which, of the available rocks, most closely resembled the majority of the actual artefacts. It was also relatively unweathered, was dark grey in colour, and had a flat surface, enabling the incense to be burnt more easily. Frankincense resin was chosen as it is commercially available now and closely resembled the types of incense available in the past. Resin incense requires constant heating on charcoal to burn properly, meaning that quick-lighting charcoal discs have been developed for this purpose. One of these was used in this experiment as, although not available in the past, it was both easier and safer than attempting to transfer hot charcoal from a fire onto the rock and seemed to produce a similar amount of heat to a piece of charcoal. The charcoal disc was left on G074 until cool, which took approximately 3 hours. After removal, the basalt surface was soot-stained, but had not changed colour. G074 was then placed in a charcoal barbecue for approximately 2 hours. Even after this relatively limited exposure to heat, there was a notable colour change from dark grey to light grey with orange specks, which was confined to the portion of the stone which had been in the fire. Therefore, although these observations cannot be used to indicate the presence or absence of incense burning they could be used to indicate whether basaltic artefacts had been in a fire. None of the sampled artefacts had this colouration, including those from sites close to basaltic outcrops.

Although this simple experiment (which needs replication, especially with different rock types, before its results can be considered proven) provides evidence for what the artefacts were not used for, it does demonstrate how such experimental work can constrain interpretations on the possible uses of basaltic artefacts.

Conclusion

This study has successfully identified the provenance of a considerable number of basaltic artefacts. It has also demonstrated that the use of ICP-MS data and the quantification of likely source outcrops, using Euclidean distances, is a valid methodology, which has a number of advantages over the previous, semi-qualitative, methodologies. However, it has been less successful in converting this provenance data into an understanding of the procurement systems which operated. This is due to the lack of necessary archaeological data and the ambiguities inherent in attempting to correlate anthropological and archaeological data. Nonetheless, a greater understanding of some of the social structures which created and maintained the basaltic-rock procurement systems has emerged. This is most graphically illustrated by the identification of Mount Hermon as an important source of basaltic artefacts.

As shown in Chapter 5, to fully understand a procurement system it is necessary to relate the results of the provenance study to data relating to the rest of the artefact's 'life cycle'. It is hoped that this study has demonstrated that the collection of the necessary data would aid the understanding of the past societies which participated in these procurement systems. This point, along with potential future directions for research, will be further discussed in the final chapter.

Chapter 9: Conclusions

> *"Dirty British coaster with a salt-caked smoke stack*
> *Butting through the Channel in the mad March days,*
> *With a cargo of Tyne coal,*
> *Road-rail, pig-lead,*
> *Firewood, iron-ware, and cheap tin trays."*
> *(from* Cargoes, *by J. Masefield)*

Masefield's poem moves from the past long-distance trade of luxury goods to the modern trade of utilitarian items. However, this thesis has sought to show that the intra-regional procurement of less valuable and seemingly utilitarian artefacts was also an important component of past societies, and that the analysis of these intra-regional procurement systems can provide valuable information on the operation of past societies. Before this point is expanded, the conclusions of the previous chapters will be briefly summarised.

Summary

Chapter 1 discussed the work of Philip and Williams-Thorpe (1993 and 2001), who had undertaken two provenance studies of basaltic artefacts in the southern Levant, using XRF. These studies formed the basis for this present larger investigation, with their main limitations being a lack of geological samples and an inability to discriminate properly between sources using XRF. A distinction was drawn between the use of "basalt" to mean a specific rock type and "basaltic" to mean any fine-grained, dark, igneous rock. The theoretical basis of this study was also discussed, namely that of realism. This shows that it is possible to relate the observed regularities in the transport of basaltic artefacts from their original location to elsewhere to the underlying social structures without requiring either generalised rules or a, however implicit, relativistic understanding of the past.

Chapter 2 examined previous provenance studies of basaltic artefacts in the Near East. From this examination it was concluded that the most useful and informative studies had used whole-rock analyses (as opposed to analysis of individual rock minerals), using ICP-MS. This enabled important elements, such as the REE and HFSE, to be analysed. It was also concluded that the most successful provenance methodologies used element and element ratio plots.

Chapter 3 considered geological theory and standard geochemical practices. This showed that the use of the REE and HFSE, analysed by ICP-MS, to determine the geological setting of volcanic rocks was standard geochemical practice. It also highlighted the most useful elements and element ratios for attempting to provenance artefacts. The physical properties of different rocks were briefly discussed, and it was concluded that basaltic rock had properties which would have made it preferable for certain artefact types, such as quern-stones. However, it was also noted that little data existed on differences in the physical properties between the different mafic rocks. An examination of the weathering of geological and archaeological samples also showed the importance of choosing immobile trace elements, and also revealed the lack of knowledge on the anthropogenic weathering of basaltic rock.

Chapter 4 summarised the available geological and geochemical data on the basaltic outcrops of the southern Levant. This showed that many analyses of outcrop samples had been made, but with different instruments and for different elements. Furthermore, the coverage was found to be uneven and incomplete, with the majority of the studies concentrating on Cisjordan, while some of the Transjordanian outcrops had not been analysed for trace element data.

Chapter 5 examined the theoretical literature on undertaking provenance and procurement studies. From this it was concluded that there was a great variety of potential procurement mechanisms, some of which probably operated simultaneously, even for a single category of artefacts. These are sometimes difficult to distinguish archaeologically, and require the collection of a large and varied data-set for adequate identification to be attempted. Furthermore, the construction of a diagram (Fig 5.4) showing the different possible stages in the life of an artefact, including multiple uses, distributions and even discards, highlighted the fact that only part of the artefact's 'life cycle' can be reconstructed from the location of its final deposition and the examination of its final form.

Chapter 6 summarised and analysed the available data on basaltic artefacts from archaeological studies. The main conclusion was that there was a lack of properly recorded and analysed data on ground stone artefacts in general, thereby hampering a full understanding of their role in both everyday life and in socio-economic relations. However, from the available data it was still possible to conclude that the potentially advantageous properties of basaltic rock had been recognised and exploited in the past. Furthermore, it was argued that even seemingly utilitarian artefacts (such as quern-stones), when manufactured from basaltic rock, also functioned as prestige items, at least for certain levels of society and especially for groups living further from the outcrops.

Chapter 7 described the collection and analysis of the new geological and archaeological samples, as well as the creation of a database containing previous analyses. The analyses of a total of 359 geological and 140 archaeological samples were included in this database. The grouping of the geological samples and the subsequent provenancing of the archaeological samples were then discussed. The provenance study indicated that the majority of the artefacts, from all the periods studied, derived from the North Jordan Valley, the Mount Hermon or Galilee outcrops, with the Kerak plateau outcrops also being an important source, especially for sites south and east of the Dead Sea.

Chapter 8 attempted to understand how the procurement systems revealed by this provenance study operated. It was noted that from all sites during virtually all the periods a variety of sources were exploited, whether or not the site in question was near an outcrop of useable basaltic rock. It was therefore argued that the desire to maintain social relations with other groups, through the medium of procuring basaltic artefacts, was at least as important as the acquisition of the basaltic artefacts themselves. Furthermore, it is probable that the possession of basaltic artefacts, whether vessels or 'utilitarian' tools conferred some measure of social standing on the possessor, in all the periods studied. The identification of Mount Hermon as a source area for both basaltic and pottery artefacts was used as further evidence for these arguments, and also has implications for the archaeology of the area. Experimental work demonstrated that none of the artefacts examined were probably used in a fire, and it was concluded that this type of work is important in order to constrain possible interpretations of the usage of basaltic artefacts.

Conclusions

Previous provenance studies of basaltic artefacts in the southern Levant have generally examined smaller databases of analyses and relied on impressionistic and visual examinations of the data. By using a combination of element plots, Euclidean distance measurements and spidergrams where the geological samples were normalised to the artefactual sample, the variation between an artefact and a geological sample could be both graphically represented and quantified, leading to positive identifications of the source outcrop (Chapter 7). This enables provenance studies to be more rigorously investigated than has previously been the case. That this methodology is capable of generating meaningful results has been demonstrated by the successful matching of weathered and unweathered sections from the same samples. Furthermore, it has the capability to be modified in order to provenance a wide range of materials, and so has the potential to be widely adopted.

This study has also shown that major element data is not required to adequately examine basaltic artefacts; rather, a combination of petrographic analysis (including thin sections where necessary) and ICP-MS trace element data is sufficient. This significantly reduces the amount of material required for the analysis of an individual artefact and so will hopefully encourage the routine analysis of basaltic artefacts as part of post-excavation work. One current problem is that, as a representative sample of artefacts was not taken from any of the sites, it is unclear how the provenances of the artefacts analysed relate to the total assemblage. This can only be rectified by analysing representative samples from each of the sites.

This research has made clear the importance of basaltic artefacts in everyday life, at all levels of society. Quern-stones manufactured from basaltic rock appear to have been preferred to quern-stones made from other rock types throughout the periods studied. This is presumably due to the superior physical properties of basaltic rock, especially its naturally rough surface, durability and non-detachable grains. This preference is demonstrated by the small number of basaltic quern-stones that are found several hundred kilometres from the nearest basaltic outcrop (e.g. sites in the Beersheva Valley; discussed in Chapter 6). The very fact that it was considered by someone worthwhile to procure these items can be partially explained by the knowledge of their superior physical properties. That this is a plausible argument is supported by Tite et al. (2001), who demonstrated that pottery types were chosen partly because of their known physical properties (discussed in Chapter 3). Furthermore, as already mentioned, these artefacts probably had some form of prestige value, simply due to their rarity and superior physical properties (cf. Bradley and Edmonds 1993). It is also very probable that a range of procurement mechanisms operated simultaneously for the acquisition of these artefacts.

The most likely explanation for the widespread distribution of the basaltic vessels of the Chalcolithic and EBI, given evidence for their value (inclusion in ritual and mortuary contexts, the general absence of use-wear and the manufacture of phosphorite and ceramic imitations) is that they formed part of a gift-exchange network and were distributed separately to other types of basaltic artefact. This conclusion is strengthened by the results of this provenance study, which shows that even sites near basaltic outcrops also procured vessels from other outcrops, sometimes hundreds of kilometres distant. Nonetheless, the mechanisms by which basaltic artefacts were procured are still unclear, and there is also no clear understanding of the types of products, where applicable, which the manufacturers of these artefacts acquired in return. It has been shown that this situation will only be resolved when the quarries, workshops and related settlements are located, and when ground stone artefacts are properly and routinely recorded and analysed during and after excavations.

It has also been argued throughout this thesis that the proper study of ground stone artefacts, including those manufactured from basaltic rock, can provide valuable information on the operation of past societies. This has been most clearly shown by the identification of Mount Hermon as an enduring source of basaltic rock, through at least the Chalcolithic, EBI, LBA and IA. This has not been previously suspected, but, coupled with the recent pottery provenance studies of EBII Metallic Ware and MBII to LBIB Chocolate-on-White Ware (Greenberg and Porat 1996; Fischer 1999), the archaeological understanding of the role that this, usually neglected, area played in the past has been transformed. This shows the importance and use of provenance analysis in the expansion of archaeological knowledge in ways which would not otherwise be identifiable and highlights the importance of routinely incorporating provenance studies into post-excavation analysis of the artefacts.

Philip and Williams-Thorpe (2001:24) argued that sites south of the Dead Sea participated in a "discrete regional procurement system" during the EBI, with the artefacts originating from the Kerak plateau. This has been broadly confirmed by this study, but the occasional artefact has been identified as originating from outcrops further away, showing that these sites were not completely excluded from the wider procurement system. Whether these artefacts were known to originate from other outcrops, and so were treated differently from the artefacts originating from the Kerak plateau, cannot be determined without contextual analysis.

It was only possible to source a large number of artefacts with Euclidean distances of ≤50. This may be due to the lack of suitable geological samples, where the existing samples have not adequately determined the level of geochemical variability within the outcrop. As was discussed in Chapter 7, this is a real possibility, especially for the Transjordanian outcrops. However, other possibilities need to be considered. First, a substantial part of the outcrop could have been worked out (cf. Nelson 1987:122), meaning that, coupled with intra-outcrop variation, the remaining rock can only be matched to the artefact with a greater degree of variation. Nonetheless, quarrying on this scale would probably leave a significant amount of working debris, including stone flakes and broken artefacts (cf. Wilke and Quintero 1996:244f). Once identified, these could be analysed and used as samples to source other artefacts.

More seriously, an entire (small) outcrop could be destroyed by a combination of past working, weathering and modern activity. As reported in Chapter 4, a small Cisjordanian outcrop has been destroyed, apparently by a combination of weathering and modern agriculture (Williams-Thorpe n.d.:3). This outcrop was to small too be a significant source of artefacts, although the possibility remains that a small number of artefacts did originate from it (cf. Williams-Thorpe n.d.:4). This possibility is strengthened by the identification of Ghor al-Katar as a possible source of one basaltic artefacts, although these are only matched with an Euclidean distance of ≤50. If this preliminary identification is proven to be correct, it will contradict Wright et al. (in press, p.11), who report that the outcrop was too highly eroded to have been workable, and will raise the possibility that other small, relatively weathered outcrops were occasionally used for the manufacture of artefacts. This problem could potentially be overcome by the use of subcrop data, if this data were available. However, this limitation is probably only relevant to a small number of artefacts, and should not significantly affect the overall understanding of the procurement of basaltic artefacts.

Future work

This study has also demonstrated a number of ways in which further work would increase our understanding of basaltic artefacts. These can be divided into three main categories, namely directions for future provenance studies, methodological improvements and, more generally, future directions for other lines of research into basaltic artefacts. These will each be examined separately, below.

Future provenance studies

The main way in which this provenance study could be improved would be by the addition of more samples, both geological and artefactual. More geological samples are required, from all the outcrops within the southern Levant, in order to be sure that the within-outcrop variation has been adequately determined. Once this has been undertaken, it will be possible to be more confident in identifying artefacts which vary from their source outcrop due to the reasons discussed above.

More artefactual samples are required to properly understand the patterns of procurement at any one site, and how these changed through time. As discussed above, the number of artefacts analysed from any one site is relatively small, meaning that the addition of further samples has the potential to significantly alter the understanding of the procurement systems which operated at that site. This situation can only be rectified by analysing a representative sample of basaltic artefacts from each period for a site.

The best way in which this work could be undertaken would be if the analysis of a representative sample of basaltic artefacts became a routine part of post-excavation work. With the database of analyses and methodology in place the amount of work that would need to be undertaken is now significantly reduced. This routine analysis would enable a better understanding of the overall procurement systems, and, at a site level, would enable an examination of which groups the site inhabitants were in contact with, and how these contacts altered over time. This has the potential to aid the overall understanding of how the site operated, especially if coupled with a contextual analysis of the basaltic artefacts, which could aid the understanding of how the artefacts were procured and used.

It would also be useful to provenance the local Chalcolithic and EBI phosphorite and pottery imitations of basaltic artefacts, to examine their procurement patterns. Again, if contextual analysis also took place, it could provide data on the social structure of the society in question, if different sections of society were shown to have access to different, but similar looking, artefacts.

This provenance study could also be expanded by the analysis of artefacts dating to other periods. The most obvious, intentional, gap in this present study is that of most of the EBA and all of the MBA. As this and previous studies have shown, it is never possible to assume that the proximal outcrop is the source outcrop and so there is potential to examine the changes in the procurement systems during these periods. However, analysis of artefacts from the Neolithic and the later historical periods also have the potential to provide a greater understanding of procurement systems during these periods than currently exists.

Methodological issues

As well as these ways of continuing and expanding the present study, the methodology used to provenance the artefacts has the potential to be refined, allowing improvements in the identification of the source of artefacts. One way to make the provenancing of artefacts easier to undertake and less prone to variation between workers would be the creation of a computer program similar to that of SINCLAS. This program was able to take data from Microsoft Excel or Statistica, analyse the data and calculate a number of element ratios and chemical parameters, as well as the mineral norms; these results could then be written to another Microsoft Excel or Statistica spreadsheet (Verma and Torres-Alvarado 2002). It should therefore be possible for a program to be written which could take ICP-MS analyses of artefacts, compare them, using element ratios such as Zr/Nb, Yb/Nb, La/Yb and La/Ce, identify potential sources and then calculate and list the Euclidean distances for the likely sources. This data could then be written to another spreadsheet. The possible creation of such a program would enable the data to be more easily examined, while it could also be modified for use in other areas, by changing the database of outcrop samples. This program should enable provenance studies to be more easily and rigorously undertaken and would hopefully encourage their use as a routine procedure.

Advances in analytical techniques may also enable better discrimination between outcrops. As discussed in Chapter 3, there are two main refinements to ICP-MS which have the potential to enable the more effective analysis of samples. Laser ablation ICP-MS (LA-ICP-MS) can analyse high quality, valuable or rare artefacts due to the microscopic samples required (Mallory-Greenough et al. 1999:1265), as long as the artefacts are relatively small. LA-ICP-MS also enables the elemental composition of individual minerals to be analysed.

Multi-collector ICP-MS (MC-ICP-MS) enables the routine analysis of isotope ratios (Halliday et al. 1998), which allows better discrimination between outcrops, including the discrimination of distinct sources which, if produced from the same mantle melting processes at the same magnitudes, cannot be distinguished using trace element data alone. These different forms of analysis, especially isotope analyses, could significantly improve the provenancing of artefacts. However, one current problem is the virtual absence of data on mineral compositions or isotope ratios with which to compare analyses. Until a database of analyses can be created, the improvements offered by these techniques cannot be fully realised. Nonetheless, MC-ICP-MS offers the more immediate potential of cross-checking the provenances made using trace elements, as the same powdered samples can be used for both analyses. This would require the analysis of a relatively small number of samples and would enable the provenances to be assessed and be the first step towards creating a database of isotope analyses in such a way that the data-sets could be related to each other (cf. Knapp and Cherry 1994:36).

Further examination of basaltic artefacts

As has been frequently discussed, for the provenances of the basaltic artefacts to be properly understood, they must be placed in the context of the rest of the artefact's 'life cycle'. That the required data has not been gathered has therefore hampered a full understanding of these artefacts. However, this present study has highlighted a number of ways in which this data could be gathered, including the identification of quarries and workshops, investigating sites for basaltic debitage, the contextual analysis of where basaltic artefacts were deposited, a better examination of the artefacts themselves and experimental studies.

One unexpected outcome of this research has been the identification of the continued (although not necessarily continuous) exploitation from the Chalcolithic to the Iron Age of two important sources of basaltic rock, namely the North Jordan Valley and Mount Hermon areas. The enduring use of these areas of production will probably have structured inter-group relationships in previously unexpected ways. However, there is currently no evidence to suggest that the changing geo-political boundaries of the southern Levantine polities and their fluctuating relationships dramatically affected the flow of basaltic artefacts. Nonetheless, this observation is obscured by the lack of proper recording and analysis of ground stone artefacts at most sites in the region, especially from the later periods.

Furthermore, these two relatively small areas of basaltic rock should be the primary location for archaeological surveys attempting to identify quarries and primary manufacturing workshops. Especially for the Mount Hermon area, where sample G160 (SL116 on Plate 14) has been identified as the closest match to a large number of artefacts, the area that would have to be searched is considerably smaller than would otherwise be the case. As highlighted in Chapter 5 and mentioned elsewhere, it is only when these sites are located that a proper understanding of the manufacture and procurement of basaltic artefacts can be reached.

It is also possible that the continued exploitation of these two sources was partially (and only partially) due to the basaltic rock in these locations having physical properties that were recognised as superior by past craft workers. The small amount of physical data that it was possible to obtain as part of the research for this thesis suggests that this may be the case. However, it will only be possible to properly examine this theory by collecting more samples for physical tests. An examination of the rock type and its strength, density and porosity for both outcrop samples and artefacts has the potential to provide a greater understanding of the technological choices which were made by craft workers when producing the artefact. An examination of strength using the point load test may also provide greater flexibility in testing, especially for the analysis of artefacts.

Another area which requires further research is the existence of weathering rinds on a small number of artefacts. Unlike geological weathering rinds, which are lighter than the unweathered rock, the artefactual weathering rinds are darker. If the conditions in which these weathering rinds are formed could be determined, this should provide information on the depositional history of these artefacts. As discussed in Chapter 3, the most likely explanation for these atypical weathering rinds is an anthropogenic component, possibly due to the creation of microfractures due to stoneworking, coupled with an unusually long surface exposure. To test this hypothesis, it will be necessary to examine recently broken basaltic rock from the outcrops and compare these results with an examination of artefacts freshly manufactured from basaltic rock and then exposed outside for a period of months or years.

As has been frequently mentioned, a better understanding of the basaltic artefacts could be reached through a greater emphasis on the excavation, recording, post-excavation analysis and publication of these artefacts. This would include recording the context of each artefact, actively looking for basaltic rock debitage (for evidence of both primary and secondary manufacture of artefacts) and their systematic evaluation, preferably by a geoarchaeologist or geologist. Data to be gathered would include the precise rock type of each artefact, an examination of the artefacts for weathering rinds, metric data, contextual information, and macroscopic use-wear descriptions. As part of the post-excavation analysis, the sampling of a representative selection of basaltic artefacts for geochemical analysis and provenancing would provide additional information on the site's participation in regional procurement systems. Even if not all of these elements were collected, a very useful first step would be the publication of a complete inventory of all the ground stone artefacts recovered during excavation, which would enable the statistical analysis of the data, thereby providing a better understanding of the operation of basaltic-rock procurement systems.

For this data to be comparable between publications it is necessary to develop a universally applicable (and accepted!) typology for basaltic artefacts from all periods. A number of studies have developed typologies for specific periods or artefact types, but it is now necessary to develop a consistent, easily useable typology which can be adopted by a variety of workers examining individual site assemblages dating from different periods.

As well as the spatial analysis of the arrangement of structures and artefacts (cf. Chapter 6; Wright 2000) a greater understanding of the use of basaltic artefacts could be obtained by the examination of any residues and the systematic analysis of a representative sample of artefacts for starch grains, lipids, proteins, and other biomolecules. This analysis would either provide a direct identification of the types of material contained in or processed by basaltic artefacts, or would at least constrain speculation on the ways in which the artefacts were used.

Experimental studies also have the potential to aid in the understanding of the manufacture and use of basaltic artefacts. Such studies can suggest the *chaîne opératoire* for the production of different artefact types. This can then be tested by comparing it to the original artefacts, and can also suggest how long it took to manufacture different types of artefact. This data has important implications for understanding the organisation of production and the level of value of the artefacts (there being a, somewhat complex, relationship between value and the time required to produce an artefact). Furthermore, as Rosen (1997a:161) noted, experimental work is required to determine the relative efficiency of flint, copper and bronze celts in the manufacture of basaltic artefacts, as this has important implications for the decline in the quality of basaltic artefacts between the Chalcolithic and EBI (as discussed in Chapter 6).

As already mentioned, the exposure of experimentally produced artefacts to the climatic conditions for a significant period of time may aid in the understanding of weathering rinds. Even small-scale studies, such as that can undertaken as part of this research, can aid in the understanding of how artefacts were (or were not) manufactured, procured and used.

Conclusion

There are therefore many ways in which the understanding of basaltic artefacts can be extended, beyond those gained by this current research. Nonetheless, this study has expanded our understanding of how basaltic artefacts were procured. It has developed a new methodology for the provenancing of basaltic artefacts and has demonstrated its usefulness. The creation of a database of analyses, which can be easily updated, and the use of a methodology that can be easily replicated, should enable (and hopefully encourage) the analysis of basaltic artefacts as part of the routine post-excavation analyses on sites in the southern Levant. This methodology should also be applicable, with minor modifications, to the provenancing of a wide variety of materials both in Near Eastern archaeology and more widely.

The identification of particular, enduring sources of raw material, especially those of the North Jordan Valley and Mount Hermon, has improved our understanding of the history of the southern Levant, whilst the identification of future directions of research has shown how this understanding can be further improved. Above all, it is hoped that this study has shown that the examination of even the most neglected categories of materials and artefacts can contribute to the wider understanding of the past and, indeed, can provide information that could not be discerned from any other available source.

Basaltic-rock procurement systems in the southern Levant: Case studies from the Chalcolithic-Early Bronze I and the Late Bronze-Iron Ages

Graham Piers Rutter

Two volumes

Volume 2: Appendices

Thesis submitted for the degree of Doctor of Philosophy, for research conducted in the Departments of Archaeology and Geological Sciences at the University of Durham, AD 2003.

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Volume 2

Attached CD: Version of Appendix 7 in Microsoft Excel 97 and html formats

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(Scale: width=c.4mm)

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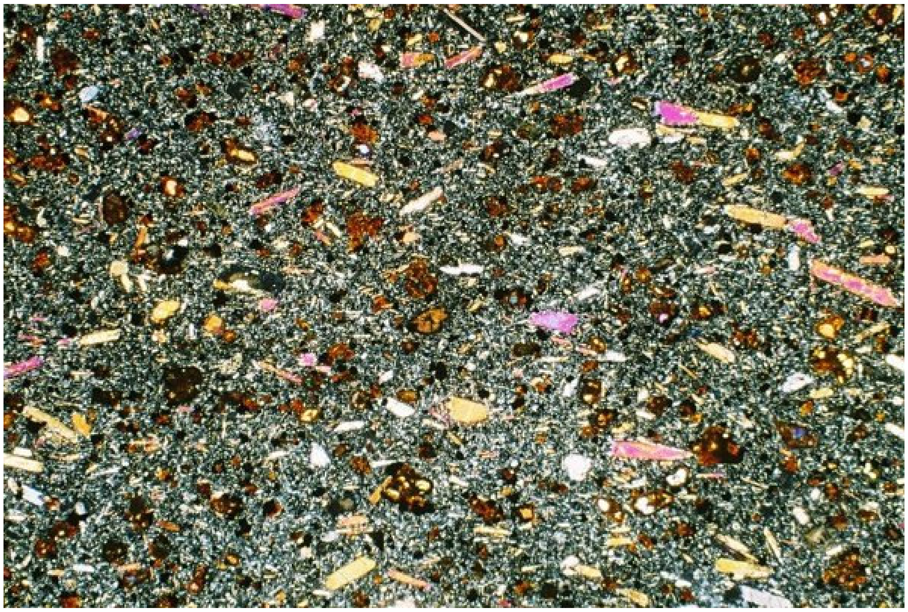

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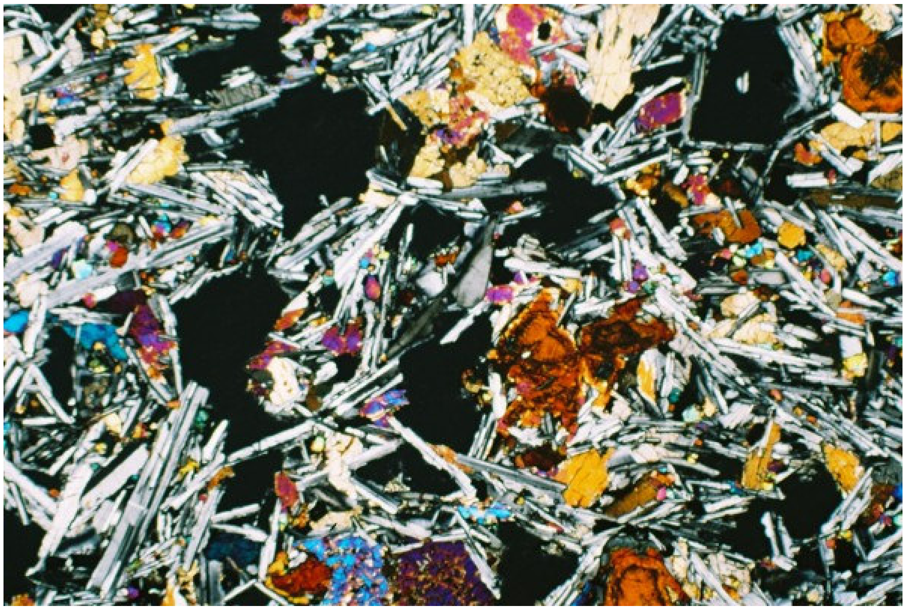
Plate 11: A075 (Hazor), basalt in XPL



(Scale: width=c.4mm)

Plate 12: A091 (Rehov), basanite in XPL

(Scale: width=c.4mm)

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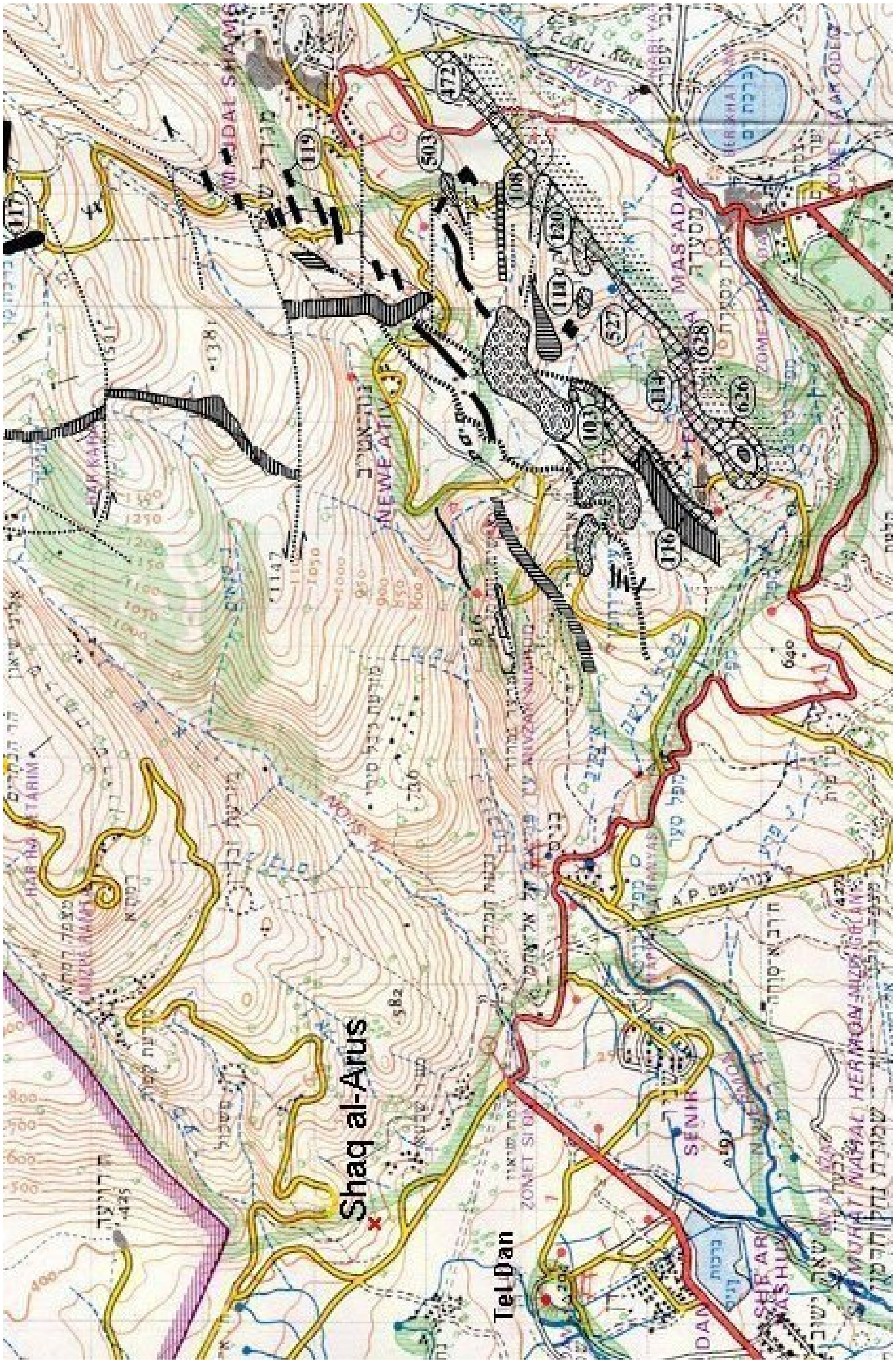
Plate 14: Map of southwestern Mount Hermon



Appendix 1: Correlation between strength and weathering

Weathering	Strength	Weather rank	Strength rank
FRESH	491.94	1	35
FRESH	450.00	1	34
FRESH	400.00	1	33
FRESH	350.00	1	31
FRESH	326.61	1	28
FRESH	283.30	1	26
FRESH	229.00	1	22
FRESH	212.50	1	19
SLIGHTLY W.	379.00	2	32
SLIGHTLY W.	345.16	2	30
SLIGHTLY W.	339.89	2	29
SLIGHTLY W.	291.13	2	27
SLIGHTLY W.	273.59	2	25
SLIGHTLY W.	267.98	2	24
SLIGHTLY W.	250.00	2	23
SLIGHTLY W.	225.00	2	21
SLIGHTLY W.	212.36	2	17
SLIGHTLY W.	202.25	2	16
SLIGHTLY W.	162.92	2	14
SLIGHTLY W.	158.10	2	13
SLIGHTLY W.	108.67	2	7
SLIGHTLY W.	93.67	2	5
MOD. W.	217.42	3	20
MOD. W.	212.36	3	17
MOD. W.	196.63	3	15
MOD. W.	152.25	3	12
MOD. W.	147.19	3	11
MOD. W.	140.45	3	10
MOD. W.	129.21	3	9
MOD. W.	114.05	3	8
MOD. W.	103.18	3	6
MOD. W.	92.00	3	4
MOD. W.	63.50	3	3
MOD. W.	43.00	3	1
HIGHLY W.	58.50	4	2
		Spearman's	-0.75

Appendix 2: Accuracy of data

XRF Data

	WS-E			**Average**	**StdDev**	**%RSD**	**%Bias**
Wt. %	**Standard**	**Start**	**End**				
SiO_2	51.1	51.1	50.95	*51.03*	*0.106*	***0.21***	***0.15***
TiO_2	2.40	2.42	2.43	*2.43*	*0.006*	***0.23***	***1.17***
Al_2O_3	13.78	13.93	13.89	*13.91*	*0.028*	***0.20***	***0.94***
Fe_2O_3	13.15	13.30	13.33	*13.32*	*0.021*	***0.16***	***1.25***
MnO	0.17	0.17	0.17	*0.169*	*0.001*	***0.84***	***1.17***
MgO	5.55	5.60	5.56	*5.58*	*0.028*	***0.51***	***0.54***
CaO	8.95	9.07	9.08	*9.075*	*0.007*	***0.08***	***1.40***
Na_2O	2.47	2.47	2.45	*2.46*	*0.014*	***0.57***	***0.40***
K_2O	1.0	1.0	0.99	*0.995*	*0.007*	***0.71***	***0.50***
P_2O_5	0.30	0.30	0.31	*0.31*	*0.004*	***1.16***	***1.83***
Total	99.72	100.21	100.01	*100.11*	*0.141*	***0.14***	***0.39***
						0.44	**0.89**

	OUG94			**Average**	**StdDev**	**%RSD**	**%Bias**
Wt. %	**Standard**	**Start**	**End**				
SiO_2	69.95	70.05	69.97	*70.01*	*0.057*	***0.08***	***0.09***
TiO_2	0.31	0.31	0.32	*0.31*	*0.002*	***0.68***	***0.16***
Al_2O_3	14.66	14.64	14.71	*14.68*	*0.049*	***0.34***	***0.10***
Fe_2O_3	3.05	3.02	3.02	*3.02*	*0.000*	***0.00***	***0.98***
MnO	0.08	0.08	0.07	*0.07*	*0.001*	***0.95***	***0.67***
MgO	1.04	1.01	1.01	*1.01*	*0.000*	***0.00***	***2.88***
CaO	1.34	1.36	1.37	*1.37*	*0.007*	***0.52***	***1.87***
Na_2O	4.60	4.64	4.65	*4.65*	*0.007*	***0.15***	***0.98***
K_2O	2.96	2.98	2.98	*2.98*	*0.000*	***0.00***	***0.68***
P_2O_5	0.17	0.16	0.17	*0.16*	*0.004*	***2.16***	***0.91***
Total	100.12	100.21	100.25	*100.23*	*0.028*	***0.03***	***0.11***
						0.45	**0.86**

ICP-MS Data
Precision

NBS688

	Run 2					Run 3		Run 4		Average	StDev	%RSD
Y	20.31	20.27	20.55	20.60	20.57	20.92	21.17	20.98	21.14	*20.72*	*0.32*	**1.53**
Zr	54.03	54.01	54.65	54.69	54.77	55.13	55.82	55.07	55.49	*54.85*	*0.57*	**1.04**
Nb	4.23	4.19	4.21	4.21	4.26	4.29	4.31	4.22	4.26	*4.24*	*0.04*	**0.92**
La	4.84	5.06	5.06	5.11	5.13	5.16	5.20	5.09	5.19	*5.09*	*0.10*	**1.98**
Ce	11.01	11.47	11.50	11.64	11.75	11.80	11.76	11.60	11.79	*11.59*	*0.23*	**2.02**
Nd	8.27	8.63	8.68	8.70	8.88	8.79	8.89	8.83	8.71	*8.71*	*0.18*	**2.04**
Sm	2.29	2.38	2.40	2.41	2.38	2.42	2.45	2.45	2.45	*2.40*	*0.05*	**2.00**
Tb	0.51	0.52	0.53	0.53	0.52	0.54	0.55	0.55	0.55	*0.53*	*0.01*	**2.64**
Yb	1.98	2.00	2.03	2.01	2.01	2.06	2.07	2.09	2.11	*2.04*	*0.04*	**2.06**
Lu	0.32	0.33	0.33	0.32	0.33	0.34	0.35	0.35	0.36	*0.34*	*0.01*	**3.72**
Hf	1.41	1.45	1.45	1.45	1.45	1.50	1.52	1.52	1.52	*1.47*	*0.04*	**2.64**
Ta	0.28	0.28	0.29	0.28	0.29	0.30	0.31	0.33	0.28	*0.29*	*0.01*	**5.05**
Th	0.32	0.32	0.31	0.31	0.31	0.33	0.34	0.32	0.33	*0.32*	*0.01*	**2.91**

G009

	Run 1	Run 2	Run 3					Run 4					%RSD	StDev	Average
Y	23.24	24.13	22.64	22.61	22.69	22.79	22.74	24.74	24.64	24.50	24.79	24.64	**4.05**	*0.96*	*23.68*
Zr	173.09	179.66	168.64	168.62	169.95	169.40	168.89	185.95	183.42	182.67	184.23	183.51	**4.12**	*7.27*	*176.50*
Nb	37.07	38.61	36.28	36.14	36.25	36.20	36.13	39.66	38.84	38.52	38.92	38.63	**3.64**	*1.37*	*37.60*
La	28.46	29.20	27.24	27.50	28.08	27.74	27.47	29.89	30.11	29.94	29.57	29.73	**3.84**	*1.10*	*28.74*
Ce	59.47	61.01	56.97	57.60	58.84	58.48	57.61	62.29	63.39	63.00	62.37	63.16	**4.04**	*2.44*	*60.35*
Nd	33.23	33.89	31.86	32.03	32.83	32.76	32.41	34.35	35.44	35.57	35.16	35.57	**4.22**	*1.42*	*33.76*
Sm	6.77	6.85	6.49	6.56	6.72	6.66	6.59	7.00	7.31	7.27	7.15	7.26	**4.37**	*0.30*	*6.89*
Tb	0.88	0.92	0.86	0.86	0.87	0.88	0.86	0.93	0.96	0.95	0.95	0.96	**4.64**	*0.04*	*0.91*
Yb	1.62	1.70	1.57	1.57	1.58	1.57	1.57	1.69	1.76	1.74	1.75	1.75	**4.97**	*0.08*	*1.66*
Lu	0.24	0.25	0.24	0.24	0.23	0.24	0.24	0.26	0.27	0.27	0.26	0.27	**6.21**	*0.02*	*0.25*
Hf	3.82	4.08	3.78	3.80	3.84	3.82	3.76	4.10	4.25	4.27	4.25	4.25	**5.41**	*0.22*	*4.00*
Ta	2.11	2.22	2.07	2.07	2.11	2.10	2.08	2.30	2.19	2.15	2.13	2.12	**3.19**	*0.07*	*2.14*
Th	2.41	2.53	2.35	2.36	2.40	2.38	2.36	2.60	2.55	2.52	2.50	2.51	**3.56**	*0.09*	*2.46*

B-EN

	Run 1	Run 2		Run 3		Run 4		Average	StDev	RSD%
Y	30.299	30.61	31.58	30.37	30.69	30.42	30.45	*30.63*	*0.44*	**1.43**
Zr	272.9	273.51	281.35	272.77	275.96	273.40	273.55	*274.78*	*3.08*	**1.12**
Nb	117.84	117.37	119.16	117.49	118.42	116.15	116.68	*117.59*	*1.01*	**0.86**
La	81.073	81.46	85.23	81.48	81.87	79.89	81.71	*81.82*	*1.64*	**2.01**
Ce	146.9	145.54	152.90	146.15	147.60	145.37	148.60	*147.58*	*2.61*	**1.77**
Nd	68.629	69.36	72.99	69.18	70.31	69.03	71.05	*70.08*	*1.53*	**2.18**
Sm	12.058	12.26	12.83	12.26	12.51	12.22	12.49	*12.37*	*0.26*	**2.07**
Tb	1.3085	1.32	1.32	1.32	1.30	1.30	1.32	*1.31*	*0.01*	**0.70**
Yb	1.8398	1.85	1.87	1.83	1.85	1.84	1.85	*1.84*	*0.01*	**0.66**
Lu	0.273	0.27	0.27	0.27	0.27	0.26	0.27	*0.27*	*0.00*	**1.25**
Hf	5.692	5.69	5.74	5.66	5.71	5.75	5.86	*5.73*	*0.06*	**1.13**
Ta	5.94	6.11	6.15	6.15	6.13	5.69	5.72	*5.98*	*0.20*	**3.42**
Th	10.747	10.77	10.55	10.73	10.77	10.43	10.56	*10.65*	*0.14*	**1.27**

AGV-1

	Run 1	Run 2		Run 3		Run 4		Average	StDev	RSD%
Y	19.64	20.14	20.70	19.86	20.12	19.76	19.42	*19.95*	*0.42*	**2.11**
Zr	228.02	231.10	234.91	230.18	233.58	229.01	225.42	*230.32*	*3.25*	**1.41**
Nb	14.44	14.70	14.84	14.61	14.70	14.53	14.13	*14.56*	*0.23*	**1.59**
La	38.18	38.26	39.61	38.29	38.27	38.02	37.31	*38.28*	*0.68*	**1.78**
Ce	67.26	67.37	69.88	67.54	67.34	66.81	66.09	*67.47*	*1.17*	**1.74**
Nd	33.34	33.42	35.18	33.44	33.43	33.17	33.02	*33.57*	*0.73*	**2.16**
Sm	5.94	5.93	6.12	5.86	5.98	5.83	5.87	*5.93*	*0.10*	**1.62**
Tb	0.69	0.67	0.67	0.66	0.67	0.66	0.67	*0.67*	*0.01*	**1.49**
Yb	1.67	1.66	1.68	1.66	1.66	1.66	1.65	*1.66*	*0.01*	**0.54**
Lu	0.27	0.27	0.27	0.27	0.27	0.26	0.27	*0.27*	*0.00*	**1.37**
Hf	5.08	5.14	5.15	5.10	5.14	5.09	5.11	*5.11*	*0.03*	**0.53**
Ta	0.91	0.91	0.91	0.90	0.91	0.86	0.82	*0.89*	*0.04*	**3.94**
Th	6.42	6.43	6.30	6.43	6.42	6.43	6.21	*6.38*	*0.09*	**1.36**

BHVO-1

	Run 1	Run 2		Run 3		Run 4		Average	StDev	RSD%
Y	27.64	27.33	28.13	27.50	27.77	27.56	27.09	*27.57*	*0.30*	**1.10**
Zr	175.99	173.37	176.87	174.71	176.59	175.28	173.06	*175.12*	*1.39*	**0.79**
Nb	19.46	19.33	19.46	19.41	19.48	19.48	19.06	*19.38*	*0.14*	**0.72**
La	15.38	15.33	15.99	15.29	15.56	15.54	15.40	*15.50*	*0.22*	**1.43**
Ce	37.07	37.07	38.68	36.84	37.61	37.36	37.22	*37.41*	*0.57*	**1.52**
Nd	25.90	25.90	27.26	25.96	26.16	25.98	25.85	*26.14*	*0.46*	**1.78**
Sm	6.19	6.22	6.50	6.26	6.30	6.25	6.31	*6.29*	*0.09*	**1.49**
Tb	0.96	0.98	0.99	0.98	0.99	0.98	0.97	*0.98*	*0.01*	**1.08**
Yb	2.02	2.01	2.04	2.02	2.02	2.00	2.01	*2.02*	*0.01*	**0.56**
Lu	0.30	0.30	0.30	0.30	0.31	0.30	0.30	*0.30*	*0.00*	**0.83**
Hf	4.43	4.42	4.47	4.46	4.44	4.44	4.50	*4.45*	*0.02*	**0.55**
Ta	1.24	1.25	1.26	1.27	1.27	1.26	1.21	*1.25*	*0.02*	**1.58**
Th	1.25	1.26	1.24	1.24	1.25	1.26	1.23	*1.25*	*0.01*	**0.84**

Bias

B-EN

	Certified	Run 1	*%Bias*	Run 2	*%Bias*	Run 3	*%Bias*	Run 4	*%Bias*	Average
Y	30	30.30	*1.00*	31.09	*3.64*	31.14	*3.80*	30.44	*1.46*	2.47
Zr	265	272.90	*2.98*	277.43	*4.69*	279.85	*5.60*	273.48	*3.20*	4.12
Nb	100	117.84	*17.84*	118.26	*18.26*	120.32	*20.32*	116.42	*16.42*	18.21
La	82	81.07	*1.13*	83.35	*1.64*	83.31	*1.60*	80.80	*1.46*	1.46
Ce	152	146.90	*3.36*	149.22	*1.83*	149.81	*1.44*	146.99	*3.30*	2.48
Nd	70	68.63	*1.96*	71.17	*1.68*	71.14	*1.63*	70.04	*0.05*	1.33
Sm	12	12.06	*0.48*	12.55	*4.54*	12.63	*5.28*	12.35	*2.94*	3.31
Tb	1.3	1.31	*0.65*	1.32	*1.46*	1.34	*2.74*	1.31	*0.46*	1.33
Yb	1.8	1.84	*2.21*	1.86	*3.14*	1.87	*4.02*	1.84	*2.39*	2.94
Lu	0.24	0.27	*13.75*	0.27	*11.25*	0.27	*14.30*	0.27	*11.46*	12.69
Hf	5.4	5.69	*5.41*	5.71	*5.83*	5.80	*7.43*	5.80	*7.48*	6.54
Ta	5.5	5.94	*8.00*	6.13	*11.46*	6.26	*13.87*	5.71	*3.74*	9.27
Th	11	10.75	*2.30*	10.66	*3.10*	10.97	*0.31*	10.50	*4.58*	2.57

AGV-1

	Certified	Run 1	*%Bias*	Run 2	*%Bias*
Y	20	19.64	*1.79*	20.42	*2.11*
Zr	227	228.02	*0.45*	233.00	*2.64*
Nb	15	14.44	*3.75*	14.77	*1.56*
La	38	38.18	*0.48*	38.93	*2.45*
Ce	67	67.26	*0.39*	68.63	*2.43*
Nd	33	33.34	*1.02*	34.30	*3.94*
Sm	5.9	5.94	*0.73*	6.02	*2.07*
Tb	0.7	0.69	*1.43*	0.67	*3.93*
Yb	1.72	1.67	*3.14*	1.67	*2.99*
Lu	0.27	0.27	*0.00*	0.27	*0.56*
Hf	5.1	5.08	*0.33*	5.14	*0.86*
Ta	0.9	0.91	*0.78*	0.91	*1.06*
Th	6.5	6.42	*1.17*	6.37	*2.08*

BHVO-1

	Certified	Run 1	*%Bias*	Run 2	*%Bias*	Run 3	*%Bias*	Run 4	*%Bias*	Average
Y	28	27.64	*1.29*	27.73	*0.96*	27.64	*1.30*	27.32	*2.42*	1.49
Zr	179	175.99	*1.68*	175.12	*2.17*	175.65	*1.87*	174.17	*2.70*	2.11
Nb	19	19.46	*2.43*	19.39	*2.08*	19.44	*2.34*	19.27	*1.41*	2.07
La	16	15.38	*3.86*	15.66	*2.13*	15.42	*3.60*	15.47	*3.33*	3.23
Ce	39	37.07	*4.95*	37.87	*2.89*	37.22	*4.56*	37.29	*4.40*	4.20
Nd	25	25.90	*3.58*	26.58	*6.32*	26.06	*4.24*	25.92	*3.66*	4.45
Sm	6.2	6.19	*0.15*	6.36	*2.52*	6.28	*1.24*	6.28	*1.21*	1.28
Tb	0.96	0.96	*0.31*	0.98	*2.55*	0.99	*2.81*	0.97	*1.30*	1.74
Yb	2	2.02	*0.88*	2.03	*1.41*	2.02	*1.00*	2.01	*0.35*	0.91
Lu	0.29	0.30	*4.48*	0.30	*3.45*	0.30	*4.48*	0.30	*4.83*	4.31
Hf	4.4	4.43	*0.73*	4.44	*1.01*	4.45	*1.07*	4.47	*1.62*	1.11
Ta	1.2	1.24	*3.42*	1.26	*4.83*	1.27	*5.58*	1.23	*2.75*	4.15
Th	1.1	1.25	*14.00*	1.25	*13.64*	1.25	*13.32*	1.25	*13.23*	13.55

AGV-1

	Run 3	*%Bias*	Run 4	*%Bias*	Average
Y	19.99	*0.04*	19.59	*2.07*	1.50
Zr	231.88	*2.15*	227.21	*0.09*	1.33
Nb	14.66	*2.29*	14.33	*4.48*	3.02
La	38.28	*0.73*	37.66	*0.89*	1.14
Ce	67.44	*0.65*	66.45	*0.83*	1.07
Nd	33.43	*1.31*	33.10	*0.29*	1.64
Sm	5.92	*0.33*	5.85	*0.83*	0.99
Tb	0.66	*5.14*	0.66	*5.21*	3.93
Yb	1.66	*3.66*	1.65	*3.84*	3.41
Lu	0.27	*0.37*	0.26	*2.78*	0.93
Hf	5.12	*0.35*	5.10	*0.06*	0.40
Ta	0.91	*0.67*	0.84	*6.56*	2.26
Th	6.42	*1.16*	6.32	*2.75*	1.79

Reproducibility

B-EN

	Run 1	Run 2	Run 3	Run 4	Average	StDev	%RSD
Y	30.30	31.09	31.14	30.44	30.74	0.22	*0.71*
Zr	272.90	277.43	279.85	273.48	275.92	1.65	*0.60*
Nb	117.84	118.26	120.32	116.42	118.21	0.81	*0.68*
La	81.07	83.35	83.31	80.80	82.13	0.69	*0.84*
Ce	146.90	149.22	149.81	146.99	148.23	0.75	*0.51*
Nd	68.63	71.17	71.14	70.04	70.24	0.60	*0.85*
Sm	12.06	12.55	12.63	12.35	12.40	0.13	*1.03*
Tb	1.31	1.32	1.34	1.31	1.32	0.01	*0.51*
Yb	1.84	1.86	1.87	1.84	1.85	0.01	*0.40*
Lu	0.27	0.27	0.27	0.27	0.27	0.00	*0.69*
Hf	5.69	5.71	5.80	5.80	5.75	0.03	*0.50*
Ta	5.94	6.13	6.26	5.71	6.01	0.12	*2.02*
Th	10.75	10.66	10.97	10.50	10.72	0.10	*0.91*

G009

	Run 1	Run 2	Run 3	Run 4	Average	StDev	%RSD
Y	23.24	24.13	22.70	24.66	23.68	0.44	*1.86*
Zr	173.09	179.66	169.10	183.95	176.45	3.32	*1.88*
Nb	37.07	38.61	36.20	38.91	37.70	0.64	*1.71*
La	28.46	29.20	27.61	29.85	28.78	0.48	*1.67*
Ce	59.47	61.01	57.90	62.84	60.30	1.06	*1.75*
Nd	33.23	33.89	32.37	35.22	33.68	0.60	*1.78*
Sm	6.77	6.85	6.60	7.20	6.86	0.13	*1.83*
Tb	0.88	0.92	0.87	0.95	0.90	0.02	*2.12*
Yb	1.62	1.70	1.57	1.74	1.66	0.04	*2.26*
Lu	0.24	0.25	0.24	0.27	0.25	0.01	*3.00*
Hf	3.82	4.08	3.80	4.22	3.98	0.10	*2.58*
Ta	2.11	2.22	2.08	2.18	2.15	0.03	*1.41*
Th	2.41	2.53	2.37	2.54	2.46	0.04	*1.73*

BHVO-1

	Run 1	Run 2	Run 3	Run 4	Average	StDev	%RSD
Y	27.64	27.73	27.64	27.32	27.58	0.09	*0.32*
Zr	175.99	175.12	175.65	174.17	175.23	0.40	*0.23*
Nb	19.46	19.39	19.44	19.27	19.39	0.04	*0.23*
La	15.38	15.66	15.42	15.47	15.48	0.06	*0.40*
Ce	37.07	37.87	37.22	37.29	37.36	0.18	*0.47*
Nd	25.90	26.58	26.06	25.92	26.11	0.16	*0.61*
Sm	6.19	6.36	6.28	6.28	6.27	0.03	*0.54*
Tb	0.96	0.98	0.99	0.97	0.98	0.01	*0.57*
Yb	2.02	2.03	2.02	2.01	2.02	0.00	*0.22*
Lu	0.30	0.30	0.30	0.30	0.30	0.00	*0.29*
Hf	4.43	4.44	4.45	4.47	4.45	0.01	*0.19*
Ta	1.24	1.26	1.27	1.23	1.25	0.01	*0.62*
Th	1.25	1.25	1.25	1.25	1.25	0.00	*0.15*

AGV-1

	Run 1	Run 2	Run 3	Run 4	Average	StDev	%RSD
Y	19.64	20.42	19.99	19.59	19.91	0.19	*0.97*
Zr	228.02	233.00	231.88	227.21	230.03	1.42	*0.62*
Nb	14.44	14.77	14.66	14.33	14.55	0.10	*0.69*
La	38.18	38.93	38.28	37.66	38.26	0.26	*0.68*
Ce	67.26	68.63	67.44	66.45	67.44	0.45	*0.67*
Nd	33.34	34.30	33.43	33.10	33.54	0.26	*0.78*
Sm	5.94	6.02	5.92	5.85	5.93	0.04	*0.60*
Tb	0.69	0.67	0.66	0.66	0.67	0.01	*0.92*
Yb	1.67	1.67	1.66	1.65	1.66	0.00	*0.21*
Lu	0.27	0.27	0.27	0.26	0.27	0.00	*0.63*
Hf	5.08	5.14	5.12	5.10	5.11	0.01	*0.26*
Ta	0.91	0.91	0.91	0.84	0.89	0.02	*1.87*
Th	6.42	6.37	6.42	6.32	6.38	0.03	*0.39*

NBS688

	Run 2	Run 3	Run 4	Average	StDev	%RSD
Y	21.26	21.04	21.06	21.12	0.06	*0.29*
Zr	55.53	55.48	55.28	55.43	0.06	*0.12*
Nb	4.41	4.30	4.24	4.32	0.04	*0.99*
La	5.31	5.18	5.14	5.21	0.05	*0.89*
Ce	12.03	11.78	11.69	11.83	0.09	*0.73*
Nd	9.01	8.84	8.77	8.87	0.06	*0.70*
Sm	2.48	2.43	2.45	2.45	0.01	*0.47*
Tb	0.54	0.54	0.55	0.54	0.00	*0.32*
Yb	2.09	2.07	2.10	2.08	0.01	*0.43*
Lu	0.34	0.35	0.36	0.35	0.00	*0.99*
Hf	1.48	1.51	1.52	1.51	0.01	*0.63*
Ta	0.31	0.30	0.30	0.31	0.00	*0.71*
Th	0.33	0.33	0.33	0.33	0.00	*0.66*

Appendix 3: Comparison of XRF and ICP-MS data

A015

	ICP-MS	XRF	Average	StDev	RSD
Sc	23.12	22	*22.56*	*0.79*	**3.50**
V	207.34	195.5	*201.42*	*8.37*	**4.16**
Zn	111.42	93.5	*102.46*	*12.67*	**12.37**
Ga	19.89	22	*20.94*	*1.50*	**7.14**
Y	25.62	26.35	*25.99*	*0.51*	**1.98**
Zr	183.01	180.5	*181.76*	*1.78*	**0.98**
Nb	29.15	25.15	*27.15*	*2.83*	**10.42**

A020

	ICP-MS	XRF	Average	StDev	RSD
Sc	19.51	19	19.25	0.36	**1.85**
V	196.82	192	194.41	3.41	**1.75**
Zn	127.46	115	121.23	8.81	**7.26**
Ga	21.24	22	21.62	0.54	**2.48**
Y	22.61	24.6	23.60	1.41	**5.96**
Zr	218.71	215	216.86	2.62	**1.21**
Nb	64.90	59	61.95	4.17	**6.73**

A023

	ICP-MS	XRF	Average	StDev	RSD
Sc	21.00	19	20.00	1.42	**7.08**
V	185.05	174	179.53	7.82	**4.35**
Zn	104.51	105	104.75	0.35	**0.33**
Ga	18.23	19	18.61	0.55	**2.94**
Y	19.45	19.7	19.57	0.18	**0.92**
Zr	119.22	121	120.11	1.26	**1.05**
Nb	18.06	15.3	16.68	1.95	**11.71**

A046

	ICP-MS	XRF	Average	StDev	RSD
Sc	20.27	20	20.13	0.19	**0.94**
V	187.76	173	180.38	10.44	**5.79**
Zn	116.90	100	108.45	11.95	**11.02**
Ga	19.16	21	20.08	1.30	**6.47**
Y	17.25	17.7	17.47	0.32	**1.83**
Zr	106.05	104	105.03	1.45	**1.38**
Nb	20.38	17.6	18.99	1.96	**10.33**

G001

	ICP-MS	XRF	Average	StDev	RSD
Sc	22.97	23	22.99	0.02	**0.09**
V	206.03	185	195.52	14.87	**7.61**
Zn	120.96	103	111.98	12.70	**11.34**
Ga	21.57	20	20.78	1.11	**5.33**
Y	19.04	19.6	19.32	0.40	**2.07**
Zr	116.64	109	112.82	5.40	**4.79**
Nb	23.45	20.8	22.13	1.88	**8.48**

G005

	ICP-MS	XRF	Average	StDev	RSD
Sc	21.56	21	21.28	0.39	**1.85**
V	211.02	196	203.51	10.62	**5.22**
Zn	114.32	96	105.16	12.95	**12.32**
Ga	21.08	21	21.04	0.06	**0.27**
Y	21.06	20.7	20.88	0.25	**1.22**
Zr	143.48	136	139.74	5.29	**3.78**
Nb	34.25	30.3	32.28	2.79	**8.66**

G008

	ICP-MS	XRF	Average	StDev	RSD
Sc	25.36	23	24.18	1.67	**6.91**
V	247.29	239	243.14	5.86	**2.41**
Zn	128.85	96	112.43	23.23	**20.66**
Ga	21.03	21	21.01	0.02	**0.10**
Y	26.55	27.4	26.98	0.60	**2.22**
Zr	187.27	182	184.64	3.73	**2.02**
Nb	34.13	30	32.07	2.92	**9.11**

G009

	ICP-MS	XRF	Average	StDev	RSD
Sc	20.93	20	20.47	0.66	**3.23**
V	219.31	224	221.65	3.32	**1.50**
Zn	109.35	112	110.67	1.88	**1.70**
Ga	18.80	20	19.40	0.85	**4.37**
Y	23.35	25.6	24.48	1.59	**6.49**
Zr	173.95	174	173.98	0.04	**0.02**
Nb	37.29	35.3	36.30	1.41	**3.88**

G018

	ICP-MS	XRF	Average	StDev	RSD
Sc	18.90	15	16.95	2.76	**16.27**
V	197.76	203	200.38	3.71	**1.85**
Zn	123.80	108	115.90	11.17	**9.64**
Ga	20.58	21	20.79	0.30	**1.44**
Y	20.35	22.9	21.62	1.81	**8.36**
Zr	182.01	177	179.51	3.55	**1.98**
Nb	57.53	49.4	53.46	5.75	**10.75**

G019

	ICP-MS	XRF	Average	StDev	RSD
Sc	25.03	24	24.51	0.73	**2.96**
V	249.83	230.5	240.17	13.67	**5.69**
Zn	113.83	91	102.42	16.15	**15.77**
Ga	22.49	22.5	22.49	0.01	**0.03**
Y	20.62	21.3	20.96	0.48	**2.30**
Zr	144.29	139.5	141.90	3.39	**2.39**
Nb	31.83	28.3	30.06	2.49	**8.30**

G025

	ICP-MS	XRF	Average	StDev	RSD
Sc	21.71	23	22.36	0.91	**4.07**
V	201.13	201	201.06	0.09	**0.04**
Zn	113.60	104	108.80	6.79	**6.24**
Ga	20.59	22	21.29	1.00	**4.69**
Y	23.91	25.7	24.80	1.27	**5.11**
Zr	159.90	166	162.95	4.31	**2.65**
Nb	27.30	24.6	25.95	1.91	**7.36**

Appendix 4: Petrographic descriptions

Geological samples

G069 (Wadi al-Khaymat) *Nephelinite*: Mesocratic, porphyritic, non-vesicular. Phenocrysts of nepheline, augite, and olivine, all completely altered to iddingsite. Microphenocrysts of magnetite. Groundmass predominately nepheline; some augite, iddingsitized olivine, ferromagnesians and interstitial glass.

G058 (Jebel al-Dakhar) *Melanephelinite*: Mesocratic, porphyritic, non-vesicular. Occasional large phenocrysts of olivine and occasional microphenocrysts of magnetite. Most phenocrysts augite, some nepheline. Groundmass nepheline, augite, ferromagnesians and interstitial glass.

G053 (Kerak plateau) *Basanite*: Mesocratic, porphyritic, very few vesicles. Some olivine phenocrysts, with partial alteration to iddingsite. Most phenocrysts plagioclase. Groundmass olivine, plagioclase, augite, ferromagnesians and interstitial glass.

G037 (Sweimah) *Basanite*: Melanocratic, porphyritic. Large vesicles, some with secondary rim of calcite. Most phenocrysts augite, some olivine. Groundmass augite, plagioclase, ferromagnesians and interstitial glass.

G079 (Al Baqura) *Basalt*: Mesocratic, porphyritic, very few vesicles. Large phenocrysts of olivine, partially altered to iddingsite. Most phenocrysts plagioclase, occasional micropheoncrysts of magnetite. Groundmass olivine, plagioclase, augite, ferromagnesians and interstitial glass.

Artefacts

A054 (Miqne) *Granodiorite*: Leucocratic, porphyritic, non-vesicular. Pheoncrysts of biotite mica, hornblende, quartz, plagioclase and muscovite mica.

A072 (Miqne) *Basalt*: Mesocratic, porphyritic, vesicular. Phenocrysts of plagioclase, augite and olivine, with partial alteration to iddingsite. Groundmass plagioclase, augite, olivine, ferromagnesians and interstitial glass.

A091 (Rehov) *Basanite*: Mesocratic, porphyritic. Large vesicles, some with secondary rim of calcite. Large olivine phenocrysts of olivine, partially altered to iddingsite. Occasional augite phenocrysts. Microphenocrysts of plagioclase. Groundmass olivine, plagioclase, augite, ferromagnesians and interstitial glass.

A075 (Hazor) *Basalt*: Mesocratic, porphyritic, large vesicles. Phenocrysts of augite, plagioclase and olivine, most completely altered to iddingsite. Groundmass augite, iddingsitized olivine, plagioclase, ferromagnesians and interstitial glass.

A108 (Pella) *Basalt*: Mesocratic, porphyritic. Large vesicles, some with secondary rim of calcite. Large olivine phenocrysts of olivine, partially altered to iddingsite. Some smaller olivine phenocrysts completely altered to iddingsite. Plagioclase and occasional augite phenocrysts. Groundmass plagioclase, augite, olivine, ferromagnesians and interstitial glass.

A151 (Shuna) *Basalt*: Mesocratic, porphyritic, vesicular. Phenocrysts of plagioclase, augite and olivine, with partial alteration to iddingsite. Groundmass plagioclase, augite, olivine, ferromagnesians and interstitial glass.

	Nb, Zr, Y	
G025	**37.90**	15.65
G090	**33.73**	20.37
G140	**29.48**	23.80
G355	**21.57**	21.57
G378	**20.45**	9.67
G380	**26.43**	19.34

Appendix 5: Lowest Euclidean distance for each artefact
New (ICP-MS-analysed) artefacts

For an explanation of the occasional additional column, see page 209

A015

ID	Location	Euclidean distance	Nb, Zr, Y
G025	NJV	**37.90**	15.65
G090	Ramon	**33.73**	20.37
G140	Mt Hermon	**29.48**	23.80
G355	Harrat Ash Shaam	**21.57**	21.57
G378	Galilee	**20.45**	9.67
G380	Galilee	**26.43**	19.34

A020

ID	Location	Euclidean distance
G029	Dead Sea	**11.67**
G035	Dead Sea	**9.48**
G037	Dead Sea	**15.20**
G270	Ma'in	**22.80**

A023

ID	Location	Euclidean distance
G084	Sinai	**62.97**
G116	Mt Hermon	**55.87**
G160	Mt Hermon	**55.34**

A046

ID	Location	Euclidean distance
G001	Kerak	**44.24**
G055	Kerak	**8.77**
G088	Ramon	**44.03**

A055

ID	Location	Euclidean distance	As G398
G019	NJV	**51.69**	20.38
G192	Galilee	**46.34**	43.46
G398	Harrat Ash Shaam	**31.89**	31.89

A060

ID	Location	Euclidean distance
G055	Kerak	**61.15**
G116	Mt Hermon	**62.43**
G131	Mt Hermon	**71.81**
G371	S Transjordan	**71.85**

A061

ID	**Location**	**Euclidean distance**	As G140
G081	NJV	**47.79**	21.96
G125	Mt Hermon	**37.66**	37.66
G140	Mt Hermon	**24.61**	24.61
G192	Galilee	**43.91**	21.94

A062

ID	**Location**	**Euclidean distance**	As G300
G271	NJV	**178.41**	13.16
G281	ESE Mafraq	**81.87**	77.19
G292	Jordan eastern margin	**149.30**	8.54
G300	Golan	**15.76**	15.76
G381	Galilee	**50.26**	46.18

A066

ID	**Location**	**Euclidean distance**	As G125
G025	NJV	**39.64**	24.18
G077	NJV	**39.20**	22.68
G079	NJV	**32.62**	21.55
G125	Mt Hermon	**26.93**	26.93
G140	Mt Hermon	**28.25**	28.25

A067

ID	**Location**	**Euclidean distance**
G053	Kerak	**23.28**
G140	Mt Hermon	**36.72**
G191	Galilee	**27.33**

A068

ID	**Location**	**Euclidean distance**
G081	NJV	**17.40**
G125	Mt Hermon	**20.70**
G140	Mt Hermon	**25.22**

A071

ID	**Location**	**Euclidean distance**
G084	Sinai	**55.56**
G116	Mt Hermon	**42.90**
G131	Mt Hermon	**39.13**
G159	Mt Hermon	**51.36**
G160	Mt Hermon	**36.52**

A072

ID	**Location**	**Euclidean distance**
G084	Sinai	**63.33**
G116	Mt Hermon	**56.27**
G131	Mt Hermon	**53.10**
G160	Mt Hermon	**41.22**

A075

ID	Location	Euclidean distance
G025	NJV	**21.23**
G077	NJV	**28.40**
G125	Mt Hermon	**29.81**
G140	Mt Hermon	**21.71**

A076

ID	Location	Euclidean distance
G111	Mt Carmel	**26.62**
G139	Mt Hermon	**27.42**
G353	Harrat Ash Shaam	**19.21**
G388	Golan	**9.41**

A078

ID	Location	Euclidean distance
G139	Mt Hermon	**15.27**
G157	Golan	**17.90**
G340	Harrat Ash Shaam	**15.55**

A080

ID	Location	Euclidean distance
G084	Sinai	**58.67**
G116	Mt Hermon	**51.47**
G131	Mt Hermon	**49.76**
G160	Mt Hermon	**40.68**

A081

ID	Location	Euclidean distance	As G140
G077	NJV	**26.98**	14.26
G081	NJV	**22.39**	15.92
G125	Mt Hermon	**18.42**	18.42
G140	Mt Hermon	**16.90**	16.90

A082

ID	Location	Euclidean distance
G084	Sinai	**65.96**
G131	Mt Hermon	**35.40**
G160	Mt Hermon	**31.01**

A083

ID	Location	Euclidean distance
G084	Sinai	**62.73**
G116	Mt Hermon	**56.05**
G131	Mt Hermon	**30.26**
G160	Mt Hermon	**67.03**

A088

ID	**Location**	**Euclidean distance**
G084	Sinai	**63.17**
G116	Mt Hermon	**53.91**
G131	Mt Hermon	**31.59**
G160	Mt Hermon	**66.88**

A089

ID	**Location**	**Euclidean distance**	As G200	As G274
G009	NJV	**47.04**	25.80	27.93
G108	Mt Carmel	**41.55**	29.97	31.58
G200	Galilee	**24.95**	24.95	24.95
G274	NJV	**77.74**	21.27	77.74
G382	Galilee	**41.01**	39.53	41.01

A092

ID	**Location**	**Euclidean distance**
G140	Mt Hermon	**23.43**
G349	Harrat Ash Shaam	**32.74**
G356	Harrat Ash Shaam	**29.72**

A093

ID	**Location**		As G089
G007	Jordan Valley	**36.09**	29.75
G008	Jordan Valley	**35.09**	17.27
G089	Ramon	**21.71**	21.71

A094

ID	**Location**	**Euclidean distance**
G025	NJV	**19.77**
G079	NJV	**19.11**
G140	Mt Hermon	**21.19**

A095

ID	**Location**	**Euclidean distance**	As G089	As G390
G025	NJV	**33.83**	24.40	21.69
G089	Ramon	**24.41**	24.41	10.33
G291	Jordan eastern margin	**29.99**	29.99	23.42
G390	Golan	**27.61**	4.56	27.61

A096

ID	**Location**	**Euclidean distance**
G081	NJV	**21.04**
G125	Mt Hermon	**25.04**
G140	Mt Hermon	**24.72**

A101

ID	Location	Euclidean distance
G023	NJV	**23.09**
G055	Kerak	**65.90**
G398	Harrat Ash Shaam	**29.83**

A104

ID	Location	Euclidean distance
G025	NJV	**17.91**
G077	NJV	**11.69**
G125	Mt Hermon	**19.49**
G140	Mt Hermon	**22.28**

A105

ID	Location	Euclidean distance	Nb, Zr, Y	La, Ce
G055	Kerak	**72.27**	38.49	4.48
G371	S Transjordan	**56.79**	-	13.89
G377	Galilee	**68.80**	12.28	-
G381	Galilee	**68.41**	9.92	-
G398	Harrat Ash Shaam	**47.79**	46.01	12.91

A106

ID	Location	Euclidean distance	As G398
G081	NJV	**35.12**	26.85
G125	Mt Hermon	**35.77**	33.57
G398	Harrat Ash Shaam	**34.70**	34.70

A108

ID	Location	Euclidean distance
G055	Kerak	**38.16**
G081	NJV	**59.74**
G125	Mt Hermon	**58.21**
G398	Harrat Ash Shaam	**49.36**

A109

ID	Location	Euclidean distance
G055	Kerak	**49.38**
G088	Ramon	**51.04**
G395	Kerak	**55.92**

A115

ID	Location	Euclidean distance
G090	Ramon	**128.17**
G125	Mt Hermon	**108.24**
G140	Mt Hermon	**148.06**
G275	ESE Mafraq	**91.08**
G355	Harrat Ash Shaam	**148.58**

A116

ID	Location	**Euclidean distance**	As G383
G222	Golan	**104.51**	37.97
G377	Galilee	**48.21**	48.21
G381	Galilee	**53.14**	53.14
G383	Galilee	**43.62**	43.62
G395	Kerak	**71.14**	37.80
G397	Jordan eastern margin	**61.56**	49.89

A120

ID	Location	**Euclidean distance**
G077	NJV	**37.63**
G081	NJV	**39.22**
G125	Mt Hermon	**28.85**
G140	Mt Hermon	**11.38**

A122

ID	Location	**Euclidean distance**	Nb, Zr, Y
G108	Mt Carmel	**39.63**	26.44
G155	Golan	**13.80**	9.20
G376	Galilee	**35.78**	4.07

A126

ID	Location	**Euclidean distance**	Nb, Zr, Y
G023	NJV	**17.95**	15.87
G077	NJV	**33.20**	10.32
G090	Ramon	**39.44**	10.65
G125	Mt Hermon	**21.82**	20.60
G140	Mt Hermon	**34.78**	31.12

A127

ID	Location	**Euclidean distance**	As G140
G081	NJV	**33.50**	18.57
G125	Mt Hermon	**24.68**	24.68
G140	Mt Hermon	**18.80**	18.80
G357	Harrat Ash Shaam	**32.79**	32.79

A128

ID	Location	**Euclidean distance**
G023	NJV	**56.69**
G055	Kerak	**69.04**
G276	ESE Mafraq	**69.18**
G280	ESE Mafraq	**69.14**
G371	S Transjordan	**63.76**

A129

ID	Location	Euclidean distance	As G126
G017	Ma'in	**22.12**	18.17
G029	Dead Sea	**27.21**	15.77
G037	Dead Sea	**29.83**	14.79
G044	Ma'in	**30.44**	12.86
G126	Mt Hermon	**21.42**	21.42

A132

ID	Location	Euclidean distance	As G221
G055	Kerak	**41.94**	16.66
G221	Golan	**29.16**	29.16
G395	Kerak	**68.27**	65.69

A134

ID	Location	Euclidean distance
G081	NJV	**20.03**
G125	Mt Hermon	**25.34**
G140	Mt Hermon	**27.97**
G175	Galilee	**29.40**

A135

ID	Location	Euclidean distance
G081	NJV	**20.44**
G125	Mt Hermon	**26.30**
G140	Mt Hermon	**25.17**
G175	Galilee	**29.51**

A138

ID	Location	Euclidean distance
G084	Sinai	**53.67**
G116	Mt Hermon	**45.73**
G131	Mt Hermon	**43.77**
G160	Mt Hermon	**36.50**

A139

ID	Location	Euclidean distance	As G116
G084	Sinai	**51.91**	51.91
G116	Mt Hermon	**43.60**	43.60
G131	Mt Hermon	**46.98**	46.98
G160	Mt Hermon	**46.43**	41.53

A140

ID	Location	Euclidean distance
G025	NJV	**32.55**
G079	NJV	**35.09**
G140	Mt Hermon	**17.67**

A141

ID	Location	Euclidean distance
G084	Sinai	**54.35**
G116	Mt Hermon	**44.39**
G131	Mt Hermon	**44.64**
G160	Mt Hermon	**40.84**

A142

ID	Location	Euclidean distance	As G140
G008	Jordan Valley	**29.28**	16.18
G025	NJV	**32.24**	23.38
G140	Mt Hermon	**23.33**	23.33

A143

ID	Location	Euclidean distance
G084	Sinai	**52.10**
G131	Mt Hermon	**36.43**
G160	Mt Hermon	**20.95**

A144

ID	Location	Euclidean distance
G084	Sinai	**59.27**
G131	Mt Hermon	**50.24**
G160	Mt Hermon	**39.13**

A148

ID	Location	Euclidean distance	As G140
G005	Jordan eastern margin	**43.40**	15.88
G053	Kerak	**39.96**	20.81
G140	Mt Hermon	**18.84**	18.84

A149

ID	Location	Euclidean distance
G084	Sinai	**61.34**
G131	Mt Hermon	**35.79**
G160	Mt Hermon	**24.01**

A150

ID	Location	Euclidean distance
G084	Sinai	**53.25**
G116	Mt Hermon	**41.27**
G131	Mt Hermon	**34.39**
G160	Mt Hermon	**32.40**

A152

ID	Location	Euclidean distance	As G116
G084	Sinai	**56.42**	56.42
G116	Mt Hermon	**47.12**	47.12
G131	Mt Hermon	**49.94**	49.94
G160	Mt Hermon	**48.18**	41.03

A153

ID	Location	Euclidean distance
G084	Sinai	**56.22**
G116	Mt Hermon	**40.75**
G131	Mt Hermon	**37.91**
G160	Mt Hermon	**43.39**

A154

ID	Location	Euclidean distance
G084	Sinai	**56.95**
G116	Mt Hermon	**49.24**
G131	Mt Hermon	**51.45**
G160	Mt Hermon	**46.67**

Reassigned (XRF-analysed) artefacts

A001

ID	Location	Euclidean distance	As G160
G055	Kerak	**24.20**	23.71
G088	Ramon	**37.05**	37.05
G160	Mt Hermon	**24.11**	24.11

A002

ID	Location	Euclidean distance
G055	Kerak	**28.88**
G088	Ramon	**38.71**
G160	Mt Hermon	**21.84**

A003

ID	Location	Euclidean distance
G055	Kerak	**24.14**
G088	Ramon	**35.45**
G160	Mt Hermon	**23.95**

A004

ID	Location	Euclidean distance
G007	Jordan Valley	**75.45**
G055	Kerak	**26.11**
G088	Ramon	**36.68**

A005

ID	Location	Euclidean distance
G002	Kerak	**25.16**
G222	Golan	**24.66**
G360	Jordan eastern margin	**19.48**

A006

ID	Location	Euclidean distance	As G222
G002	Kerak	**28.11**	16.24
G005	Jordan eastern margin	**20.10**	18.00
G221	Golan	**25.25**	25.25
G222	Golan	**18.70**	18.70

A007

ID	Location	Euclidean distance
G055	Kerak	**24.39**
G088	Ramon	**35.43**
G160	Mt Hermon	**24.31**

A008

ID	Location	Euclidean distance
G007	Jordan Valley	**65.28**
G055	Kerak	**18.45**
G088	Ramon	**26.42**

A009

ID	Location	Euclidean distance
G007	Jordan Valley	**55.69**
G055	Kerak	**13.07**
G088	Ramon	**21.88**

A010

ID	Location	Euclidean distance
G055	Kerak	**33.17**
G088	Ramon	**38.51**
G160	Mt Hermon	**44.50**

A011

ID	Location	Euclidean distance
G002	Kerak	**27.10**
G005	Jordan eastern margin	**22.84**
G221	Golan	**26.66**
G222	Golan	**16.87**

A012

ID	Location	Euclidean distance	As G222
G002	Kerak	**31.50**	17.12
G005	Jordan eastern margin	**30.14**	23.89
G221	Golan	**22.31**	22.31
G222	Golan	**19.57**	19.57

A013

ID	Location	Euclidean distance
G001	Kerak	**35.97**
G020	NJV	**17.59**
G279	ESE Mafraq	**29.93**

A017

ID	Location	Euclidean distance
G022	NJV	**23.98**
G023	NJV	**16.40**
G079	NJV	**27.37**
G090	Ramon	**33.59**

A018

ID	Location	Euclidean distance
G022	NJV	**36.62**
G377	Galilee	**27.64**
G381	Galilee	**23.27**

A019

ID	Location	Euclidean distance
G012	Dead Sea	**12.23**
G013	Dead Sea	**15.08**
G029	Dead Sea	**10.11**
G035	Dead Sea	**11.13**
G193	Galilee	**15.34**

A021

ID	Location	Euclidean distance	As G168
G013	Dead Sea	**18.38**	16.19
G168	Mt Hermon	**16.88**	16.88
G193	Galilee	**17.18**	17.18
G385	Galilee	**19.82**	17.81

A022

ID	Location	Euclidean distance
G022	NJV	**73.86**
G281	ESE Mafraq	**73.77**
G377	Galilee	**67.80**
G381	Galilee	**63.70**

A024

ID	Location	Euclidean distance
G022	NJV	**46.54**
G281	ESE Mafraq	**41.79**
G377	Galilee	**31.70**
G381	Galilee	**18.72**

A025

ID	Location	Euclidean distance
G212	Galilee	**35.78**
G287	Jordan eastern margin	**21.56**
G295	Jordan eastern margin	**30.26**

A026

ID	Location	Euclidean distance
G055	Kerak	**18.79**
G088	Ramon	**32.60**
G160	Mt Hermon	**27.39**

A027

ID	Location	Euclidean distance
G001	Kerak	**27.00**
G020	NJV	**27.39**
G279	ESE Mafraq	**32.92**

A028

ID	Location	Euclidean distance
G281	ESE Mafraq	**41.23**
G377	Galilee	**28.64**
G381	Galilee	**23.06**

A029

ID	Location	Euclidean distance
G022	NJV	**22.85**
G023	NJV	**22.82**
G079	NJV	**20.71**
G378	Galilee	**27.02**

A030

ID	Location	Euclidean distance
G022	NJV	**26.03**
G023	NJV	**14.63**
G079	NJV	**20.59**
G090	Ramon	**24.46**

A031

ID	Location	Euclidean distance
G131	Mt Hermon	**42.42**
G160	Mt Hermon	**29.51**
G281	ESE Mafraq	**54.45**
G381	Galilee	**56.14**

A032

ID	Location	Euclidean distance
G131	Mt Hermon	**56.37**
G160	Mt Hermon	**41.32**
G377	Galilee	**56.63**
G381	Galilee	**46.56**

A033

ID	Location	Euclidean distance
G131	Mt Hermon	**47.08**
G160	Mt Hermon	**46.55**
G381	Galilee	**71.43**

A034

ID	Location	Euclidean distance
G022	NJV	**38.45**
G023	NJV	**31.38**
G079	NJV	**36.35**
G090	Ramon	**36.93**

A035

ID	Location	Euclidean distance
G008	Jordan Valley	**22.12**
G379	Galilee	**40.45**
G382	Galilee	**40.65**

A036

ID	Location	Euclidean distance
G022	NJV	**22.70**
G023	NJV	**22.11**
G026	NJV	**17.06**
G383	Galilee	**18.56**

A037

ID	Location	Euclidean distance
G160	Mt Hermon	**44.47**
G281	ESE Mafraq	**42.95**
G381	Galilee	**41.84**

A038

ID	Location	Euclidean distance
G022	NJV	**39.10**
G377	Galilee	**26.27**
G381	Galilee	**27.47**

A039

ID	Location	Euclidean distance
G022	NJV	**40.51**
G377	Galilee	**35.12**
G381	Galilee	**20.73**

A040

ID	Location	Euclidean distance
G022	NJV	**32.84**
G023	NJV	**24.14**
G079	NJV	**35.94**
G090	Ramon	**38.40**
G285	ESE Mafraq	**38.43**

A041

ID	Location	Euclidean distance	As G355
G087	Ramon	**34.44**	9.26
G348	Harrat Ash Shaam	**11.63**	11.63
G352	Harrat Ash Shaam	**11.54**	11.54
G355	Harrat Ash Shaam	**8.01**	8.01
G380	Galilee	**22.33**	7.37

A042

ID	Location	Euclidean distance
G022	NJV	**27.31**
G023	NJV	**27.96**
G079	NJV	**30.13**
G090	Ramon	**34.53**

A043

ID	Location	Euclidean distance
G022	NJV	**25.53**
G023	NJV	**20.64**
G079	NJV	**24.95**
G090	Ramon	**24.58**

A044

ID	Location	Euclidean distance
G022	NJV	**28.78**
G023	NJV	**28.63**
G079	NJV	**27.80**
G378	Galilee	**28.67**

A045

ID	Location	Euclidean distance
G131	Mt Hermon	**44.88**
G160	Mt Hermon	**30.51**
G281	ESE Mafraq	**57.12**
G381	Galilee	**57.16**

A047

ID	Location	Euclidean distance
G003	Kerak	**24.95**
G141	Mt Hermon	**23.90**
G192	Galilee	**9.23**

A048

ID	Location	Euclidean distance	As G192
G003	Kerak	**21.97**	8.09
G192	Galilee	**15.30**	15.30
G221	Golan	**21.63**	21.63

A049

ID	Location	Euclidean distance
G055	Kerak	**19.71**
G088	Ramon	**37.01**
G160	Mt Hermon	**26.33**

A050

ID	Location	Euclidean distance	As G222
G002	Kerak	**37.03**	9.75
G005	Jordan eastern margin	**19.39**	8.27
G222	Golan	**9.63**	9.63

A051

ID	Location	Euclidean distance
G022	NJV	**21.33**
G377	Galilee	**30.00**
G381	Galilee	**25.29**

A052

ID	Location	Euclidean distance
G131	Mt Hermon	**52.77**
G160	Mt Hermon	**36.31**
G381	Galilee	**44.73**

A053

ID	Location	Euclidean distance
G131	Mt Hermon	**46.89**
G160	Mt Hermon	**45.25**
G381	Galilee	**66.15**

A156

ID	Location	Euclidean distance
G087	Ramon	**15.45**
G089	Ramon	**14.61**
G348	Harrat Ash Shaam	**9.80**
G350	Harrat Ash Shaam	**10.80**
G352	Harrat Ash Shaam	**10.41**
G355	Harrat Ash Shaam	**5.89**
G357	Harrat Ash Shaam	**7.81**
G375	Galilee	**17.52**
G380	Galilee	**22.38**

A157

ID	Location	Euclidean distance
G089	Ramon	**14.37**
G348	Harrat Ash Shaam	**13.15**
G350	Harrat Ash Shaam	**12.07**
G352	Harrat Ash Shaam	**14.47**
G355	Harrat Ash Shaam	**11.79**
G357	Harrat Ash Shaam	**9.92**
G375	Galilee	**22.33**

A158

ID	Location	Euclidean distance
G089	Ramon	**9.34**
G355	Harrat Ash Shaam	**15.18**
G357	Harrat Ash Shaam	**8.83**
G375	Galilee	**15.44**

A159

ID	Location	Euclidean distance
G089	Ramon	**11.02**
G348	Harrat Ash Shaam	**10.97**
G350	Harrat Ash Shaam	**13.92**
G355	Harrat Ash Shaam	**5.29**
G357	Harrat Ash Shaam	**4.85**
G375	Galilee	**14.30**

A160

ID	Location	Euclidean distance
G089	Ramon	**10.08**
G348	Harrat Ash Shaam	**12.11**
G350	Harrat Ash Shaam	**16.71**
G352	Harrat Ash Shaam	**17.44**
G355	Harrat Ash Shaam	**4.45**
G357	Harrat Ash Shaam	**3.92**
G375	Galilee	**24.04**

A161

ID	Location	Euclidean distance
G348	Harrat Ash Shaam	**6.16**
G350	Harrat Ash Shaam	**8.97**
G352	Harrat Ash Shaam	**9.29**
G355	Harrat Ash Shaam	**5.73**
G357	Harrat Ash Shaam	**9.81**
G375	Galilee	**16.69**

A162

ID	Location	Euclidean distance
G089	Ramon	**15.00**
G348	Harrat Ash Shaam	**8.22**
G350	Harrat Ash Shaam	**10.20**
G352	Harrat Ash Shaam	**11.80**
G355	Harrat Ash Shaam	**6.86**
G357	Harrat Ash Shaam	**8.34**
G375	Galilee	**15.10**

A163

ID	Location	Euclidean distance
G089	Ramon	**9.63**
G357	Harrat Ash Shaam	**9.17**
G375	Galilee	**13.90**

A164

ID	Location	Euclidean distance
G089	Ramon	**14.08**
G348	Harrat Ash Shaam	**10.34**
G350	Harrat Ash Shaam	**11.14**
G352	Harrat Ash Shaam	**10.66**
G355	Harrat Ash Shaam	**6.08**
G357	Harrat Ash Shaam	**7.59**
G375	Galilee	**15.39**

A165

ID	Location	Euclidean distance	As G285
G026	NJV	**37.84**	25.70
G285	ESE Mafraq	**28.03**	28.03
G383	Galilee	**37.72**	33.83

A166

ID	Location	Euclidean distance	As G285
G026	NJV	**33.33**	25.83
G285	ESE Mafraq	**30.11**	30.11
G383	Galilee	**36.68**	35.13

A167

ID	Location	**Euclidean distance**	As G090
G026	NJV	**16.54**	15.91
G090	Ramon	**16.45**	16.45
G383	Galilee	**17.70**	17.11

A168

ID	Location	**Euclidean distance**
G022	NJV	**20.25**
G079	NJV	**25.86**
G090	Ramon	**22.60**

A169

ID	Location	**Euclidean distance**
G116	Mt Hermon	**32.30**
G160	Mt Hermon	**43.47**
G285	ESE Mafraq	**24.40**

A170

ID	Location	**Euclidean distance**
G022	NJV	**28.26**
G090	Ramon	**29.98**
G383	Galilee	**27.69**

A171

ID	Location	**Euclidean distance**	As G285
G026	NJV	**48.27**	20.38
G090	Ramon	**33.29**	33.29
G285	ESE Mafraq	**31.76**	31.76

A172

ID	Location	**Euclidean distance**
G022	NJV	**23.87**
G377	Galilee	**27.54**
G381	Galilee	**19.52**

A173

ID	Location	**Euclidean distance**
G022	NJV	**41.36**
G281	ESE Mafraq	**8.86**
G381	Galilee	**38.42**

A174

ID	Location	**Euclidean distance**	As G200
G156	Golan	**33.64**	22.28
G200	Galilee	**30.70**	30.70
G277	ESE Mafraq	**30.76**	23.09

A175

ID	Location	**Euclidean distance**	As G200
G156	Golan	**20.41**	11.12
G200	Galilee	**19.64**	19.64
G277	ESE Mafraq	**20.11**	16.35

A176

ID	Location	**Euclidean distance**
G156	Golan	**28.13**
G200	Galilee	**26.92**
G277	ESE Mafraq	**20.29**

A177

ID	Location	**Euclidean distance**	As G089
G089	Ramon	**8.14**	8.14
G357	Harrat Ash Shaam	**10.36**	10.36
G375	Galilee	**13.09**	8.44
G390	Golan	**12.74**	7.89

A178

ID	Location	**Euclidean distance**	As G370
G089	Ramon	**13.16**	12.02
G370	S Transjordan	**6.69**	6.69
G390	Golan	**6.74**	4.69

A179

ID	Location	**Euclidean distance**
G079	NJV	**11.24**
G090	Ramon	**15.46**
G370	S Transjordan	**11.38**

A180

ID	Location	**Euclidean distance**	As G370
G089	Ramon	**10.99**	10.95
G370	S Transjordan	**7.94**	7.94
G390	Golan	**11.69**	2.01

A181

ID	Location	**Euclidean distance**	As G370
G089	Ramon	**13.08**	13.04
G357	Harrat Ash Shaam	**16.16**	16.16
G370	S Transjordan	**13.51**	13.51
G390	Golan	**18.17**	8.18

A182

ID	Location	Euclidean distance
G089	Ramon	**5.71**
G357	Harrat Ash Shaam	**8.15**
G375	Galilee	**8.89**
G390	Golan	**9.56**

A183

ID	Location	Euclidean distance
G023	NJV	**29.54**
G024	NJV	**25.50**
G090	Ramon	**20.22**

A184

ID	Location	Euclidean distance
G370	S Transjordan	**13.61**
G375	Galilee	**13.97**
G378	Galilee	**13.24**

A185

ID	Location	Euclidean distance	As G357
G089	Ramon	**12.26**	7.87
G355	Harrat Ash Shaam	**13.74**	13.74
G357	Harrat Ash Shaam	**10.03**	10.03
G370	S Transjordan	**14.54**	14.54
G375	Galilee	**18.76**	7.48
G390	Golan	**18.65**	8.50

A186

ID	Location	Euclidean distance
G089	Ramon	**19.16**
G199	Galilee	**11.15**
G348	Harrat Ash Shaam	**19.39**
G350	Harrat Ash Shaam	**19.26**
G357	Harrat Ash Shaam	**17.38**

A187

ID	Location	Euclidean distance
G089	Ramon	**13.55**
G355	Harrat Ash Shaam	**16.12**
G357	Harrat Ash Shaam	**9.25**
G370	S Transjordan	**18.93**
G382	Galilee	**20.15**

A188

ID	Location	Euclidean distance	As G352
G274	NJV	**20.05**	15.35
G350	Harrat Ash Shaam	**19.62**	19.62
G352	Harrat Ash Shaam	**19.28**	19.28
G391	Golan	**20.36**	14.57

A189

ID	Location	Euclidean distance
G079	NJV	**11.67**
G370	S Transjordan	**12.39**
G386	Galilee	**10.05**

A190

ID	Location	Euclidean distance
G199	Galilee	**38.86**
G202	Galilee	**29.15**
G395	Kerak	**34.95**

Appendix 6: Comparison of assignments

ID	Sample	Previous	This study	Match?
A001	GP18	Kerak	Kerak	**Y**
A002	GP19	Kerak	Mt Hermon	N
A003	GP20	Kerak	Mt Hermon	N
A004	GP21	Kerak	Kerak	**Y**
A005	GP22	Eastern margin	W Mujib	**Y**
A006	GP23	W Mujib	Kerak/W Mujib	**Y**
A007	GP24	Kerak	Mt Hermon	N
A008	GP25	Kerak	Kerak	**Y**
A009	GP26	Kerak	Kerak	**Y**
A010	GP27	Kerak	Kerak	**Y**
A011	GP28	W Mujib	Golan	N
A012	GP29	Eastern margin	Kerak	N
A013	GP30	Kerak	NJV	N
A015	GP35	North Cis/Trans	Galilee/NJV	-
A017	GP36	North Cis/Trans	NJV	-
A018	GP37	North Cis/Trans	Galilee	-
A019	J1	Sweimah/Ma'in	Dead Sea	**Y**
A020	J2	Sweimah/Ma'in	Sweimah	**Y**
A021	J3	Sweimah/Ma'in	Dead Sea	**Y**
A022	J5	North Cis/Trans	Galilee	-
A023	J6	?	Mt Hermon	-
A024	J8	North Cis/Trans	Galilee	-
A025	J10	Eastern margin	Eastern margin	**Y**
A026	J11	Kerak	Kerak	**Y**
A027	J12	W Mujib	Kerak	N
A028	J13	North Cis/Trans	Galilee	-
A029	J15	?	NJV	-
A030	J16	?	NJV	-
A031	J17	?	Mt Hermon	-
A032	J26	?	Mt Hermon	-
A033	J27	?	Mt Hermon	-
A034	J29	Galilee?	NJV	N
A035	J31	NJV	Jordan Valley	N
A036	J32	NJV	NJV	**Y**
A037	J35	North Cis/Trans	Galilee	-
A038	J38	North Cis/Trans	Galilee	-
A039	J39	North Cis/Trans	Galilee	-
A040	J40	North Cis/Trans	NJV	-
A041	J42	NJV	Galilee	N
A042	J44	Galilee?	NJV	N
A043	J45	Galilee?	NJV	N
A044	J46	Galilee?	NJV	N
A045	J47	North Cis/Trans	Mt Hermon	-
A046	J51	Kerak	Kerak	**Y**
A047	J52	W Mujib	Galilee	N
A048	J53	W Mujib	Kerak	N
A049	J54	Kerak	Kerak	**Y**
A050	J55	W Mujib	Eastern margin	**Y**
A051	J56	?	NJV	-
A052	J57	?	Mt Hermon	-
A053	J58	?	Mt Hermon	-
			Match	***16***
			No match	***15***
			Other	***20***

Appendix 7: Geochemical data

The following pages contain a printed copy of the database which contains the basic data used throughout this thesis. A copy can also be found on the disk included in this thesis, which is saved in both MS Access 97 and html formats. More details are given on the ‘readme.txt’ file also contained on the disk.

The ‘Link’ table is omitted from the printed copy, as it simply reproduces the ID, Sample, and Site columns from the ‘Artefacts’ table and ID, Sample and Location columns from the ‘Geological’ table, which are combined as ID, Sample and Sample Site columns. Also, throughout the printed copy, Philip and Williams-Thorpe is abbreviated to P&W-T.

In the Major and Trace Analysis tables the column ‘Use’ denotes those analyses used in the provenance analyses. The analyses marked “No” are generally duplicate analyses of the same sample, except for G137, which was not used for the reasons discussed in Chapter 7.

In the Major Analysis and Norms tables, all measurements are given in wt%. In the Trace Analysis table, all measurements are given in parts per million.

Artefacts databse

ID	Sample	Site	Artefact	Period	Object	Context	Other
A001	GP18	Bab edh-Dhra'	Bowl	EBI		1979 S-26	
A002	GP19	Bab edh-Dhra'	?Bowl	EBI		?	
A003	GP20	Bab edh-Dhra'	Bowl	EBI		1979 S of F4	
A004	GP21	Bab edh-Dhra'	Bowl	EBI		1979 XIX.2	
A005	GP22	Bab edh-Dhra'	Bowl	EBI		1979 or 1981	
A006	GP23	Bab edh-Dhra'	Bowl	EBI		?	
A007	GP24	Bab edh-Dhra'	Bowl	EBI		?	
A008	GP25	Bab edh-Dhra'	Bowl	EBI		?	
A009	GP26	Bab edh-Dhra'	Bowl	EBI		?	
A010	GP27	Safi	Bowl	EBI		surface	
A011	GP28	Safi	Bowl	EBI		surface	
A012	GP29	Faynan	Bowl	EBI		surface	
A013	GP30	Faynan	Bowl	EBI		surface	
A015	GP35	Sal	Bowl	Chalcolithic		ZS89:7:7A14	
A017	GP36	Sal	Bowl	Chalcolithic		ZS89:7:2A22	
A018	GP37	Sal	Bowl	Chalcolithic		ZS89:7:1A7	
A019	J1	Ghassul	Grinder/ rubber	Chalcolithic	TG 950484	E XXIV 9.8	
A020	J2	Ghassul	Grinder/ rubber	Chalcolithic	TG 950563	A XI 11.21	
A021	J3	Ghassul	Grinder/ rubber	Chalcolithic	TG 950552	A X unstratfied	
A022	J5	Ghassul	Fenestrated bowl	Chalcolithic	TG 950291	P I 1.1	
A023	J6	Ghassul	Fenestrated bowl	Chalcolithic	TG 950576	P I 1.2	
A024	J8	Maadi	Spindle whorl	Chalcolithic	S.20026		
A025	J10	W. Fidan 4	Mortar	EBI		surface	
A026	J11	W. Faynan 100	Bowl	EBI		surface	
A027	J12	W. Faynan 100	Rubber	EBI		surface	
A028	J13	Tell Erani	Pedestal bowl	Chalcolithic	IDA96-1811	D1960 499/13	
A029	J15	Tell Erani	Bowl	EBI	IDA60-355	D1960 54/	
A030	J16	Tell Erani	Bowl	EBI	IDA96-1817	D1959 189/47	
A031	J17	Tell Erani	Four handled	EBI	IDA58-?	D 1956 2158	
A032	J26	Shuna	Bowl	EBI	SF 398	A 557	
A033	J27	Shuna	Bowl	Chalcolithic	SF 258	D 413	
A034	J29	Shuna	Bowl	Chalcolithic	SF 324	D 441	
A035	J31	Shuna	Bowl	EBI	SF 133	A 111	
A036	J32	Shuna	Mortar	Chalcolithic	SF 332	D 500	
A037	J35	Abu Matar	?Bowl	Chalcolithic		757.342	
A038	J38	Abu Matar	?Bowl	Chalcolithic		725	
A039	J39	Abu Matar	?Bowl	Chalcolithic		510.1	
A040	J40	Abu Matar	?Bowl	Chalcolithic		88.5	
A041	J42	es-Safadi	?Bowl	Chalcolithic		104.1	
A042	J44	es-Safadi	?Bowl	Chalcolithic		1719.2	

ID	Sample	Site	Artefact	Period	Object	Context	Other
A043	J45	es-Safadi	?Bowl	Chalcolithic		1792	
A044	J46	es-Safadi	?Bowl	Chalcolithic		2509.2	
A045	J47	Ghassul	Fenestrated bowl	Chalcolithic		surface	
A046	J51	Safi	Bowl	EBI		looting	
A047	J52	Safi	Bowl	EBI		looting	
A048	J53	Safi	Bowl	EBI		looting	
A049	J54	Safi	Bowl	EBI		looting	
A050	J55	Safi	Bowl	EBI		looting	
A051	J56	Shuna	Bowl	EBI		D 47	
A052	J57	Shuna	Bowl	EBI		tell edge	
A053	J58	Shuna	Bowl	EBI		A 32	
A054	Miqne 1	Miqne	Platter	IAI	Object 4662		
A055	Miqne 2	Miqne	Bowl	IAI	Object 4691		
A056	Miqne 3	Miqne	Lower GS	IAI	Object 6070		
A057	Miqne 4	Miqne	Lower GS	LBA	Object 6237		
A058	Miqne 5	Miqne	Upper GS	IAI	Object 4601		
A059	Miqne 6	Miqne	Bowl	IAII	Object 4089		
A060	Miqne 7	Miqne	Lower GS	LBA	Object 1272		
A061	Miqne 8	Miqne	Bowl	IAII	Object 229		
A062	Miqne 9	Miqne	(Baetyl) Drill cap	IAII	Object 1599		
A063	Miqne 10	Miqne	Lower GS	IAII	Object 3066		
A064	Miqne 11	Miqne	Upper GS	IAII	Object 2274		
A065	Miqne 12	Miqne	Rubbing stone	IAII	Object 3696		
A066	Miqne 13	Miqne	Pestle	IAI	Object 6186		
A067	Miqne 14	Miqne	Pestle	IAI	Object 5021		
A068	Miqne 15	Miqne	Rubbing stone	IAI	Object 5071		
A069	Miqne 16	Miqne	Rubbing stone	IAII	Object 7969		
A070	Miqne 17	Miqne	Mortar	IAI	Object 2191		
A071	Miqne 18	Miqne	Bowl	?EBI	Object 9777		
A072	Miqne 19	Miqne	4 handled bowl	EBI	Object 9832		
A073	Hazor 1	Hazor	Orthostat	LBA	?		
A074	Hazor 2	Hazor	GS	IA			Basket 54935
A075	Hazor 3	Hazor	Bowl	IA			Basket 55065
A076	Hazor 4	Hazor	GS	IA			Basket 16871
A077	Hazor 5	Hazor	Bowl	IA			Basket 31625
A078	Hazor 6	Hazor	Bowl	LBA			Locus 5562

ID	Sample	Site	Artefact	Period	Object	Context	Other
A079	Hazor 7	Hazor	3 legged pedestaled bowl	IA			Basket 16957
A080	Hazor 8	Hazor	GS	IA			Basket 51084
A081	Hazor 9	Hazor	Bowl	LBA			Basket 13778
A082	Hazor 10	Hazor	Bowl	LBA			Basket 13547
A083	Hazor 11	Hazor	Bowl	LBA			Basket 13548
A084	Hazor 12	Hazor	GS	IA			Basket 51243
A085	Hazor 13	Hazor	GS	LBA			Basket 26875
A086	Hazor 14	Hazor	Orthostat	LBA			W1212
A087	Hazor 15	Hazor	Lower GS	IA	?		
A088	Hazor 16	Hazor	Bowl	IA			Basket 53686
A089	Rehov 1	Rehov	GS	IAII			Basket 28535
A090	Rehov 2	Rehov	GS	IAII	?		
A091	Rehov 3	Rehov	GS	IAII			25/96
A092	Rehov 4	Rehov	GS	IAII	?		
A093	Rehov 5	Rehov	Saddle quern	IAII	?		
A094	Rehov 6	Rehov	Mortar	IAII	?		
A095	Rehov 7	Rehov	Quern	IAII			Basket 18075
A096	Rehov 8	Rehov	Saddle quern	IAII	?		
A097	Rehov 9	Rehov	GS	IAII			Basket 48580
A098	Rehov 10	Rehov	GS	IAII			Basket 48584
A099	Pella 1	Pella	Bowl	LBII	60260	IIIN 17.9	
A100	Pella 2	Pella	Bowl	LBI-II	920453	IIIS 6.1	
A101	Pella 3	Pella	Bowl	LBI-II	920042	IIIS 3.9	
A102	Pella 4	Pella	Bowl	Late Chalco	920668	XXXIID 18.34	
A102	Pella 5	Pella	Bowl	MBIIA	920544	IIIC 101.4	
A103	Pella 6	Pella	Bowl	LBII	130015	IIIQ 115.2	
A104	Pella 7	Pella	Fenestrated Bowl	Late Chalco	60461	XIVM 3.12	
A105	Pella 8	Pella	Bowl	IAI-II	861006	IIIP 108.4	
A106	Pella 9	Pella	Bowl	Late Chalco	920316	XIVM 3.3	
A107	Pella 10	Pella	Plate	LBII	900889	IIIQ 117.55	
A108	Pella 11	Pella	Bowl	IAI	60443	IIIN 18.6	
A109	Pella 12	Pella	Bowl	IAI	90023	IVE 103.1	
A110	Pella 13	Pella	Bowl	IAII	110194	XXXIIB 19.3	
A111	Pella 14	Pella	Tripod Bowl	IAII	861182	IIIP 109.5	
A112	Pella 15	Pella	Bowl	EBI-II	920545	XXXIID 17.22	
A113	Pella 16	Pella	Bowl	Late Chalco	60478	XIVM 4.1	
A114	Pella 17	Pella	Footed Bowl	IAII	90081	IIIP 107.1	
A115	Pella 18	Pella	Bowl	IAI-II	70075	IIIN 31.2	
A116	Pella 19	Pella	Bowl	IAII	900551	XXXIIB 12.35	
A117	Zippori 1	Zippori	GS	LBA			
A118	Zippori 2	Zippori	Basering mortar	LBA			
A119	Zippori 3	Zippori	Upper GS	LBA			
A120	Zippori 4	Zippori	Pestle	LBA			
A121	Zippori 5	Zippori	Quern	LBA			
A122	Zippori 6	Zippori	Upper GS	LBA			
A123	Zippori 7	Zippori	Upper GS	LBA			

ID	Sample	Site	Artefact	Period	Object	Context	Other
A124	Zippori 8	Zippori	?	LBA			
A125	Zippori 9	Zippori	Upper GS	LBA			
A126	Zippori 10	Zippori	Upper GS	LBA			
A127	Iktanu 1	Iktanu	Bowl	EBI	780.1.3		
A128	Iktanu 2	Iktanu	Bowl	EBI	6		
A129	Iktanu 3	Iktanu	Pestle	EBIV (EBI?)	7		
A130	Iktanu 4	Iktanu	Mortar	IA	47		
A131	Iktanu 5	Iktanu	Bowl	IA	54		
A132	Iktanu 6	Iktanu	Lower GS	EBI	55		
A133	Iktanu 7	Iktanu	Lower GS	EBI	56		
A134	Iktanu 8	Iktanu	Bowl	EBI	61		
A135	Iktanu 9	Iktanu	Bowl	EBI	109		
A136	Iktanu 10	Iktanu	Bowl	EBI	120		
A137	Iktanu 11	Iktanu	Bowl	EBI	780.1.4		
A138	Abu Matar 1	Abu Matar	Bowl	Chalcolithic		135.3	
A139	Abu Matar 2	Abu Matar	Bowl	Chalcolithic		135.5	
A140	Abu Matar 3	Abu Matar	Bowl	Chalcolithic		276	
A141	Abu Matar 4	Abu Matar	Bowl	Chalcolithic		298.3	
A142	Bir es-Safadi 1	Bir es-Safadi	Bowl	Chalcolithic		Surface	
A143	Bir es-Safadi 2	Bir es-Safadi	Bowl	Chalcolithic		256	
A144	Bir es-Safadi 3	Bir es-Safadi	Bowl	Chalcolithic		538	
A145	Bir es-Safadi 4	Bir es-Safadi	Bowl	Chalcolithic		2587	
A146	Shuna 1	Shuna	Bowl	EBI	SF 26	A6	
A147	Shuna 2	Shuna	Bowl	EBI	SF 60	A59	
A148	Shuna 3	Shuna	Bowl	Chalcolithic	SF 85	D98	
A149	Shuna 4	Shuna	Bowl	EBI	SF 211	F256	
A150	Shuna 5	Shuna	?Bowl	EBI	SF 218		
A151	Shuna 6	Shuna	Bowl	Chalcolithic	SF 416	D439	
A152	Shuna 7	Shuna	Bowl	EBI	SF 462	Ab633	
A153	Shuna 8	Shuna	Bowl	EBI	SF 486	Ab643	
A154	Shuna 9	Shuna	Bowl	EBA	SF 489	H672	
A155	Shuna 10	Shuna	Bowl	EBI	SF 630	Ab759	
A156	TM 2674	Miqne	?Quern-stone	IA	Object 2674		
A157	TM 872	Miqne	?Quern-stone	IA	Object 872		
A158	TM 879	Miqne	?Quern-stone	IA	Object 879		
A159	TM 2642	Miqne	?Quern-stone	IA	Object 2642		
A160	TM 653	Miqne	?Quern-stone	IA	Object 653		
A161	TM 1509	Miqne	?Quern-stone	IA	Object 1509		
A162	TM 2420	Miqne	Bowl	IA	Object 2420		
A163	TM 2676	Miqne	?Quern-stone	IA	Object 2676		

ID	Sample	Site	Artefact	Period	Object	Context	Other
A164	TM 2671	Miqne	?Quern-stone	IA	Object 2671		
A165	TM 1729	Miqne	?Bowl	IA	Object 1729		
A166	TM 1540	Miqne	?Bowl	IA	Object 1540		
A167	TM 1665	Miqne	?Bowl	IA	Object 1665		
A168	TM 822	Miqne	Mortar	IA	Object 822		
A169	TM 10	Miqne	?Bowl	IA	Object 10		
A170	TM 1795	Miqne	?Bowl	IA	Object 1795		
A171	TM 2678	Miqne	Altar	IA	Object 2678		
A172	TM 1743	Miqne	?Bowl	IA	Object 1743		
A173	TM 1686	Miqne	?Bowl	IA	Object 1686		
A174	TM 2673	Miqne	?Quern-stone	IA	Object 2673		
A175	TM 11	Miqne	?Quern-stone	IA	Object 11		
A176	TM 2669	Miqne	?Quern-stone	IA	Object 2669		
A177	TM 2000	Miqne	?Quern-stone	IA	Object 2000		
A178	TM 1781	Miqne	?Quern-stone	IA	Object 1781		
A179	TM 2677	Miqne	?Quern-stone	IA	Object 2677		
A180	TM 2672	Miqne	?Quern-stone	IA	Object 2672		
A181	TM 1113	Miqne	?Quern-stone	IA	Object 1113		
A182	TM 2675	Miqne	?Quern-stone	IA	Object 2675		
A183	TM 71	Miqne	?Quern-stone	IA	Object 71		
A184	TM 952	Miqne	?Quern-stone	IA	Object 952		
A185	TM 1565	Miqne	?Quern-stone	IA	Object 1565		
A186	TM 243	Miqne	?Quern-stone	IA	Object 243		
A187	TM 1476	Miqne	?Quern-stone	IA	Object 1476		
A188	TM 2668	Miqne	?Quern-stone	IA	Object 2668		
A189	TM 2670	Miqne	?Quern-stone	IA	Object 2670		
A190	TM 703	Miqne	?Quern-stone	IA	Object 703		
A191	TM 1109	Miqne	?	IA	Object 1109		

Geological samples database

ID	Sample	Location	Notes	Classification	Source
G001	GP2	E. of Kerak			P & W-T 1993
G002	GP4	E. of Kerak			P & W-T 1993
G003	GP5A	E. of Kerak			P & W-T 1993
G004	GP5B	E. of Kerak			P & W-T 1993
G005	GP6	Wadi Mujib			P & W-T 1993
G006	GP7	Wadi Mujib			P & W-T 1993
G007	GP8	Ghor el-Katar			P & W-T 1993
G008	GP9	Ghor el-Katar			P & W-T 1993
G009	GP10	Yarmouk			P & W-T 1993
G010	GP11	Yarmouk			P & W-T 1993
G011	GP12A	Sweimeh			P & W-T 1993
G012	GP12B	Sweimeh			P & W-T 1993
G013	GP12C	Sweimeh			P & W-T 1993
G014	GP14A	Zarqa Ma'in			P & W-T 1993
G015	GP14B	Zarqa Ma'in			P & W-T 1993
G016	GP16	Unnamed, N of Zarqa Ma'in			P & W-T 1993
G017	GP17	Unnamed, N of Zarqa Ma'in	XRF analysis x2		P & W-T 1993
G018	GP31	Dana Flow			P & W-T 1993
G019	GP33	Sal	XRF analysis x2		P & W-T 1993
G020	GP34	Sal			P & W-T 1993
G021	J18	N. of Shuna			P & W-T 2001
G022	J19	N of Shuna			P & W-T 2001
G023	J20	Adasiyeh			P & W-T 2001
G024	J21	Adasiyeh			P & W-T 2001
G025	J22	Wadi 'Arab			P & W-T 2001
G026	J23	Wadi 'Arab			P & W-T 2001
G027	J24	Maqarin			P & W-T 2001
G028	J25	Maqarin			P & W-T 2001
G029	Dead Sea 1	Sweimah			This study
G030	Dead Sea 2	Sweimah (1st outcrop)			This study
G031	Dead Sea 3	Sweimah (1st outcrop)			This study
G032	Dead Sea 4	Sweimah (1st outcrop)		Basanite	This study
G033	Dead Sea 5	Sweimah (1st outcrop)			This study
G034	Dead Sea 6	Sweimah (2nd outcrop)			This study
G035	Dead Sea 7	Sweimah (2nd outcrop)	Weathered section analysed		This study
G036	Dead Sea 8	Sweimah (2nd outcrop)			This study
G037	Dead Sea 9	Sweimah (2nd outcrop)		Basanite	This study
G038	Dead Sea 10	Sweimah (2nd outcrop)			This study
G039	Dead Sea 11	Zarqa Ma'in			This study
G040	Dead Sea 12	Zarqa Ma'in			This study
G041	Dead Sea 13	Zarqa Ma'in			This study
G042	Dead Sea 14	Zarqa Ma'in			This study
G043	Dead Sea 15	Zarqa Ma'in			This study
G044	Dead Sea 16	Zarqa Ma'in		Basanite	This study
G045	Dead Sea 17	Wadi Zarqa Ma'in			This study
G046	Dead Sea 18	Wadi Zarqa Ma'in			This study
G047	Dead Sea 19	Wadi Zarqa Ma'in			This study
G048	Dead Sea 20	Wadi Zarqa Ma'in			This study
G049	Kerak 1	Near Kerak (1)			This study
G050	Kerak 2	Near Kerak (1)			This study
G051	Kerak 3	Near Kerak (1)			This study
G052	Kerak 4	Near Kerak (2)			This study

ID	Sample	Location	Notes	Classification	Source
G053	Kerak 5	Near Kerak (2)		Basanite	This study
G054	Kerak 6	Near Kerak (2)			This study
G055	Kerak 7	Near Kerak (2)		Basanite	This study
G056	Kerak 8	Near Kerak (2)			This study
G057	Hasa 1	Black Mountain			This study
G058	Hasa 2	Black Mountain		Melanephelinite	This study
G059	Hasa 3	Black Mountain			This study
G060	Hasa 4	Black Mountain			This study
G061	Hasa 5	Black Mountain			This study
G062	Hasa 6	Black Mountain			This study
G063	Hasa 7	Black Mountain			This study
G064	Hasa 8	Black Mountain		Melanephelinite	This study
G065	Hasa 9	Black Mountain			This study
G066	Hasa 10	Black Mountain			This study
G067	Hasa 11	Near Wadi Hasa			This study
G068	Hasa 12	Near Wadi Hasa			This study
G069	Hasa 13	Near Wadi Hasa		Nephelinite	This study
G070	Hasa 14	Near Wadi Hasa			This study
G071	Hasa 15	Near Wadi Hasa			This study
G072	Hasa 16	Near Wadi Hasa	Weathered section analysed	Nephelinite	This study
G073	NJV 1	Near Baqura (1)			This study
G074	NJV 2	Near Baqura (1)			This study
G075	NJV 3	Near Baqura (1)			This study
G076	NJV 4	Near Baqura (1)			This study
G077	NJV 5	Near Baqura (1)		Alkali basalt	This study
G078	NJV 6	Near Baqura (1)			This study
G079	NJV 7	Near Baqura (2)		Alkali basalt	This study
G080	NJV 8	Near Baqura (2)			This study
G081	NJV 9	Near Baqura (2)		Alkali basalt	This study
G082	NJV 10	Near Baqura (2)			This study
G083	NJV 11	Near Baqura (2)			This study
G084	I93-72	Areif en Naqa, Sinai		Alkali basalt	Laws 1997
G085	I93-40	Makhtesh Ramon		Benmoreite	Laws 1997
G086	I93-41A	Ramon Laccolith		Hawaiite	Laws 1997
G087	I93-41B	Ramon Laccolith		Hawaiite	Laws 1997
G088	I93-41C	Ramon Laccolith		Alkali basalt	Laws 1997
G089	I93-41D	Ramon Laccolith		Hawaiite	Laws 1997
G090	I93-42	Wadi Ardon, Ramon		Tholeiitic basalt	Laws 1997
G091	I93-43A	Wadi Ardon, Ramon		Phonotephrite	Laws 1997
G092	I93-43B	Wadi Ardon, Ramon		Phonotephrite	Laws 1997
G093	I93-31	Makhtesh Ramon		Tholeiitic basalt	Laws 1997
G094	I93-32	Makhtesh Ramon		Alkali basalt	Laws 1997
G095	I93-33	Makhtesh Ramon		Alkali basalt	Laws 1997
G096	I93-34	Makhtesh Ramon		Basanite	Laws 1997
G097	I93-35	Makhtesh Ramon		Melanephelinite	Laws 1997
G098	I93-37	Mt. Arod upper intrusive, Ramon		Melanephelinite	Laws 1997
G099	I93-38	Mt. Arod lower intrusive, Ramon		Basanite	Laws 1997
G100	I93-39	Makhtesh Ramon		Melanephelinite	Laws 1997
G101	J94-1	Wadi Dardur, E of Dead Sea		Shoshonite	Laws 1997
G102	J94-2	Wadi Himara, E of Dead Sea		Picrobasalt	Laws 1997
G103	J94-4	Nr Madaba		Basanite	Laws 1997
G104	J94-5	Nr Madaba		Mugearite	Laws 1997
G105	I94-16	Wadi Malih, W Jordan Valley		Phonotephrite	Laws 1997
G106	I94-17	Wadi Malih, W Jordan Valley		Alkali basalt	Laws 1997

ID	Sample	Location	Notes	Classification	Source
G107	I94-18	Wadi Malih, W Jordan Valley		Potassic trachybasalt	Laws 1997
G108	I93-58A	Mt. Carmel		Tholeiitic basalt	Laws 1997
G109	I93-58B	Mt. Carmel		Tholeiitic basalt	Laws 1997
G110	I93-59	Mt. Carmel		Alkali basalt	Laws 1997
G111	I93-60	Mt. Carmel		Basanite	Laws 1997
G112	I93-3A	SE Mt. Hermon		Alkali basalt	Laws 1997
G113	I93-4	SE Mt. Hermon		Breccia	Laws 1997
G114	I93-5A	SE Mt. Hermon		Breccia	Laws 1997
G115	I93-7A	SE Mt. Hermon		Potassic trachybasalt	Laws 1997
G116	I93-9C	SE Mt. Hermon		Tholeiitic basalt	Laws 1997
G117	I93-13A	SE Mt. Hermon		Alkali basalt	Laws 1997
G118	I93-13B	SE Mt. Hermon		Alkali basalt	Laws 1997
G119	I93-14A	SE Mt. Hermon		Breccia	Laws 1997
G120	I93-15	SE Mt. Hermon		Breccia	Laws 1997
G121	I93-17	SE Mt. Hermon		Alkali basalt	Laws 1997
G122	I93-19A	SE Mt. Hermon		Basanite	Laws 1997
G123	I93-19B	SE Mt. Hermon		Basanite	Laws 1997
G124	I93-21	SE Mt. Hermon		Alkali basalt	Laws 1997
G125	I93-45A	SE Mt. Hermon		Tholeiitic basalt	Laws 1997
G126	I93-46	SE Mt. Hermon		Alkali basalt	Laws 1997
G127	I93-47	SE Mt. Hermon		Nephelinite	Laws 1997
G128	I93-52	SE Mt. Hermon		Basanite	Laws 1997
G129	I93-61	SE Mt. Hermon		Potassic trachybasalt	Laws 1997
G130	I93-62	SE Mt. Hermon		Potassic trachybasalt	Laws 1997
G131	I94-15	SE Mt. Hermon		Tholeiitic basalt	Laws 1997
G132	I93-2	SE Mt. Hermon		Basanite	Laws 1997
G133	I93-8	SE Mt. Hermon		Basanite	Laws 1997
G134	I93-10	SE Mt. Hermon		Alkali basalt	Laws 1997
G135	I93-11	SE Mt. Hermon		Basanite	Laws 1997
G136	I93-12	SE Mt. Hermon		Alkali basalt	Laws 1997
G137	I93-18B	SE Mt. Hermon	Anomalous trace-element data	Alkali basalt	Laws 1997
G138	I93-18C	SE Mt. Hermon		Hawaiite	Laws 1997
G139	I93-48	SE Mt. Hermon		Basanite	Laws 1997
G140	I93-50	SE Mt. Hermon		Alkali basalt	Laws 1997
G141	I93-51	SE Mt. Hermon		Alkali basalt	Laws 1997
G142	I94-6B	SE Mt. Hermon		Alkali basalt	Laws 1997
G143	I94-6C	SE Mt. Hermon		Potassic trachybasalt	Laws 1997
G144	I94-6D	SE Mt. Hermon		Trachyte	Laws 1997
G145	I94-9	SE Mt. Hermon		Hawaiite	Laws 1997
G146	J94-6	Ed Dabbusa, Jordan		Alkali basalt	Laws 1997
G147	I94-19A	Galilee Tiberias		Basanite	Laws 1997
G148	I94-19B	Galilee Tiberias		Alkali basalt	Laws 1997
G149	I94-20	Galilee Tiberias		Basanite	Laws 1997
G150	I93-20A	Golan Heights		Basanite	Laws 1997
G151	I93-22	Golan Heights		Basanite	Laws 1997
G152	I93-24	Golan Heights		Basanite	Laws 1997
G153	I93-25	Golan Heights		Basanite	Laws 1997
G154	I93-26	Golan Heights		Alkali basalt	Laws 1997
G155	I93-27	Golan Heights		Tholeiitic basalt	Laws 1997
G156	I93-28	Golan Heights		Hawaiite	Laws 1997
G157	I93-53	Golan Heights		Alkali basalt	Laws 1997
G158	AS 505	Mt Hermon dyke		Dolerite (Tholeiitic basalt)	Wilson et al 2000
G159	SL 103	Mt Hermon dyke		Dolerite (Tholeiitic basalt)	Wilson et al 2000
G160	SL 116	Mt Hermon dyke		Dolerite (Tholeiitic basalt)	Wilson et al 2000
G161	AS 626	Mt Hermon		Hawaiite	Wilson et al 2000

ID	Sample	Location	Notes	Classification	Source
G162	AS 628	Mt Hermon		Tholeiitic basalt	Wilson et al 2000
G163	AS 472	Mt Hermon		Hawaiite	Wilson et al 2000
G164	AS 527	Mt Hermon		Alkali basalt	Wilson et al 2000
G165	AS 114	Mt Hermon		Alkali basalt	Wilson et al 2000
G166	AS 525	Mt Hermon dyke		Hawaiite	Wilson et al 2000
G167	SL 119	Mt Hermon dyke		Hawaiite	Wilson et al 2000
G168	SL 117	Mt Hermon dyke		Alkali basalt	Wilson et al 2000
G169	AS 503	Mt Hermon		Alkali basalt	Wilson et al 2000
G170	SL 111	Mt Hermon		Basanite	Wilson et al 2000
G171	SL 120	Mt Hermon		Alkali basalt	Wilson et al 2000
G172	SL 108	Mt Hermon		Alkali basalt	Wilson et al 2000
G173	Wy-351	Poria, Galilee		Alkali basalt	Weinstein 2000
G174	Wy-352	Poria, Galilee		Alkali basalt	Weinstein 2000
G175	Wy-368	Poria, Galilee		Tholeiitic basalt	Weinstein 2000
G176	Wy-369	Poria, Galilee		Alkali basalt	Weinstein 2000
G177	Wy-149	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G178	Wy-158	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G179	Wy-159	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G180	Wy-164	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G181	Wy-168	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G182	Wy-171	Kaukab, Galilee			Weinstein 2000
G183	Wy-172	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G184	Wy-179	Kaukab, Galilee		Basanite	Weinstein 2000
G185	Wy-181	Kaukab, Galilee		Basanite	Weinstein 2000
G186	Wy-182	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G187	Wy-188	Kaukab, Galilee		Hawaiite	Weinstein 2000
G188	Wy-190	Kaukab, Galilee			Weinstein 2000
G189	Wy-192	Kaukab, Galilee		Basanite	Weinstein 2000
G190	Wy-193	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G191	Wy-194	Kaukab, Galilee			Weinstein 2000
G192	Wy-195	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G193	Wy-196	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G194	Wy-199	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G195	Wy-203	Kaukab, Galilee		Mugearite	Weinstein 2000
G196	Wy-222	Kaukab, Galilee			Weinstein 2000
G197	Wy-224	Kaukab, Galilee		Basanite	Weinstein 2000
G198	Wy-226	Kaukab, Galilee		Hawaiite	Weinstein 2000
G199	Wy-318	Wadi Tavor dyke, Galilee		Tholeiitic basalt	Weinstein 2000
G200	Wy-320	Wadi Tavor dyke, Galilee		Tholeiitic basalt	Weinstein 2000
G201	Wy-20001	Wadi Tavor dyke, Galilee		Tholeiitic basalt	Weinstein 2000
G202	Wy-346	Mt Gilboa, Galilee		Alkali basalt	Weinstein 2000
G203	Wy-347a	Mt Gilboa, Galilee		Hawaiite	Weinstein 2000
G204	Wy-349	Mt Gilboa, Galilee		Tholeiitic basalt	Weinstein 2000
G205	Wy-350	Mt Gilboa, Galilee		Basanite	Weinstein 2000
G206	Wy-353	Yizreel Valley		Nephelinite	Weinstein 2000
G207	Wy-354	Yizreel Valley			Weinstein 2000
G208	Wy-356	Yizreel Valley		Nephelinite	Weinstein 2000
G209	Wy-357	Yizreel Valley			Weinstein 2000
G210	Wy-359	Yizreel Valley			Weinstein 2000
G211	Wy-360	Yizreel Valley		Hawaiite	Weinstein 2000
G212	Wy-361	Yizreel Valley		Basanite	Weinstein 2000
G213	Wy-402	Yizreel Valley		Basanite	Weinstein 2000
G214	Wy-322	Yizreel Valley		Basanite	Weinstein 2000
G215	Wy-324	Yizreel Valley		Basanite	Weinstein 2000
G216	Wy-325	Yizreel Valley		Basanite	Weinstein 2000
G217	Wy-327	Yizreel Valley		Basanite	Weinstein 2000
G218	Wy-329	Yizreel Valley		Tephrite	Weinstein 2000
G219	Wy-332	Yizreel Valley		Potassic trachybasalt	Weinstein 2000
G220	Wy-333	Yizreel Valley		Basanite	Weinstein 2000
G221	Wy-334	Golan		Alkali basalt	Weinstein 2000
G222	Wy-335	Golan		Alkali basalt	Weinstein 2000

ID	Sample	Location	Notes	Classification	Source
G223	Wy-218	Kaukab, Galilee		Alkali basalt	Weinstein 2000
G224	Wy-214	Kaukab, Galilee		Hawaiite	Weinstein 2000
G225	BW-20	Roded		Mugearite	Bogoch et al. 1993
G226	BW-21	Roded		Mugearite	Bogoch et al. 1993
G227	BW-26	Roded		Shoshonite	Bogoch et al. 1993
G228	BW-27	Roded		Shoshonite	Bogoch et al. 1993
G229	BW-18	Roded		Benmoreite	Bogoch et al. 1993
G230	TY-7	Roded		Latite	Bogoch et al. 1993
G231	TY-19	Roded		Tholeiitic basalt	Bogoch et al. 1993
G232	TV22	Roded		Mugearite	Bogoch et al. 1993
G233	CB3	Wadis Subda and Rahma, Araba		Alkali basalt	Jarrar et al. 1992
G234	CB4	Wadis Subda and Rahma, Araba		Mugearite	Jarrar et al. 1992
G235	CB5	Wadis Subda and Rahma, Araba		Mugearite	Jarrar et al. 1992
G236	CB6	Wadis Subda and Rahma, Araba		Mugearite	Jarrar et al. 1992
G237	CB7	Wadis Subda and Rahma, Araba		Tholeiitic basalt	Jarrar et al. 1992
G238	CC1	Wadis Subda and Rahma, Araba		Shoshonite	Jarrar et al. 1992
G239	W15	Wadis Subda and Rahma, Araba		Shoshonite	Jarrar et al. 1992
G240	W51	Wadis Subda and Rahma, Araba		Phonotephrite	Jarrar et al. 1992
G241	Q9-N	Wadi Faynan		Shoshonite	Jarrar et al. 1992
G242	Q13-N	Wadi Faynan		Mugearite	Jarrar et al. 1992
G243	17-N	Wadi Faynan		Shoshonite	Jarrar et al. 1992
G244	10-N	Wadi Faynan		Shoshonite	Jarrar et al. 1992
G245	26-N	Wadi Faynan		Mugearite	Jarrar et al. 1992
G246	31-N	Wadi Faynan		Mugearite	Jarrar et al. 1992
G247	Q1-N	Wadi Faynan		Shoshonite	Jarrar et al. 1992
G248	37-N	Wadi Faynan		Mugearite	Jarrar et al. 1992
G249	39-N	Wadi Faynan		Potassic trachybasalt	Jarrar et al. 1992
G250	CB8	Wadis Faynan and Abu-Kusheiba, Araba		Benmoreite	Jarrar et al. 1992
G251	CB9	Wadis Faynan and Abu-Kusheiba, Araba		Andesite	Jarrar et al. 1992
G252	W12	Wadis Faynan and Abu-Kusheiba, Araba		Andesite	Jarrar et al. 1992
G253	W52	Wadis Faynan and Abu-Kusheiba, Araba		Latite	Jarrar et al. 1992
G254	Q2-N	Wadis Faynan and Abu-Kusheiba, Araba		Trachyte	Jarrar et al. 1992
G255	Q7-N	Wadis Faynan and Abu-Kusheiba, Araba		Rhyolite	Jarrar et al. 1992
G256	12-N	Wadis Faynan and Abu-Kusheiba, Araba		Andesite	Jarrar et al. 1992
G257	16-N	Wadis Faynan and Abu-Kusheiba, Araba		Trachyte	Jarrar et al. 1992
G258	24-N	Wadis Faynan and Abu-Kusheiba, Araba		Benmoreite	Jarrar et al. 1992
G259	CA2	Wadi Rahma,		Latite	Jarrar et al. 1992
G260	CA3	Wadi Rahma,		Benmoreite	Jarrar et al. 1992

ID	Sample	Location	Notes	Classification	Source
G261	CA4	Wadi Rahma,		Benmoreite	Jarrar et al. 1992
G262	CA5	Wadi Rahma,		Trachyte	Jarrar et al. 1992
G263	CA6	Wadi Rahma,		Basaltic andesite	Jarrar et al. 1992
G264	CA7	Wadi Rahma,		Benmoreite	Jarrar et al. 1992
G265	CA8	Wadi Rahma,		Latite	Jarrar et al. 1992
G266	CA9	Wadi Rahma,		Andesite	Jarrar et al. 1992
G267	1	Zarqa Ma'in River		Basanite	Saffarini et al.
G268	2	Zarqa Ma'in River		Basanite	Saffarini et al.
G269	3	Zarqa Ma'in River		Potassic trachybasalt	Saffarini et al. 1987
G270	4	Zarqa Ma'in River		Basanite	Saffarini et al.
G271	5	Dhuleil area		Basanite	Saffarini et al.
G272	6	Dhuleil area		Picrite	Saffarini et al.
G273	7	Dhuleil area		Alkali basalt	Saffarini et al.
G274	8	Dhuleil area		Hawaiite	Saffarini et al.
G275	9	ESE Mafraq		Alkali basalt	Saffarini et al.
G276	10	ESE Mafraq		Alkali basalt	Saffarini et al.
G277	11	ESE Mafraq		Basanite	Saffarini et al.
G278	12	ESE Mafraq		Alkali basalt	Saffarini et al.
G279	13	ESE Mafraq		Alkali basalt	Saffarini et al.
G280	14	ESE Mafraq		Alkali basalt	Saffarini et al.
G281	15	ESE Mafraq		Alkali basalt	Saffarini et al.
G282	16	ESE Mafraq		Alkali basalt	Saffarini et al.
G283	17	ESE Mafraq		Alkali basalt	Saffarini et al.
G284	18	ESE Mafraq		Alkali basalt	Saffarini et al.
G285	19	ESE Mafraq		Alkali basalt	Saffarini et al.
G286	20	ESE Mafraq		Alkali basalt	Saffarini et al.
G287	21	Jurf ad-Darawish		Melanephelinite	Saffarini et al.
G288	22	Jurf ad-Darawish		Melanephelinite	Saffarini et al.
G289	23	Jurf ad-Darawish		Nephelinite	Saffarini et al.
G290	24	Jurf ad-Darawish		Alkali basalt	Saffarini et al.
G291	25	Jurf ad-Darawish		Alkali basalt	Saffarini et al.
G292	26	Jebel Unayzah		Alkali basalt	Saffarini et al.
G293	27	Jebel Unayzah		Nephelinite	Saffarini et al.
G294	28	W of Jurf ad-Darawish		Melanephelinite	Saffarini et al. 1987
G295	29	W of Jurf ad-Darawish		Nephelinite	Saffarini et al. 1987
G296	30	W of Jurf ad-Darawish		Nephelinite	Saffarini et al. 1987
G297	2	Wadi Dardur, E of Dead Sea		Tholeiitic basalt	Shawabekeh 1998
G298	4	Wadi Dardur, E of Dead Sea		Basanite	Shawabekeh 1998
G299	5	Wadi Dardur, E of Dead Sea		Mugearite	Shawabekeh 1998
G300	WY-1	En Zivan, Golan		Hawaiite	Weinstein et al. 1994
G301	WY-2	En Zivan, Golan		Hawaiite	Weinstein et al. 1994
G302	WY-5	En Zivan, Golan		Hawaiite	Weinstein et al. 1994
G303	WY-17	En Zivan, Golan		Alkali basalt	Weinstein et al. 1994
G304	WY-18	En Zivan, Golan		Basanite	Weinstein et al. 1994
G305	WY-19	En Zivan, Golan		Basanite	Weinstein et al. 1994
G306	WY-20	En Zivan, Golan		Basanite	Weinstein et al. 1994
G307	WY-21	En Zivan, Golan		Basanite	Weinstein et al. 1994
G308	WY-22	En Zivan, Golan		Basanite	Weinstein et al. 1994

ID	Sample	Location	Notes	Classification	Source
G309	WY-28	En Zivan, Golan		Basanite	Weinstein et al. 1994
G310	WY-29	En Zivan, Golan		Basanite	Weinstein et al. 1994
G311	WY-30	En Zivan, Golan		Basanite	Weinstein et al. 1994
G312	WY-56	En Zivan, Golan		Basanite	Weinstein et al. 1994
G313	WY-74	En Zivan, Golan		Alkali basalt	Weinstein et al. 1994
G314	WY-44	Odem Scoria, Golan		Hawaiite	Weinstein et al. 1994
G315	WY-50	Odem Scoria, Golan		Basanite	Weinstein et al. 1994
G316	WY-25	Kibbutz Basalt, Golan		Basanite	Weinstein et al. 1994
G317	WY-26	Kibbutz Basalt, Golan		Hawaiite	Weinstein et al. 1994
G318	WY-33	Kibbutz Basalt, Golan		Hawaiite	Weinstein et al. 1994
G319	WY-9	Muweisse, Golan		Basanite	Weinstein et al. 1994
G320	WY-10	Muweisse, Golan		Alkali basalt	Weinstein et al. 1994
G321	WY-13	Muweisse, Golan		Basanite	Weinstein et al. 1994
G322	WY-16	Muweisse, Golan		Basanite	Weinstein et al. 1994
G323	WY-67	Muweisse, Golan		Alkali basalt	Weinstein et al. 1994
G324	WY-70	Muweisse, Golan		Hawaiite	Weinstein et al. 1994
G325	WY-71	Muweisse, Golan		Basanite	Weinstein et al. 1994
G326	WY-72	Muweisse, Golan		Potassic trachybasalt	Weinstein et al. 1994
G327	WY-3	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G328	WY-6	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G329	WY-7	Dalwe, Golan		Basanite	Weinstein et al. 1994
G330	WY-8	Dalwe, Golan		Basanite	Weinstein et al. 1994
G331	WY-27	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G332	WY-32	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G333	WY-65	Dalwe, Golan		Alkali basalt	Weinstein et al. 1994
G334	WY-66	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G335	P-63	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G336	WY-77	Dalwe, Golan		Hawaiite	Weinstein et al. 1994
G337	WY-62	Sheivan Scoria, Golan		Tholeiitic basalt	Weinstein et al. 1994
G338	A1c	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G339	A3	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G340	A3b	Jebel Aritain, N of Azraq		Hawaiite	Al-Malabeh 1994

ID	Sample	Location	Notes	Classification	Source
G341	A8	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G342	A9a	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G343	A9b	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G344	A10b	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G345	A20a	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G346	A19	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G347	A21c	Jebel Aritain, N of Azraq		Alkali basalt	Al-Malabeh 1994
G348	M3b	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G349	M3c	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G350	M7	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G351	M10	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G352	M10c	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G353	M11a	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G354	M12	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G355	M14	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G356	M17	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G357	M22	Jebel Fahem, N of Azraq		Alkali basalt	Al-Malabeh 1994
G358	REE average	Jebel Aritain, N of Azraq			Al-Malabeh 1994
G359	REE average	Jebel Fahem, N of Azraq			Al-Malabeh 1994
G360	Average	Wadi al-Mujib		Tholeiitic basalt	Khalil 1992
G361	Average	Wadi al-Hidan		Basanite	Khalil 1992
G362	WF-3	Sweimah		Basanite	Duffield et al. 1988
G363	WF-4	Zarqa Ma'in		Tephrite	Duffield et al. 1988
G364	WF-6	Zarqa Ma'in		Basanite	Duffield et al. 1988
G365	Average	Shurairyh	Average of 8 samples	Tholeiitic basalt	Jarrar 2001
G366	Average	Quweira	Average of 15 samples	Tholeiitic basalt	Jarrar 2001
G367	Average	Yutum	Average of 11 samples	Tholeiitic basalt	Jarrar 2001
G368	Average	Filk	Average of 2 samples	Basaltic andesite	Jarrar 2001
G369	Average	Rahma	Average of 4 samples	Basaltic andesite	Jarrar 2001
G370	Average	Mubarak	Average of 2 samples	Phonotephrite	Jarrar 2001
G371	SH-5	Shurairyh	REE analysis		Jarrar 2001
G372	SJ-4	Quweira	REE analysis		Jarrar 2001
G373	SJ-9	Quweira	REE analysis		Jarrar 2001
G374	GB1	Tiberias area (W side)		Alkali basalt	W-T and Thorpe 1993
G375	GB2	Tiberias area (W side)		Alkali basalt	W-T and Thorpe 1993
G376	GB3	Tiberias area (W side)		Tholeiitic basalt	W-T and Thorpe 1993

ID	Sample	Location	Notes	Classification	Source
G377	GB4	Tiberias area (W side)		Tholeiitic basalt	W-T and Thorpe 1993
G378	GB5	Tiberias area (W side)		Tholeiitic basalt	W-T and Thorpe 1993
G379	GB6	Tiberias area (W side)		Alkali basalt	W-T and Thorpe 1993
G380	GB7	Tiberias area (E side)		Alkali basalt	W-T and Thorpe 1993
G381	GB8	Tiberias area (E side)		Tholeiitic basalt	W-T and Thorpe 1993
G382	GB9	Tiberias area (W side)		Basanite	W-T and Thorpe 1993
G383	GB10	Tiberias area (W side)		Alkali basalt	W-T and Thorpe 1993
G384	GB11	Tiberias area (W side)			W-T and Thorpe 1993
G385	GB12	Tiberias area (W side)		Basanite	W-T and Thorpe 1993
G386	GB13	Tiberias area (W side)			W-T and Thorpe 1993
G387	GOL1	Golan		Basanite	W-T and Thorpe 1993
G388	GOL2	Golan		Hawaiite	W-T and Thorpe 1993
G389	GOL4	Golan		Hawaiite	W-T and Thorpe 1993
G390	GOL5	Golan		Alkali basalt	W-T and Thorpe 1993
G391	GOL6	Golan		Hawaiite	W-T and Thorpe 1993
G392	BR1	Berekhat Ram, Golan		Basanite	W-T and Thorpe 1993
G393	I	Ma'in	Average of 8 samples	Basanite	Nasir 1990
G394	II (AOB)	Kerak	Average of 4 samples	Alkali basalt	Nasir 1990
G395	II (H)	Kerak	Average of 5 samples	Hawaiite	Nasir 1990
G396	III	Tafila	Average of 7 samples	Basanite	Nasir 1990
G397	IV	Unyza	Average of 5 samples	Alkali basalt	Nasir 1990
G398	V (AOB)	Harrat Ash Shaam	Average of 6 samples	Alkali basalt	Nasir 1990
G399	V (B)	Harrat Ash Shaam	Average of 10 samples	Basanite	Nasir 1990

Major analyses database

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
A001	XRF		Y		1.45		12.78		
A002	XRF		Y		1.42		12.47		
A003	XRF		Y		1.44		12.71		
A004	XRF		Y		1.48		12.9		
A005	XRF		Y		1.6		11.7		
A006	XRF		Y		2.01		13.15		
A007	XRF		Y		1.44		12.77		
A008	XRF		Y		1.55		12.85		
A009	XRF		Y		1.62		13.08		
A010	XRF		Y		1.42		12.17		
A011	XRF		Y		1.96		12.55		
A012	XRF		Y		1.73		11.94		
A013	XRF	Average	Y		1.775		11.64		
A013a	XRF	93/30.1	N		1.76		11.61		
A013b	XRF	93/30.2	N		1.79		11.67		
A015	XRF	Average	Y		1.825		11.97		
A015a	XRF	93/35.1	N		1.83		11.86		
A015b	XRF	93/35.1	N		1.82		12.08		
A017	XRF		Y		1.69		12.47		
A018	XRF		Y		2.03		11.98		
A019	XRF		Y		2.69		13.16		
A020	XRF		Y		2.65		13.49		
A021	XRF		Y		2.8		13.63		
A022	XRF		Y		2.11		12.31		
A023	XRF		Y		1.65		12.72		
A024	XRF		Y		2.08		12.49		
A025	XRF		Y		3.44		14.59		
A026	XRF		Y		1.54		13.17		
A027	XRF		Y		1.93		12.5		
A028	XRF		Y		2.05		11.87		
A029	XRF		Y		2.46		12.75		
A030	XRF		Y		2.32		12.33		
A031	XRF		Y		1.73		13.05		
A032	XRF		Y		1.96		13.45		
A033	XRF		Y		1.68		13.12		
A034	XRF		Y		1.94		13.28		
A035	XRF		Y		2.35		12.63		
A036	XRF		Y		1.7		11.9		
A037	XRF		Y		1.78		13.25		
A038	XRF		Y		1.92		11.72		
A039	XRF		Y		2.05		13.52		
A040	XRF		Y		1.85		11.65		
A041	XRF		Y		2.29		12.01		
A042	XRF		Y		2		13.45		
A043	XRF		Y		2.05		12.68		
A044	XRF		Y		2.11		12.93		
A045	XRF		Y		1.74		13.18		
A046	XRF		Y		1.38		12.7		
A047	XRF		Y		1.95		12.96		
A048	XRF		Y		1.98		12.89		
A049	XRF		Y		1.61		13.43		
A050	XRF		Y		2.12		13.17		
A051	XRF		Y		1.93		13.85		
A052	XRF		Y		1.68		12.27		
A053	XRF		Y		1.6		12.54		

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
A001										P & W-T 1993
A002										P & W-T 1993
A003										P & W-T 1993
A004										P & W-T 1993
A005										P & W-T 1993
A006										P & W-T 1993
A007										P & W-T 1993
A008										P & W-T 1993
A009										P & W-T 1993
A010										P & W-T 1993
A011										P & W-T 1993
A012										P & W-T 1993
A013										P & W-T 1993
A013a										P & W-T 1993
A013b										P & W-T 1993
A015										P & W-T 1993
A015a										P & W-T 1993
A015b										P & W-T 1993
A017										P & W-T 1993
A018										P & W-T 1993
A019										P & W-T 2001
A020										P & W-T 2001
A021										P & W-T 2001
A022										P & W-T 2001
A023										P & W-T 2001
A024										P & W-T 2001
A025										P & W-T 2001
A026										P & W-T 2001
A027										P & W-T 2001
A028										P & W-T 2001
A029										P & W-T 2001
A030										P & W-T 2001
A031										P & W-T 2001
A032										P & W-T 2001
A033										P & W-T 2001
A034										P & W-T 2001
A035										P & W-T 2001
A036										P & W-T 2001
A037										P & W-T 2001
A038										P & W-T 2001
A039										P & W-T 2001
A040										P & W-T 2001
A041										P & W-T 2001
A042										P & W-T 2001
A043										P & W-T 2001
A044										P & W-T 2001
A045										P & W-T 2001
A046										P & W-T 2001
A047										P & W-T 2001
A048										P & W-T 2001
A049										P & W-T 2001
A050										P & W-T 2001
A051										P & W-T 2001
A052										P & W-T 2001
A053										P & W-T 2001

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
A156	XRF		Y	46.08	2.29	14.62	12.47	2.49	9.98
A165	XRF		Y	47.55	1.81	15.18	13.07	2.61	10.46
A174	XRF		Y	45.89	2.65	15.1	12.63	3.79	8.84
A177	XRF		Y	46.65	2.24	14.66	12.71	2.54	10.17
A186	XRF		Y	46.51	2.78	13.93	13.3	3.99	9.31
A188	XRF		Y	48.06	2.75	16.59	12.98	3.89	9.09
A189	XRF		Y	45.75	1.98	13.77	13.04	2.61	10.43
A190	XRF		Y	46.5	2.28	13.57	13.3	3.99	9.31
A191	XRF		Y	52.29	0.19				
G001	XRF		Y		1.47		12.77		
G002	XRF		Y		1.93		11.91		
G003	XRF		Y		1.7		11.9		
G004	XRF		Y		2.85		12.88		
G005	XRF		Y		1.78		12.33		
G006	XRF		Y		1.65		12.39		
G007	XRF		Y		2.38		12.32		
G008	XRF		Y		1.78		12.33		
G009	XRF		Y		2.38		12.25		
G010	XRF		Y		2.69		12.97		
G011	XRF		Y		2.64		13.07		
G012	XRF		Y		2.71		12.86		
G013	XRF		Y		2.57		12.8		
G014	XRF		Y		2.99		13.21		
G015	XRF		Y		2.8		13.87		
G016	XRF		Y		2.82		13.7		
G017a	XRF		Y		2.66		13.24		
G017b	XRF		Y		2.69		13.22		
G018	XRF		Y		2.45		13.38		
G019	XRF		Y		1.42		12.47		
G019a	XRF		Y		2.11		11.6		
G019b	XRF		Y		2.13		11.66		
G020	XRF		Y		1.75		11.73		
G021	XRF		Y		1.82		13.36		
G022	XRF		Y		2		12.12		
G023	XRF		Y		1.8		11.87		
G024	XRF		Y		1.88		11.78		
G025	XRF		Y		1.97		12.56		
G026	XRF		Y		1.85		11.61		
G027	XRF		Y		2.38		13.29		
G028	XRF		Y		2.37		12.92		
G032	XRF		Y	43.64	2.831	13.92	13.599	4.11	9.59
G037	XRF		Y	44.01	2.727	13.908	13.27	2.69	10.75
G044	XRF		Y	43.5	2.582	13.728	13.8	2.8	11.19
G053	XRF		Y	43.29	2.072	13.808	12.458	2.56	10.24
G055	XRF		Y	43.53	1.634	14.517	12.719	2.63	10.52
G058	XRF		Y	42.02	2.551	12.387	13.788	2.78	11.14
G064	XRF		Y	41.47	2.567	11.399	14.062	2.83	11.33
G069	XRF		Y	39.4	3.608	12.37	15.002	4.61	10.76
G072	XRF		Y	39.57	3.59	12.384	15.009	4.59	10.72
G077	XRF		Y	45.7	1.92	15.457	12.376	2.54	10.17
G079	XRF		Y	47.41	2.118	16.339	12.165	2.45	9.78
G081	XRF		Y	47.82	1.915	15.962	12.332	2.46	9.83
G084	XRF		Y	45.9	1.43	14.55	12.67	2.53	10.14
G085	XRF		Y	55.3	1.11	15.98	8.08	3.23	4.85
G086	XRF		Y	46.9	2.81	19.08	9.71	1.94	7.77
G087	XRF		Y	47.64	2.98	15.51	12.59	3.78	8.81
G088	XRF		Y	47.02	2.44	17.43	10.75	2.15	8.6

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
A156	0.16	5.84	11.96	3.86	0.87	0.65	1.82	100.63	52.261	W-T n.d.
A165	0.17	6.98	9.76	3.75	0.73	0.41	0.62	100.04	55.524	W-T n.d.
A174	0.16	6.58	10.1	3.84	1.25	0.95	0.94	100.1	56.724	W-T n.d.
A177	0.17	6.11	11.35	3.23	0.75	0.54	1.7	100.12	52.915	W-T n.d.
A186	0.17	7.43	10.12	3.8	1.16	0.8	-0.01	100	58.427	W-T n.d.
A188	0.17	4.19	9.51	3.99	1.21	0.69	1.45	101.59	44.813	W-T n.d.
A189	0.18	8.68	10.75	3.67	0.74	0.54	1	100.11	60.876	W-T n.d.
A190	0.18	8.77	9.78	3.88	1.1	0.51	0.29	100.17	62.392	W-T n.d.
A191										W-T n.d.
G001										P & W-T 1993
G002										P & W-T 1993
G003										P & W-T 1993
G004										P & W-T 1993
G005										P & W-T 1993
G006										P & W-T 1993
G007										P & W-T 1993
G008										P & W-T 1993
G009										P & W-T 1993
G010										P & W-T 1993
G011										P & W-T 1993
G012										P & W-T 1993
G013										P & W-T 1993
G014										P & W-T 1993
G015										P & W-T 1993
G016										P & W-T 1993
G017a										P & W-T 1993
G017b										P & W-T 1993
G018										P & W-T 1993
G019										P & W-T 1993
G019a										P & W-T 1993
G019b										P & W-T 1993
G020										P & W-T 1993
G021										P & W-T 2001
G022										P & W-T 2001
G023										P & W-T 2001
G024										P & W-T 2001
G025										P & W-T 2001
G026										P & W-T 2001
G027										P & W-T 2001
G028										P & W-T 2001
G032	0.171	8.785	9.626	4.13	1.842	0.761	0.59	99.89	61.91	This study
G037	0.17	9.166	9.451	3.759	1.564	0.693	1.31	100.03	61.753	This study
G044	0.177	9.693	9.014	4.288	1.193	0.689	1.17	99.829	62.148	This study
G053	0.162	9.51	11.67	3.047	0.934	0.406	2.69	100.05	64.085	This study
G055	0.158	7.806	12.302	3.225	0.562	0.284	3.18	99.918	58.926	This study
G058	0.185	11.851	10.138	4.026	1.237	0.876	1.16	100.22	66.769	This study
G064	0.187	14.653	10.191	3.391	0.848	0.561	0.88	100.21	70.894	This study
G069	0.197	9.168	10.233	4.704	1.72	1.162	2.23	99.792	58.822	This study
G072	0.197	9.578	10.36	4.248	1.897	1.207	1.86	99.898	59.866	This study
G077	0.163	6.07	11.671	2.978	0.602	0.432	2.7	100.07	53.413	This study
G079	0.159	5.832	10.809	3.397	0.827	0.437	0.38	99.869	52.843	This study
G081	0.161	7.331	10.33	3.385	0.675	0.418	0.26	100.59	58.152	This study
G084	0.18	11.62	9.31	2.75	0.55	0.18	1.59	100.72	68.192	Laws 1997
G085	0.19	1.23	4.39	5.52	2.85	0.36	4.5	99.51	29.089	Laws 1997
G086	0.12	3.43	9.97	4	0.83	0.27	2.15	99.28	47.056	Laws 1997
G087	0.16	5.12	6.81	4.85	0.99	0.41	2.39	99.44	50.572	Laws 1997
G088	0.13	4.84	10.3	3.72	0.58	0.28	1.74	99.22	51.28	Laws 1997

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G089	XRF		Y	47.44	2.85	16.16	11.94	2.39	9.55
G090	XRF		Y	49.77	2.27	11.55	14.06	2.81	11.25
G091	XRF		Y	46.57	4.44	19.15	4.69	1.64	3.05
G092	XRF		Y	46.47	3.44	18.55	2.99	1.05	1.94
G093	XRF		Y	46.08	2.41	14.02	12.95	2.59	10.36
G094	XRF		Y	46.03	2.78	14.77	13.39	2.68	10.71
G095	XRF		Y	44.4	2.5	14.59	12.63	2.53	10.1
G096	XRF		Y	43.32	2.49	13.89	12.22	2.44	9.78
G097	XRF		Y	42.01	2.8	13.37	12.85	2.57	10.28
G098	XRF		Y	41.56	2.81	13.37	12.83	2.57	10.26
G099	XRF		Y	42.42	2.82	13.59	12.9	2.58	10.32
G100	XRF		Y	40.62	2.7	11.63	12.86	2.57	10.29
G101	XRF		Y	44.32	2.6	13.16	10.84	3.25	7.59
G102	XRF		Y	41.45	4.95	14.31	14.76	2.95	11.81
G103	XRF		Y	39.22	3.02	15.62	12.92	2.58	10.34
G104	XRF		Y	47.57	2.41	13.62	11.64	3.49	8.15
G105	XRF		Y	50.21	2.16	16.7	10.75	3.76	6.99
G106	XRF		Y	45.72	2.3	13.03	13.55	2.71	10.84
G107	XRF		Y	47.42	2.55	13.93	12.6	2.52	10.08
G108	XRF		Y	47.23	2.48	13.21	13.08	2.62	10.46
G109	XRF		Y	48.19	2.61	16.18	12.47	2.49	9.98
G110	XRF		Y	45.76	2.56	13	13.27	2.65	10.65
G111	XRF		Y	45.15	3.68	15.9	13.85	2.77	11.08
G112	XRF		Y	44.76	2.68	14.17	12.84	2.57	10.27
G113	XRF		Y	28.43	1.84	8.6	9.76		
G114	XRF		Y	30.35	2.04	9.49	10.97		
G115	XRF		Y	46.2	1.64	15.51	13.83	4.15	9.68
G116	XRF		Y	48.71	1.8	14.07	12.82	2.56	10.26
G117	XRF		Y	43.55	2.26	14.37	11.95	2.39	9.56
G118	XRF		Y	43.47	2.32	14.33	12.12	2.42	9.7
G119	XRF		Y	34.05	1.65	10.78	9.03		
G120	XRF		Y	29.23	1.44	9.85	8.66		
G121	XRF		Y	45.36	2.69	14.73	13.17	2.63	10.54
G122	XRF		Y	47	3.05	16.53	13.04	3.91	9.13
G123	XRF		Y	46.94	3.04	16.7	13.03	3.91	9.12
G124	XRF		Y	44.5	2.39	13.8	11.35	2.27	9.08
G125	XRF		Y	49.45	2.15	14.7	11.14	2.23	8.91
G126	XRF		Y	44.04	2.7	13.9	12.84	2.57	10.27
G127	XRF		Y	41.4	2.19	13.48	10.11	2.02	8.09
G128	XRF		Y	43.19	2.4	14.2	12.41	2.48	9.93
G129	XRF		Y	46.38	2.27	14.78	12.39	2.48	9.91
G130	XRF		Y	46.02	2.49	12.9	13.09	2.62	10.47
G131	XRF		Y	50.06	1.77	14.56	11.84	2.37	9.47
G132	XRF		Y	43.05	3.44	13.39	14.36	2.87	11.49
G133	XRF		Y	43.43	3.51	14.82	14.81	2.96	11.85
G134	XRF		Y	43.53	3.44	14.92	14.76	2.95	11.81
G135	XRF		Y	45.02	2.72	15.28	13.07	3.92	9.15
G136	XRF		Y	43.84	3.3	14.67	14.38	2.88	11.5
G137	XRF		Y	46.13	1.78	17.09	9.01	1.8	7.21
G138	XRF		Y	46.26	2.65	15.56	13.09	2.62	10.47
G139	XRF		Y	43.48	3	14.59	13.87	2.77	11.1
G140	XRF		Y	45.96	2.11	12.49	12.82	2.56	10.26
G141	XRF		Y	46.26	2.13	12.6	12.85	2.57	10.28
G142	XRF		Y	45.6	2.53	13.6	13.69	2.74	10.95
G143	XRF		Y	44.47	3.43	15.03	13.9	2.78	11.12
G144	XRF		Y	61.2	0.47	17.12	5.45	2.73	2.73
G145	XRF		Y	48.06	2.7	16.25	12.94	3.88	9.06
G146	XRF		Y	45.19	2.26	13.89	13.06	2.61	13.06
G147	XRF		Y	44.02	3.15	14.64	12.97	2.59	12.97
G148	XRF		Y	46.09	2.35	15.09	12.75	2.55	10.2
G149	XRF		Y	43.83	3.14	14.5	12.77	2.55	10.22

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G089	0.16	4.71	8.3	4.27	0.79	0.38	2.11	99.1	49.808	Laws 1997
G090	0.16	8.92	8.97	2.49	0.76	0.3	0.86	100.11	59.727	Laws 1997
G091	0.04	1.42	5.08	0.67	7.56	0.77	7.4	97.78	44.088	Laws 1997
G092	0.04	0.55	8.6	0.59	7.66	0.56	9.7	99.13	32.381	Laws 1997
G093	0.18	9.02	8.63	2.83	0.88	0.47	2.11	99.58	61.952	Laws 1997
G094	0.19	7.3	8.28	3.24	1.22	0.69	1.36	99.26	56.031	Laws 1997
G095	0.19	8.41	9.27	2.97	1.53	0.74	2.15	99.38	60.884	Laws 1997
G096	0.19	9.57	11.04	3.72	1.27	0.68	1.19	99.58	64.672	Laws 1997
G097	0.19	10.1	10.68	4.43	1.36	1.03	0.85	99.66	64.755	Laws 1997
G098	0.19	9.73	10.59	4.37	1.27	1.02	1.31	99.05	63.934	Laws 1997
G099	0.19	9.76	10.59	4.63	1.22	1.09	0.95	100.15	63.882	Laws 1997
G100	0.19	12.99	11.6	2.78	0.78	0.88	2.77	99.8	70.248	Laws 1997
G101	0.18	3.81	6.97	3.37	2.07	1	10.88	99.2	47.793	Laws 1997
G102	0.11	7.64	11.72	1.85	0.5	0.18	1.75	99.21	53.784	Laws 1997
G103	0.19	3.98	8.84	2.71	2.74	0.86	9.66	99.76	43.664	Laws 1997
G104	0.19	3.51	6.48	4.01	1.85	0.74	6.43	98.44	43.997	Laws 1997
G105	0.13	2.8	4.82	6.02	2.57	0.68	2.41	99.25	40.422	Laws 1997
G106	0.18	10.23	9.43	2.9	0.76	0.46	1.81	100.36	63.83	Laws 1997
G107	0.16	8.42	7.85	3.38	2.06	0.78	0.77	99.94	62.704	Laws 1997
G108	0.16	8.71	9.16	2.81	1.13	0.62	1.29	99.87	60.885	Laws 1997
G109	0.16	5.8	9.98	3.07	1.18	0.6	0	100.24	52.09	Laws 1997
G110	0.18	9.64	9.26	2.96	0.89	0.75	1.56	99.83	62.936	Laws 1997
G111	0.19	6.16	8.22	3.93	1.68	0.68	0.62	100.05	50.973	Laws 1997
G112	0.18	8.58	10.19	3.13	1.03	0.49	1.15	99.2	60.969	Laws 1997
G113	0.13	6.71	24.64	1.96	0.72	0.71	15.87	99.38		Laws 1997
G114	0.15	7.28	21.73	2.32	0.74	0.79	13.7	99.56		Laws 1997
G115	0.06	2.43	7.18	3.88	2.41	1.4	4.91	99.44	30.651	Laws 1997
G116	0.16	8.75	9.27	3.03	0.42	0.21	0.38	99.62	61.472	Laws 1997
G117	0.17	6.74	11.18	3.31	1.05	0.52	4.86	99.96	56.867	Laws 1997
G118	0.16	6.8	11.11	3.26	1.08	0.54	4.72	99.92	56.738	Laws 1997
G119	0.11	4.11	30.79	0.16	0.04	0.34	5.7	96.76		Laws 1997
G120	0.14	3.62	21.73	1.4	2.28	0.34	17.72	96.39		Laws 1997
G121	0.18	7.79	9.47	3.66	0.87	0.54	0.67	99.12	58.031	Laws 1997
G122	0.18	4.75	6.79	4.89	1.74	0.81	0.3	99.07	47.818	Laws 1997
G123	0.18	4.71	6.66	4.74	1.81	0.82	0.45	99.07	47.629	Laws 1997
G124	0.17	8.26	11.48	3.18	1.63	0.6	2.41	99.75	62.979	Laws 1997
G125	0.13	5.52	9.8	3.11	0.73	0.34	2.06	99.15	53.663	Laws 1997
G126	0.18	9.33	10.13	3.13	1.47	0.65	0.92	99.29	62.944	Laws 1997
G127	0.16	7.07	12.58	4.52	1.43	0.62	5.69	99.25	63.761	Laws 1997
G128	0.12	7.18	9.29	3.44	1.91	0.76	4.51	99.4	57.491	Laws 1997
G129	0.19	8.23	9.02	3.48	1.69	0.63	0.76	99.82	62.564	Laws 1997
G130	0.17	9.17	8.74	3.4	1.6	0.67	1.61	99.85	63.799	Laws 1997
G131	0.14	7.28	9.27	2.93	0.33	0.2	1.55	99.94	58.97	Laws 1997
G132	0.17	7.66	9.64	3.59	1.88	1.02	1.64	99.84	55.494	Laws 1997
G133	0.19	7.69	8.85	3.17	1.11	0.68	1.43	99.7	54.828	Laws 1997
G134	0.19	7.15	8.39	3.4	1.21	0.8	1.75	99.53	53.102	Laws 1997
G135	0.19	6.24	7.94	4.33	1.61	0.85	2.51	99.75	54.569	Laws 1997
G136	0.19	7.71	8.64	2.94	1.26	0.82	1.83	99.56	55.62	Laws 1997
G137	0.11	7	12.98	3.09	0.31	0.06	2.35	99.9	64.491	Laws 1997
G138	0.2	6.19	8.64	3.76	1.63	0.81	0.76	99.56	54.33	Laws 1997
G139	0.19	7.41	10.1	4.43	0.68	0.66	1	99.42	55.532	Laws 1997
G140	0.17	11.49	9.28	2.85	0.98	0.36	1.11	99.6	67.69	Laws 1997
G141	0.17	11.17	9.35	2.75	0.94	0.36	1.42	100	67.019	Laws 1997
G142	0.18	8.33	8.9	3.14	1.25	0.64	1.5	99.37	58.716	Laws 1997
G143	0.22	5.67	8.21	3.6	1.7	0.83	2.04	99.1	50.645	Laws 1997
G144	0.12	0.68	1.51	6.21	5.64	0.09	1.15	99.65	26.382	Laws 1997
G145	0.18	4.27	5.85	4.93	1.81	0.95	1.51	99.44	45.362	Laws 1997
G146	0.17	10.06	8.92	3.48	1.34	0.47	0.44	99.28	64.295	Laws 1997
G147	0.16	8.23	9.04	4.17	1.15	0.65	1.08	99.25	59.732	Laws 1997
G148	0.17	6.85	10.74	3.38	1.01	0.87	0.6	99.9	55.67	Laws 1997
G149	0.16	8.42	9.29	4.09	0.95	0.66	1.55	99.35	60.649	Laws 1997

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G150	XRF		Y	42.89	3.11	14.43	12.9	3.87	9.03
G151	XRF		Y	44.94	2.73	16.32	12.17	3.65	8.52
G152	XRF		Y	44.15	3.04	14.36	13.29	2.66	10.63
G153	XRF		Y	45.26	2.95	14.3	12.7	2.54	10.16
G154	XRF		Y	45.89	2.63	14.4	13.57	2.71	10.86
G155	XRF		Y	48.98	2.29	16.04	11.86	2.37	9.49
G156	XRF		Y	46.44	2.35	15.05	12.38	3.71	8.67
G157	XRF		Y	46.13	2.54	15.92	12.69	2.54	10.15
G158	ICP-AES		Y	46.2	1.32	13.7	12.6	2.52	10.08
G159	ICP-AES		Y	48.8	1.78	14.2	13	2.6	10.4
G160	ICP-AES		Y	49.3	1.75	14.4	12.9	2.58	10.32
G161	ICP-AES		Y	45.2	2.7	15.7	12.7	3.81	8.89
G162	ICP-AES		Y	45.5	3.3	14.9	13.8	2.76	11.04
G163	ICP-AES		Y	46.6	2.79	15.8	13	3.9	9.1
G164	ICP-AES		Y	44.5	3.42	15.5	14.5	2.9	11.6
G165	ICP-AES		Y	44	3.31	14.9	13.5	2.7	10.8
G166	ICP-AES		Y	46	2.8	15.6	12.3	3.69	8.61
G167	ICP-AES		Y	45.4	2.65	15.4	13	3.9	9.1
G168	ICP-AES		Y	45.6	2.65	14.6	13.6	2.72	10.88
G169	ICP-AES		Y	45.1	2.63	14.4	13.1	2.62	10.48
G170	ICP-AES		Y	44.7	3.64	16	13.8	2.76	11.04
G171	ICP-AES		Y	45.6	2.66	14	11.7	2.34	9.36
G172	ICP-AES		Y	45.2	2.7	14.3	12.9	2.58	10.32
G173	XRF		Y	43.65	3.18	13.44	11.74	2.348	9.392
G174	XRF		Y	44.62	2.78	13.26	11.36	2.272	9.088
G175	XRF		Y	46.35	2.61	13.44	12.07	2.414	9.656
G176	XRF		Y	43.66	2.44	13.28	11.99	2.398	9.592
G177	XRF		Y	42.1	3.2	13.25	11.15	2.23	8.92
G178	XRF		Y	42.29	3.32	13.76	10.89	2.178	8.712
G179	XRF		Y	42.95	2.65	12.32	11.24	2.248	8.992
G180	XRF		Y	42.63	2.6	12.18	11.26	2.252	9.008
G181	XRF		Y	45.71	2.84	13.68	12.15	2.43	9.72
G183	XRF		Y	44.91	2.55	13.71	11.36	2.272	9.088
G184	XRF		Y	43.82	3.01	14.11	11.85	2.37	9.48
G185	XRF		Y	43.24	2.95	13.93	11.83	2.366	9.464
G186	XRF		Y	43.92	3.05	13.67	12.45	2.49	9.96
G187	XRF		Y	46.93	3.2	15.43	11.36	3.408	7.952
G189	XRF		Y	43.73	3.39	15.08	12.61	2.522	10.09
G190	XRF		Y	44.1	2.52	13.26	11.92	2.384	9.536
G192	XRF		Y	46.19	2.16	14.06	11.73	2.346	9.384
G193	XRF		Y	43.77	2.71	13.49	11.82	2.364	9.456
G194	XRF		Y	42.6	2.92	14.16	12.47	2.494	9.976
G195	XRF		Y	47.37	2.46	16.03	11.04	3.312	7.728
G197	XRF		Y	42.65	3.37	13.73	12.1	2.42	9.68
G198	XRF		Y	45.63	2.49	14.83	10.93	3.279	7.651
G199	XRF		Y	47.8	2.4	15.45	10.85	2.17	8.68
G200	XRF		Y	48.2	2.45	15.76	11.55	2.31	9.24
G201	XRF		Y	44.6	2.52	13.63	12.44	2.488	9.952
G202	XRF		Y	45.83	2.74	13.55	11.22	2.244	8.976
G203	XRF		Y	46.72	2.72	15.26	11.15	3.345	7.805
G204	XRF		Y	45.5	3.83	16.34	12.25	2.45	9.8
G205	XRF		Y	44.03	2.96	13.87	11.19	3.357	7.833
G206	XRF		Y	37.22	3.44	10.95	13.52	2.704	10.82
G208	XRF		Y	38.4	3.62	11.38	13.28	2.656	10.62
G211	XRF		Y	45.84	2.75	15.09	11.72	3.516	8.204
G212	XRF		Y	44.19	3.14	14.68	12.03	2.406	9.624
G213	XRF		Y	43.69	2.72	14.15	11.13	3.339	7.791
G214	XRF		Y	43.01	3.24	13.9	12.54	2.508	10.03
G215	XRF		Y	42.06	3.15	13.53	12.4	2.48	9.92
G216	XRF		Y	42.19	3.12	13.61	12.37	2.474	9.896
G217	XRF		Y	43.83	3.13	14.08	11.99	2.398	9.592

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G150	0.18	7.46	9.36	5.17	2.09	1.93	-0.04	99.48	59.264	Laws 1997
G151	0.18	5.49	10.28	4.42	1.66	1.17	0.05	99.41	53.159	Laws 1997
G152	0.17	8.98	9.57	4.01	1.58	1	-0.36	99.8	61.232	Laws 1997
G153	0.16	8.36	9.47	4.08	1.48	1.08	-0.13	99.71	60.611	Laws 1997
G154	0.17	8.76	9.64	3.64	1.08	0.62	-0.55	99.86	60.143	Laws 1997
G155	0.16	5.23	9.46	3.55	1.12	0.59	0.57	99.84	50.759	Laws 1997
G156	0.17	8	8.6	3.9	1.66	0.57	0.4	99.52	61.913	Laws 1997
G157	0.18	5.75	11.01	3.7	0.98	0.84	0.61	100.37	51.438	Laws 1997
G158	0.15	12.1	7.3	2.8	0.3	0.1	4.1	100.67	69.181	Wilson et al 2000
G159	0.16	8.8	9.2	2.93	0.41	0.25	0.75	100.28	61.276	Wilson et al 2000
G160	0.14	8.2	9.2	2.95	0.34	0.25	1.38	100.81	59.773	Wilson et al 2000
G161	0.19	6.4	8.4	3.6	1.6	1	0	97.49	55.905	Wilson et al 2000
G162	0.17	7.4	8.6	2.6	1.3	1	0	98.57	55.624	Wilson et al 2000
G163	0.2	5.6	7.6	4.05	1.45	0.9	0	97.99	52.009	Wilson et al 2000
G164	0.18	7.2	9.1	2.8	1.3	0.9	0.9	100.3	53.717	Wilson et al 2000
G165	0.19	7.9	8.8	2.9	1.06	0.8	1.64	99	57.768	Wilson et al 2000
G166	0.17	7	8.5	3.9	1.5	0.5	1.5	99.77	58.876	Wilson et al 2000
G167	0.2	6.3	10	4.1	1.06	0.8	1.12	100.03	54.938	Wilson et al 2000
G168	0.18	8.8	10.4	3.1	0.51	0.5	0.64	100.58	60.2	Wilson et al 2000
G169	0.18	8.5	10.5	3.35	0.75	0.5	1.33	100.34	60.265	Wilson et al 2000
G170	0.18	6.2	8	3.9	1.7	0.7	1.6	100.42	51.223	Wilson et al 2000
G171	0.17	9.4	9.7	3.3	1.54	0.54	1.12	99.69	65.255	Wilson et al 2000
G172	0.18	9.4	10.3	3.3	1.2	0.7	0.81	100.99	63.009	Wilson et al 2000
G173	0.18	9.63	9.67	2.22	1.25	0.51	4.39	99.86	65.723	Weinstein 2000
G174	0.16	10.93	9.42	2.42	1.36	0.51	2.87	99.69	69.222	Weinstein 2000
G175	0.12	7.99	8.66	2.63	0.67	0.3	5.56	100.4	60.745	Weinstein 2000
G176	0.17	10.54	10.52	1.89	1.04	0.47	3.66	99.66	67.266	Weinstein 2000
G177	0.15	8.1	9.93	3.42	0.83	1.54	5.3	98.97	62.938	Weinstein 2000
G178	0.25	8.7	9.49	2.57	1.63	1.2	5.71	99.81	65.124	Weinstein 2000
G179	0.16	10.7	10.67	2.92	0.8	0.88	4.41	99.7	68.994	Weinstein 2000
G180	0.17	10.6	10.48	3	0.76	0.82	4.78	99.28	68.756	Weinstein 2000
G181	0.14	7.17	9.05	2.89	1.62	0.6	3.87	99.72	57.973	Weinstein 2000
G183	0.16	10	8.85	2.79	1.17	0.72	3.86	100.08	67.296	Weinstein 2000
G184	0.17	7.88	8.88	4.11	1.36	1.19	3.71	100.09	60.851	Weinstein 2000
G185	0.17	7.85	8.73	4.2	1.25	1.24	4.49	99.88	60.801	Weinstein 2000
G186	0.16	8.18	8.69	2.67	1.3	0.65	5.2	99.94	60.567	Weinstein 2000
G187	0.15	4.49	6.5	4.56	1.88	1	3.89	99.39	49.858	Weinstein 2000
G189	0.14	5.59	8.55	3.66	1.76	0.99	4.07	99.57	50.891	Weinstein 2000
G190	0.16	11.29	9.04	3.41	0.93	0.74	2.6	99.97	68.888	Weinstein 2000
G192	0.16	9.91	8.32	3.05	1.11	0.4	2.76	99.85	66.387	Weinstein 2000
G193	0.16	10.38	9.6	3.54	0.78	0.96	3.02	100.23	67.242	Weinstein 2000
G194	0.13	7.12	10.18	2.75	0.65	1.2	5.56	99.74	57.167	Weinstein 2000
G195	0.14	4.6	6.52	4.58	2.33	0.78	3.47	99.32	52.048	Weinstein 2000
G197	0.16	7.14	9.71	4.12	1.05	0.94	4.92	99.89	57.97	Weinstein 2000
G198	0.14	6.67	7.49	3.97	1.74	1	4.07	98.96	60.558	Weinstein 2000
G199	0.15	6.61	8.94	3.36	1.16	0.44	2.72	99.88	58.747	Weinstein 2000
G200	0.11	4.18	9.05	3.39	1.18	0.41	3.6	99.88	45.827	Weinstein 2000
G201	0.02	8.93	9.48	2.09	1.36	0.62	3.51	99.2	62.658	Weinstein 2000
G202	0.16	9.15	10.24	3.2	1.35	0.47	1.81	99.72	65.593	Weinstein 2000
G203	0.15	6.31	7.69	4.49	1.8	1.12	2.02	99.43	58.743	Weinstein 2000
G204	0.14	4.17	6.79	2.04	1.06	1.19	6.61	99.92	44.31	Weinstein 2000
G205	0.17	8.04	9.36	3.89	2.14	0.94	2.46	99.05	64.384	Weinstein 2000
G206	0.21	10.85	12.71	4.72	1.66	1.93	2.12	99.33	65.228	Weinstein 2000
G208	0.2	9.66	13.64	2.51	0.98	1.53	4.33	99.53	62.969	Weinstein 2000
G211	0.18	5.8	8.77	4.14	1.6	1.22	2.43	99.54	55.458	Weinstein 2000
G212	0.17	6.5	9.39	3.9	1.79	1.04	2.91	99.74	55.81	Weinstein 2000
G213	0.18	7.26	10.2	4.27	1.73	1.36	2.71	99.4	62.134	Weinstein 2000
G214	0.18	7.91	9.79	3.84	1.89	1	1.87	99.17	59.586	Weinstein 2000
G215	0.18	8.27	9.86	4.18	1.56	1.61	2.09	98.89	60.921	Weinstein 2000
G216	0.18	8.43	9.93	4.01	1.54	1.61	2.36	99.35	61.436	Weinstein 2000
G217	0.18	7.87	9.55	3.64	1.85	1.11	2.12	99.35	60.543	Weinstein 2000

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G218	XRF		Y	43.63	3.62	13.76	11.51	3.453	8.057
G219	XRF		Y	43.85	2.83	14.31	11.93	2.386	9.544
G220	XRF		Y	41.33	3.48	13.28	12.03	2.406	9.624
G221	XRF		Y	42.93	2.03	13.69	11.62	2.324	9.296
G222	XRF		Y	45.69	2.22	14.07	11.7	2.34	9.36
G223	XRF		Y	42.24	3.02	12.66	11.65	2.33	9.32
G224	XRF		Y	43.24	3.53	13.37	11.66	2.332	9.328
G225	ICP-AES		Y	53	1	17.8	8.7	3.045	5.655
G226	ICP-AES		Y	52.7	1	17.9	8.2	2.87	5.33
G227	ICP-AES		Y	51.8	0.9	17.4	8.7	3.045	5.655
G228	ICP-AES		Y	51.2	0.95	18.7	8.1	2.835	5.265
G229	ICP-AES	MnO >0.1	Y	55.1	0.75	17.7	8.4	3.36	5.04
G230	ICP-AES		Y	51.8	0.95	17.9	8.7	3.48	5.22
G231	ICP-AES		Y	49.5	0.9	16.3	8.8	1.76	7.04
G232	ICP-AES		Y	52.7	0.9	15.9	8	2.8	5.2
G233	XRF		Y	45.3	1.76	17.88	11.4	2.28	9.12
G234	XRF		Y	51.5	2.41	13.88	11.9	4.165	7.735
G235	XRF		Y	51.55	2.6	13.58	12.4	4.34	8.06
G236	XRF		Y	52	2.38	13.78	11.7	4.095	7.605
G237	XRF		Y	46	1.76	17.48	11.6	2.32	9.28
G238	XRF		Y	52.2	2.46	14.58	11.5	4.025	7.475
G239	XRF		Y	48	1.89	15.08	8.38	2.933	5.447
G240	XRF		Y	48.1	3.76	14.93	10.7	3.745	6.955
G241	XRF		Y	47.28	1.67	16.46	9.25	3.2375	6.013
G242	XRF		Y	50.28	1.67	15.55	9.39	3.2865	6.104
G243	XRF		Y	44.21	1.14	11.49	8.63	3.0205	5.61
G244	XRF		Y	48.94	1.62	16.27	9.26	3.241	6.019
G245	XRF		Y	48.7	1.66	15.9	9.91	3.4685	6.442
G246	XRF		Y	49.21	1.47	15.02	8.96	3.136	5.824
G247	XRF		Y	49.48	1.71	16.01	8.69	3.0415	5.649
G248	XRF		Y	51.32	1.73	15.17	9.08	3.178	5.902
G249	XRF		Y	48.2	1.91	15.71	10.36	3.108	7.252
G250	XRF		Y	56.1	0.8	15.68	6.89	2.756	4.134
G251	XRF		Y	60.1	0.83	17.18	7.48	2.618	4.862
G252	XRF		Y	59.9	0.98	14.87	7.24	2.534	4.706
G253	XRF		Y	55.64	1.34	14.08	7.17	2.868	4.302
G254	XRF		Y	66.25	0.83	14.97	3.26	1.63	1.63
G255	XRF		Y	69.44	0.48	13.2	3.37	1.685	1.685
G256	XRF		Y	57.16	1.33	13.15	7.43	2.6005	4.83
G257	XRF		Y	56.54	1.01	14.33	6.09	3.045	3.045
G258	XRF		Y	55.16	1.63	14.24	9.26	3.704	5.556
G259	XRF		Y	55.4	0.78	14.58	6.68	2.672	4.008
G260	XRF		Y	55.8	0.78	14.98	6.58	2.632	3.948
G261	XRF		Y	55.2	0.81	15.18	6.91	2.764	4.146
G262	XRF		Y	60.2	0.67	15.48	5.29	2.645	2.645
G263	XRF		Y	51	0.75	13.58	9.02	2.706	6.314
G264	XRF		Y	55.6	0.81	15.88	7.02	2.808	4.212
G265	XRF		Y	55.45	0.84	16.38	6.3	2.52	3.78
G266	XRF		Y	55.4	0.79	15.08	6.85	2.3975	4.453
G267	XRF	LOI not given	Y	43.08	3.021	13.53	13.4	4.02	9.38
G268	XRF	LOI not given	Y	43.36	2.847	13.93	13.29	2.658	10.63

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G218	0.14	5.99	9.98	4.34	1.62	1.14	3.2	98.93	56.695	Weinstein 2000
G219	0.15	6.99	9.32	3.45	1.63	0.94	3.66	99.06	59.58	Weinstein 2000
G220	0.18	7	11.33	3.85	0.8	1.68	4.35	99.31	57.63	Weinstein 2000
G221	0.15	7.63	12.89	2.84	0.84	0.26	5.12	100	60.551	Weinstein 2000
G222	0.17	8.25	10.69	3.47	1	0.28	2.3	99.84	62.24	Weinstein 2000
G223	0.16	9.15	10.14	3.75	0.85	1.05	5.03	99.7	64.738	Weinstein 2000
G224	0.15	8.25	8.89	3.71	1.34	1.16	4.25	99.55	64.027	Weinstein 2000
G225	0.13	5.5	3.1	4.48	2.31	0.1	3.5	99.62	62.218	Bogoch et al. 1993
G226	0.16	6.1	3.2	4.1	2.12	0.1	4.1	99.68	65.962	Bogoch et al. 1993
G227	0.26	7.2	2.1	4	2.7	0.1	4.3	99.46	68.312	Bogoch et al. 1993
G228	0.23	6.3	2	4.42	3.13	0.1	3.8	98.93	66.953	Bogoch et al. 1993
G229	0.1	3.7	3.1	4.64	2.5	0.1	3.7	99.69	54.27	Bogoch et al. 1993
G230	0.18	5.8	1.8	4.1	3	0.2	4.2	98.63	64.233	Bogoch et al. 1993
G231	0.19	8.5	8.5	2.5	1	0.3	3.5	99.99	69.305	Bogoch et al. 1993
G232	0.19	9	1.5	4.3	1.2	0.2	5.4	99.29	74.557	Bogoch et al. 1993
G233	0.15	8.26	6.02	3.9	0.4	0.24	4.22	99.53	62.874	Jarrar et al. 1992
G234	0.14	4.81	3.38	4.98	1.89	0.84	3.64	99.37	51.285	Jarrar et al. 1992
G235	0.18	5.1	3.24	4.77	1.73	0.8	3.27	99.22	51.724	Jarrar et al. 1992
G236	0.14	5.07	3.21	4.76	1.88	0.83	3.28	99.03	53.027	Jarrar et al. 1992
G237	0.17	8.14	5.99	3.63	0.55	0.26	3.84	99.45	62.126	Jarrar et al. 1992
G238	0.17	3.65	3.83	4.14	3.03	0.83	3.86	100.25	45.256	Jarrar et al. 1992
G239	0.38	5.31	4.42	3.61	4.06	0.62	9.16	100.95	62.272	Jarrar et al. 1992
G240	0.21	4.22	5.28	3.05	5.35	0.61	3.23	99.48	50.678	Jarrar et al. 1992
G241	0.2	6.65	5.44	2.55	3.54	0.56	6.01	99.62	65.191	Jarrar et al. 1992
G242	0.12	4.93	5.02	5.08	1.67	0.63	5.09	99.43	57.766	Jarrar et al. 1992
G243	0.14	11.99	3	1.85	3.43	0.6	12.07	100.55	78.351	Jarrar et al. 1992
G244	0.13	4.08	5.48	4.18	2.78	0.61	5.88	99.23	53.439	Jarrar et al. 1992
G245	0.14	5.27	6.49	4.81	1.55	0.65	4.16	99.27	58.077	Jarrar et al. 1992
G246	0.11	5.87	4.86	4.68	2.28	0.56	7.36	100.39	63.053	Jarrar et al. 1992
G247	0.12	5.24	4.96	3.48	3.59	0.84	5.16	99.29	61.101	Jarrar et al. 1992
G248	0.07	5.32	5.02	4.9	2.09	0.66	4.21	99.58	60.418	Jarrar et al. 1992
G249	0.13	7.33	5.63	2.87	2.37	0.89	4.28	99.69	64.029	Jarrar et al. 1992
G250	0.11	4.74	5.26	5.09	2.09	0.21	2.32	99.29	64.955	Jarrar et al. 1992
G251	0.17	2.44	2.43	3.65	2.48	0.25	3.67	100.67	45.935	Jarrar et al. 1992
G252	0.11	3.8	2.9	3.15	3.25	0.34	3.14	99.68	57.759	Jarrar et al. 1992
G253	0.31	2.98	3.12	3.01	5.16	0.46	5.93	99.21	52.824	Jarrar et al. 1992
G254	0.06	1.36	1.16	4.64	4.51	0.21	1.87	99.17	54.517	Jarrar et al. 1992
G255	0.01	3.25	1.32	3.73	2.86	0.14	1.51	99.37	73.471	Jarrar et al. 1992
G256	0.09	5.41	3.17	5.36	0.31	0.47	6.79	100.68	65.478	Jarrar et al. 1992
G257	0.1	4.17	2.71	5.78	2.71	0.14	5.55	99.17	66.292	Jarrar et al. 1992
G258	0.11	3.54	3.38	5.08	2.16	0.63	4.16	99.36	50.739	Jarrar et al. 1992
G259	0.1	5.05	5.64	3.96	2.21	0.21	1.69	99.33	67.071	Jarrar et al. 1992
G260	0.09	5.1	5.24	4.18	2.12	0.2	1.77	99.84	67.618	Jarrar et al. 1992
G261	0.11	5.54	5.42	4.24	2.03	0.21	3.71	99.36	68.352	Jarrar et al. 1992
G262	0.08	3.96	3.58	4.95	2.27	0.21	2.97	99.66	68.256	Jarrar et al. 1992
G263	0.14	6.17	8.68	3.31	1.63	0.15	5.11	99.54	63.25	Jarrar et al. 1992
G264	0.12	5.27	5.43	4.15	2.18	0.21	2.54	99.21	66.914	Jarrar et al. 1992
G265	0.1	5.42	4.72	4.55	3.06	0.16	2.34	99.32	69.86	Jarrar et al. 1992
G266	0.12	5.02	5.85	3.9	1.32	0.2	5.2	99.73	65.625	Jarrar et al. 1992
G267	0.172	8.9	9.2	4.8	1.6	0.76		98.463	62.561	Saffarini et al. 1987
G268	0.174	8.92	9.35	4.41	1.04	0.64		97.961	61.074	Saffarini et al. 1987

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G269	XRF	LOI not given	Y	43.93	2.454	14.15	12.81	3.843	8.967
G270	XRF	LOI not given	Y	43.45	2.688	13.98	12.99	2.598	10.39
G271	XRF	LOI not given	Y	44.15	2.438	14.55	12.88	2.576	10.3
G272	XRF	LOI not given	Y	36.88	2.514	11.35	11.39	1.7085	9.682
G273	XRF	LOI not given	Y	46.15	2.416	15.03	13	2.6	10.4
G274	XRF	LOI not given	Y	47.27	4.108	13.29	15.27	4.581	10.69
G275	XRF	LOI not given	Y	47.92	2.054	16.37	11.73	2.346	9.384
G276	XRF	LOI not given	Y	47.07	2.012	14.81	12.67	2.534	10.14
G277	XRF	LOI not given	Y	42.74	2.879	14.44	13.18	2.636	10.54
G278	XRF	LOI not given	Y	46.95	2.126	16.02	11.94	2.388	9.552
G279	XRF	LOI not given	Y	45.23	2.02	14.18	12.43	2.486	9.944
G280	XRF	LOI not given	Y	46.37	1.969	14.82	12.82	2.564	10.26
G281	XRF	LOI not given	Y	46.42	2.013	14.86	13.19	2.638	10.55
G282	XRF	LOI not given	Y	48.1	1.917	16.26	11.9	2.38	9.52
G283	XRF	LOI not given	Y	47	1.94	15.93	11.92	2.384	9.536
G284	XRF	LOI not given	Y	48.65	1.764	15.74	11.18	2.236	8.944
G285	XRF	LOI not given	Y	48.66	1.816	15.71	11.41	2.282	9.128
G286	XRF	LOI not given	Y	47.08	2.075	14.81	12.49	2.498	9.992
G287	XRF	LOI not given	Y	40.56	3.377	12.45	14.06	2.812	11.25
G288	XRF	LOI not given	Y	40.08	3.37	12.42	14.06	2.812	11.25
G289	XRF	LOI not given	Y	41.45	3.457	12.85	14.42	4.326	10.09
G290	XRF	LOI not given	Y	45.11	2.279	12.95	12.36	2.472	9.888
G291	XRF	LOI not given	Y	45.25	2.191	12.94	12.36	2.472	9.888
G292	XRF	LOI not given	Y	45.13	2.281	12.83	12.45	2.49	9.96
G293	XRF	LOI not given	Y	40.74	2.842	11.35	13.1	2.62	10.48
G294	XRF	LOI not given	Y	39.42	2.713	11.26	12.69	2.538	10.15
G295	XRF	LOI not given	Y	41.54	3.243	12.06	13.96	4.188	9.772
G296	XRF	LOI not given	Y	41.17	3.056	12.14	13.21	2.642	10.57
G297	XRF		Y	41.5	4.95	14.3	14.8	2.96	11.84
G298	XRF		Y	39.2	3.02	15.6	12.9	3.87	9.03
G299	XRF		Y	47.6	2.41	13.6	11.6	4.06	7.54
G300	ICP-AES and AAS		Y	46.5	2.26	14.8	11.9	3.57	8.33

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G269	0.174	9.87	9.071	3.28	1.61	0.46		97.809	65.966	Saffarini et al. 1987
G270	0.175	9.02	9.43	4.04	1.42	0.58		97.773	61.879	Saffarini et al. 1987
G271	0.174	9.84	9.84	3.75	1.53	0.52		99.672	64.103	Saffarini et al. 1987
G272	0.145	11.41	12.75	1.49	0.96	0.44		89.329	69.252	Saffarini et al. 1987
G273	0.162	6.88	10.48	3.18	0.69	0.29		98.278	55.298	Saffarini et al. 1987
G274	0.187	3.96	9.11	4.03	1.28	0.61		99.115	39.481	Saffarini et al. 1987
G275	0.153	7.36	9.79	3.5	0.9	0.33		100.11	59.46	Saffarini et al. 1987
G276	0.166	9.44	9.66	2.94	0.75	0.27		99.788	63.524	Saffarini et al. 1987
G277	0.175	8.8	9.94	3.57	1.64	0.59		97.954	60.95	Saffarini et al. 1987
G278	1.66	7.4	10.54	3.42	0.88	0.33		101.27	59.162	Saffarini et al. 1987
G279	0.156	8.71	10.98	3.08	1.08	0.31		98.176	62.091	Saffarini et al. 1987
G280	0.16	9.27	8.92	3.62	0.9	0.32		99.169	62.826	Saffarini et al. 1987
G281	0.166	8.97	9.17	3.65	0.9	0.33		99.669	61.386	Saffarini et al. 1987
G282	0.165	6.04	10.95	3.41	0.59	0.23		99.562	54.265	Saffarini et al. 1987
G283	0.167	5.75	11.76	3.22	0.58	0.23		98.497	52.998	Saffarini et al. 1987
G284	0.152	7.75	10.03	3.25	0.88	0.29		99.686	61.836	Saffarini et al. 1987
G285	0.157	7.73	9.87	3.29	0.9	0.3		99.843	61.295	Saffarini et al. 1987
G286	0.16	9.35	9.69	3.24	0.89	0.33		100.12	63.635	Saffarini et al. 1987
G287	0.174	9.24	10.99	4.02	0.99	0.81		96.671	60.571	Saffarini et al. 1987
G288	0.179	9.27	10.94	3.9	0.85	0.82		95.889	60.648	Saffarini et al. 1987
G289	0.185	9.55	10.11	5.03	1.16	0.85		99.062	62.491	Saffarini et al. 1987
G290	0.159	9.76	10.86	3.26	1.21	0.47		98.418	64.862	Saffarini et al. 1987
G291	0.159	9.1	11.31	3.28	1.17	0.43		98.19	63.249	Saffarini et al. 1987
G292	0.16	9.64	10.89	3.32	1.2	0.45		98.351	64.412	Saffarini et al. 1987
G293	0.169	12.99	11.17	4.68	0.65	0.78		98.471	69.859	Saffarini et al. 1987
G294	0.172	11.93	12.23	3.36	0.58	0.79		95.145	68.726	Saffarini et al. 1987
G295	0.203	11.16	10.43	4.71	1.69	0.86		99.856	66.791	Saffarini et al. 1987
G296	0.175	11.59	11.33	4.44	0.98	0.8		98.891	67.223	Saffarini et al. 1987
G297	0.11	7.64	1.72	1.85	0.5	0.18	1.75	89.3	54.684	Shawabekeh
G298	0.19	3.98	8.84	2.71	2.74	0.86	9.6	99.64	43.702	Shawabekeh
G299	0.19	3.51	6.48	4.01	1.85	0.74	6.4	98.39	44.08	Shawabekeh
G300	0.14	9.2	8.9	3.63	1.33	0.6	0.95	100.2	66.043	Weinstein et al. 1994

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G301	ICP-AES and AAS		Y	46.2	2.44	14.3	10.9	3.27	7.63
G302	ICP-AES and AAS		Y	46.2	2.64	15.3	11.9	3.57	8.33
G303	ICP-AES and AAS		Y	47.3	2.54	14.8	11.1	2.22	8.88
G304	ICP-AES and AAS		Y	43.9	2.67	14.1	11	3.3	7.7
G305	ICP-AES and AAS		Y	44.7	2.76	14.3	11.3	3.39	7.91
G306	ICP-AES and AAS		Y	44.9	2.78	14.4	10.5	3.15	7.35
G307	ICP-AES and AAS		Y	46.8	2.66	14.5	10.3	3.09	7.21
G308	ICP-AES and AAS		Y	44.5	2.68	14.1	10.6	3.18	7.42
G309	ICP-AES and AAS		Y	44.6	2.49	14.3	10.8	3.24	7.56
G310	ICP-AES and AAS		Y	44.8	2.6	14	11.7	2.34	9.36
G311	ICP-AES and AAS		Y	43.7	2.49	14.3	10.7	2.14	8.56
G312	ICP-AES and AAS		Y	45.3	2.99	14.5	11.9	3.57	8.33
G313	ICP-AES and AAS		Y	46.5	2.58	15.3	12.2	2.44	9.76
G314	ICP-AES and AAS		Y	46	2.64	14.5	10.3	3.09	7.21
G315	ICP-AES and AAS		Y	44.8	2.69	14.3	10.5	3.15	7.35
G316	ICP-AES and AAS		Y	46.6	2.7	16.5	11.4	3.42	7.98
G317	ICP-AES and AAS		Y	45.6	2.7	16	11.8	3.54	8.26
G318	ICP-AES and AAS		Y	46.7	2.7	16.9	11.7	3.51	8.19
G319	ICP-AES and AAS		Y	44.5	2.61	15.3	10.7	3.21	7.49
G320	ICP-AES and AAS		Y	45.5	2.72	14	10.7	2.14	8.56
G321	ICP-AES and AAS		Y	44.4	2.66	14.1	10.6	3.18	7.42
G322	ICP-AES and AAS		Y	44	2.52	14.2	10.4	3.12	7.28
G323	ICP-AES and AAS		Y	44.9	2.54	13.4	11.6	2.32	9.28
G324	ICP-AES and AAS		Y	46.5	2.69	15.5	11.6	3.48	8.12
G325	ICP-AES and AAS		Y	45.7	2.99	15.4	11.7	3.51	8.19
G326	ICP-AES and AAS		Y	47.2	2.98	15.3	11.3	3.39	7.91
G327	ICP-AES and AAS		Y	46.6	2.61	15.4	11.3	3.39	7.91
G328	ICP-AES and AAS		Y	46.2	2.62	15	11	3.3	7.7
G329	ICP-AES and AAS		Y	45.1	2.86	15.4	11.4	2.28	9.12
G330	ICP-AES and AAS		Y	44.6	2.89	15.5	11.4	3.42	7.98

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G301	0.13	9.9	8.3	3.94	1.93	1.1	0.84	100	69.559	Weinstein et al. 1994
G302	0.14	7.7	8.5	4.03	1.59	1.3	0.62	100	61.946	Weinstein et al. 1994
G303	0.14	7.9	9.4	3.67	1.16	0.9	0	98.9	62.458	Weinstein et al. 1994
G304	0.14	8.6	10.2	4.6	1.96	2.4	0.51	100.1	66.296	Weinstein et al. 1994
G305	0.13	8.3	9.5	4.11	1.77	1.8	0.81	99.5	64.886	Weinstein et al. 1994
G306	0.13	8.4	9.5	4.43	2.05	1.4	0.64	99.1	66.806	Weinstein et al. 1994
G307	0.13	9.2	8.1	4.41	1.95	1.2	0.46	99.7	69.203	Weinstein et al. 1994
G308	0.12	8.3	9.9	4.33	2.04	1.7	0.63	98.9	66.331	Weinstein et al. 1994
G309	0.13	8.4	10.1	4.41	1.95	2.2	1.78	101.1	66.182	Weinstein et al. 1994
G310	0.14	9.1	10.4	4.1	1.57	1.3	1.26	101	64.514	Weinstein et al. 1994
G311	0.13	8.3	10.5	3.38	1.8	1.9	3.36	100.6	64.454	Weinstein et al. 1994
G312	0.18	8	9.1	4.43	1.61	1.3	1.39	100.8	62.842	Weinstein et al. 1994
G313	0.17	7.9	9.1	3.63	1.27	1	0.7	100.3	60.218	Weinstein et al. 1994
G314	0.16	8.7	8.8	3.69	1.75	1.2	1.49	99.2	68.001	Weinstein et al. 1994
G315	0.17	8.3	10.2	4.1	1.81	1.4	0.03	98.31	66.541	Weinstein et al. 1994
G316	0.1	5.1	9.8	4.6	1.54	1.3	0.5	100.24	52.953	Weinstein et al. 1994
G317	0.1	5.3	10.1	4.2	1.25	1.4	1.05	99.56	53.05	Weinstein et al. 1994
G318	0.1	5.2	10	4.1	1.48	1.3	0.88	101.19	52.789	Weinstein et al. 1994
G319	0.14	7	8.9	5.06	2.24	1.9	0.8	99.14	62.206	Weinstein et al. 1994
G320	0.13	9.2	8.9	3.15	1.46	0.8	2.31	98.86	66.776	Weinstein et al. 1994
G321	0.13	8.5	10.2	4.8	1.95	2.2	0.69	100.2	66.86	Weinstein et al. 1994
G322	0.14	8.4	10.3	4.54	1.82	2	0.76	99.1	67.017	Weinstein et al. 1994
G323	0.17	10.9	9.2	3.45	1.42	1.2	1.08	99.8	68.717	Weinstein et al. 1994
G324	0.17	7.3	8.3	4.14	1.66	1.3	0.57	99.6	61.287	Weinstein et al. 1994
G325	0.17	7.2	8.3	4.39	1.87	1.5	0.72	99.9	60.756	Weinstein et al. 1994
G326	0.16	7	8.3	3.33	1.95	1.6	0.98	100.1	60.913	Weinstein et al. 1994
G327	0.13	7	9.8	4.03	1.55	1	0.7	100.1	60.912	Weinstein et al. 1994
G328	0.14	6.6	9.7	4.34	1.65	1.1	0.9	99.3	60.15	Weinstein et al. 1994
G329	0.14	6.6	10.4	4.07	1.74	1.4	1.12	100.3	57.507	Weinstein et al. 1994
G330	0.14	6.1	10.2	4.19	1.77	1.4	1.28	99.4	57.379	Weinstein et al. 1994

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G331	ICP-AES and AAS		Y	45.6	2.76	15.2	11.5	3.45	8.05
G332	ICP-AES and AAS		Y	46.1	2.74	15.5	11.4	3.42	7.98
G333	ICP-AES and AAS		Y	47.4	2.46	16.3	11.3	2.26	9.04
G334	ICP-AES and AAS		Y	47.5	2.48	16.6	10.8	3.24	7.56
G335	ICP-AES and AAS		Y	45.3	2.8	16	10.7	3.21	7.49
G336	ICP-AES and AAS		Y	46.8	2.64	15.4	11.2	3.36	7.84
G337	ICP-AES and AAS		Y	48	2.7	15.9	11.1	2.22	8.88
G338	ICP-AES		Y	45.78	2.31	14.9		4.85	7.2
G339	ICP-AES		Y	45.55	2.83	13.42		3.01	7.31
G340	ICP-AES		Y	44.72	3.18	13.73		4.64	7.76
G341	ICP-AES		Y	44.38	3.21	14.51		3.35	7.85
G342	ICP-AES		Y	44.5	2.85	15.27		3.62	8.14
G343	ICP-AES		Y	44.7	3.05	14.93		3.25	7.9
G344	ICP-AES		Y	44.7	2.85	14.55		3.93	7.85
G345	ICP-AES		Y	45.1	3.05	13.57		3.91	8.38
G346	ICP-AES		Y	46.65	2.55	14.3		3.89	8.12
G347	ICP-AES		Y	45.41	2.65	14.82		3.97	7.44
G348	ICP-AES		Y	44.72	2.18	14.81		4.07	6.8
G349	ICP-AES		Y	44.83	2.09	14.16		3.68	6.43
G350	ICP-AES		Y	44.01	2.15	14.49		3.97	7.11
G351	ICP-AES		Y	44.09	2.22	15.13		4.05	7.19
G352	ICP-AES		Y	44.22	2.1	14.05		3.84	6.95
G353	ICP-AES		Y	44.58	2.13	14.42		3.88	6.88
G354	ICP-AES		Y	44.13	2.12	14.51		3.78	6.93
G355	ICP-AES		Y	44.17	2.14	14.53		3.82	6.83
G356	ICP-AES		Y	44.11	2.21	14.13		4.09	7.15
G357	ICP-AES		Y	44.29	2.01	13.58		3.72	6.32
G360	not reported	Average. LOI not given	Y	49.52	2.39	14.4		5.08	6.42
G361	not reported	Average. LOI not given	Y	42.32	2.06	13.5		6.46	5.98
G362	XRF		Y	43.6	2.89	13.5		6.1	7.3
G363	XRF		Y	43.3	3.16	13.9		6.8	6.93
G364	XRF		Y	44.8	2.73	13.9		4.6	8.95
G365	ICP-OES	Average. LOI not given	Y	48.85	2.2	15.94		3.02	8.16
G366	ICP-OES	Average. LOI not given	Y	48.97	2.53	14.36		3.27	8.81
G367	ICP-OES	Average. LOI not given	Y	48.05	2.6	14.79		3.29	8.89
G368	ICP-OES	Average. LOI not given	Y	50.95	2.92	13.61		3.37	9.09
G369	ICP-OES	Average. LOI not given	Y	51.43	2.13	14.95		2.79	7.61
G370	ICP-OES	Average. LOI not given	Y	50.8	1.99	16.83		2.57	6.92
G374	XRF		Y	47.1	2.66	16.28	12.74	2.548	10.19
G375	XRF		Y	47.3	2.18	15.35	13.55	2.71	10.84
G376	XRF		Y	45.87	2.35	15.61	12.01	2.402	9.608
G377	XRF		Y	48.47	2.22	15.57	12.69	2.538	10.15

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G331	0.12	6.5	10.7	3.63	1.41	1.4	1.46	100.3	58.709	Weinstein et al. 1994
G332	0.12	6.3	10.4	3.71	1.45	1.3	0.87	99.9	58.166	Weinstein et al. 1994
G333	0.18	6	10.1	3.59	1.17	0.8	0.79	100.1	55.381	Weinstein et al. 1994
G334	0.17	5.7	10.1	3.79	1.19	0.8	0.68	99.8	57.042	Weinstein et al. 1994
G335	0.17	5.1	10.5	3.8	1.5	0.7	0	96.57	54.528	Weinstein et al. 1994
G336	0.17	6.8	9.9	4.02	1.44	1.3	0.7	100.4	60.436	Weinstein et al. 1994
G337	0.25	6.4	9.9	2.48	1.42	1	2.67	101.8	57.407	Weinstein et al. 1994
G338	0.18	9.23	8.33	3.15	1.31	0.63	2.16	100.04	69.559	Al-Malabeh 1994
G339	0.16	10.45	9.2	3.44	1.18	0.49	2.79	99.83	71.817	Al-Malabeh 1994
G340	0.17	8.77	10.43	3.61	1.34	0.21	1.62	100.18	66.828	Al-Malabeh 1994
G341	0.2	8.61	9.74	3.22	1.25	0.49	2.91	99.72	66.16	Al-Malabeh 1994
G342	0.17	9.21	9.52	3.44	1.22	0.58	2	100.52	66.853	Al-Malabeh 1994
G343	0.18	8.81	9.72	3.1	1.23	0.47	2.3	99.64	66.532	Al-Malabeh 1994
G344	0.17	8.76	10.08	2.91	1.29	0.31	2.45	99.85	66.545	Al-Malabeh 1994
G345	0.18	8.99	9.8	3.16	1.28	0.32	1.9	99.64	65.662	Al-Malabeh 1994
G346	0.17	10.25	8.74	3.26	1.1	0.53	1.41	100.97	69.231	Al-Malabeh 1994
G347	0.18	8.93	9.08	3.13	1.23	0.55	2.47	99.86	68.148	Al-Malabeh 1994
G348	0.19	10.22	9.74	3.68	1.09	0.4	2.01	99.91	72.818	Al-Malabeh 1994
G349	0.2	9.56	9.52	3	1.29	0.46	3.11	98.33	72.604	Al-Malabeh 1994
G350	0.2	10.45	9.47	2.92	1.25	0.27	2.63	98.92	72.376	Al-Malabeh 1994
G351	0.2	10.26	9.44	3.09	1.15	0.29	3.09	100.2	71.78	Al-Malabeh 1994
G352	0.2	9.55	10.02	3	1.03	0.35	3.13	98.44	71.01	Al-Malabeh 1994
G353	0.2	8.29	9.9	3.14	1.02	0.21	3.19	99.84	68.231	Al-Malabeh 1994
G354	0.2	10.01	9.92	3.07	1.21	0.38	3.38	99.64	72.027	Al-Malabeh 1994
G355	0.2	10.12	9.83	3.06	1.11	0.35	3.4	99.56	72.536	Al-Malabeh 1994
G356	0.2	9.16	10.26	3.19	1.14	0.35	2.88	98.87	69.546	Al-Malabeh 1994
G357	0.19	9.33	10.23	3.63	1.05	0.36	3.53	98.24	72.463	Al-Malabeh 1994
G360	0.17	9.3	9.17	2.78	0.72	0.33		100.28	72.084	Khalil 1992
G361	0.17	10.32	10.42	2.74	1.16	0.57		95.7	75.467	Khalil 1992
G362	0.18	8.85	9.37	3.76	1.84	0.79	1.33	99.51	68.366	Duffield et al.
G363	0.18	8.28	9.39	4.32	1.04	0.82	1.82	99.94	68.049	Duffield et al.
G364	0.17	8.83	9.19	3.87	1.36	0.67	0.4	99.47	63.751	Duffield et al.
G365	0.17	5.75	7.92	3.03	1.02	1.01		97.07	55.678	Jarrar 2001
G366	0.23	4.82	7.33	2.67	1.17	1.34		95.5	49.373	Jarrar 2001
G367	0.18	5.41	7.68	3	1.16	1.34		96.39	52.034	Jarrar 2001
G368	0.19	4.73	7.16	3.09	1.12	0.95		97.18	48.119	Jarrar 2001
G369	0.16	4.44	6.68	3.07	1.85	0.86		95.97	50.977	Jarrar 2001
G370	0.15	3.31	6.54	5.5	3.18	0.35		98.14	46.025	Jarrar 2001
G374	0.18	5.16	10.13	3.74	1.03	0.82	0.53	100.4	48.634	W-T and Thorpe 1993
G375	0.17	5.7	10.37	2.79	1.51	0.34	0.02	99.28	49.58	W-T and Thorpe 1993
G376	0.17	7.29	10.63	2.63	0.92	0.77	2.31	100.6	58.66	W-T and Thorpe 1993
G377	0.17	6.41	9.62	3.36	0.76	0.3	-0.17	99.3	54.144	W-T and Thorpe 1993

ID	Analysis	Notes	Use	SiO2	TiO2	Al2O3	Fe Total	Fe2O3	FeO
G378	XRF		Y	47.48	2.25	14.61	12.35	2.47	9.88
G379	XRF		Y	45.64	2.22	15.47	12.46	2.492	9.968
G380	XRF		Y	46.1	2.25	15.62	12.09	2.418	9.672
G381	XRF		Y	49.05	2.07	15.71	13.87	2.774	11.1
G382	XRF		Y	43.53	1.65	13.08	12.6	2.52	10.08
G383	XRF		Y	48.36	2.21	15.4	13.08	2.616	10.46
G385	XRF		Y	43.58	2.9	14.43	13.22	2.644	10.58
G387	XRF		Y	45	3.2	15.14	12.3	3.69	8.61
G388	XRF		Y	46.63	2.79	16.35	12.49	3.747	8.743
G389	XRF		Y	46.95	2.75	15.42	12.88	3.864	9.016
G390	XRF		Y	46.53	2.2	14.63	13.66	2.732	10.93
G391	XRF		Y	47.2	2.36	15.78	12.44	3.732	8.708
G392	XRF		Y	45.59	3.11	14.69	12.36	2.472	9.888
G393	XRF	Average of 8 samples	Y	43.66	2.6	14.1		3.97	8.27
G394	XRF	Average of 4 samples	Y	47.3	1.93	15.6		3.25	7.8
G395	XRF	Average of 5 samples	Y	47.85	2.06	16		3.11	8.13
G396	XRF	Average of 7 samples	Y	42.99	2.38	12.78		3.95	8.19
G397	XRF	Average of 5 samples	Y	47.52	1.77	15.31		2.74	8.31
G398	XRF	Average of 6 samples	Y	46.96	1.93	15.2		2.94	7.48
G399	XRF	Average of 10 samples	Y	44.25	2.35	14.82		2.84	8.02

ID	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Mg No	Analysed by?
G378	0.15	7.75	9.12	3	0.96	0.43	2.28	100.8	59.461	W-T and Thorpe 1993
G379	0.16	5.35	12.01	2.94	0.78	0.57	2.84	100.4	50.093	W-T and Thorpe 1993
G380	0.18	4.74	12.03	2.64	0.97	0.56	3.87	101.1	47.823	W-T and Thorpe 1993
G381	0.18	5.72	9.29	3.51	0.68	0.27	0.44	100.8	49.085	W-T and Thorpe 1993
G382	0.18	11.25	12.18	2.42	0.69	0.57	3.17	101.3	67.607	W-T and Thorpe 1993
G383	0.18	7.67	9.5	3.49	0.87	0.37	0.48	100.6	57.818	W-T and Thorpe 1993
G385	0.18	8.45	9.91	3.25	1.3	1.14	1.61	99.9	59.904	W-T and Thorpe 1993
G387	0.16	6.54	9.67	4.53	1.83	1.34	0.07	100.8	57.221	W-T and Thorpe 1993
G388	0.17	5.06	9.78	4.35	1.44	1.08	-0.08	100.1	50.475	W-T and Thorpe 1993
G389	0.16	7.3	8.32	4.33	1.62	1.16	-0.42	100.5	58.776	W-T and Thorpe 1993
G390	0.17	9.48	9.61	2.84	0.89	0.65	0.63	101.3	61.866	W-T and Thorpe 1993
G391	0.17	4.4	9.03	3.79	1.45	0.8	0.01	97.4	47.082	W-T and Thorpe 1993
G392	0.16	7.06	9.61	4.23	1.66	1.33	0.1	99.9	57.175	W-T and Thorpe 1993
G393	0.18	9.81	9.75	4.15	1.31	0.71	1.2	99.71	67.891	Nasir 1990
G394	0.15	8.9	10.15	3.5	1.34	0.52	0.5	100.94	67.039	Nasir 1990
G395	0.16	6.45	9.48	4.13	1.2	0.53	1.05	100.15	58.576	Nasir 1990
G396	0.18	12.05	10.95	3.04	1.24	0.72	1.1	99.57	72.396	Nasir 1990
G397	0.16	8.75	10.29	3.53	1.04	0.55	0.82	100.79	65.243	Nasir 1990
G398	0.16	9.4	10.1	3.46	1.27	0.51	0.75	100.16	69.138	Nasir 1990
G399	0.18	11	10.2	3.72	1.06	0.66	0.85	99.95	70.971	Nasir 1990

Mineral norms database

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
A156	Alkali basalt	0	5.26	18.048	20.459	0	8.325	0	0
A165	Alkali basalt	0	4.391	26.318	22.815	0	3.23	0	0
A174	Hawaiite	0	7.529	22.312	20.653	0	5.846	0	0
A177	Alkali basalt	0	4.55	23.394	23.93	0	2.536	0	0
A186	Hawaiite	0	6.926	22.639	17.714	0	5.338	0	0
A188	Hawaiite	0	7.216	30.408	23.993	0	1.982	0	0
A189	Alkali basalt	0	4.462	17.905	19.301	0	7.467	0	0
A190	Hawaiite	0	6.577	20.31	16.558	0	6.994	0	0
G032	Basanite	0	11.08	9.254	14.258	0	14.258	0	0
G037	Basanite	0	9.467	12.321	16.862	0	10.983	0	0
G044	Basanite	0	7.233	12.686	15.067	0	13.288	0	0
G053	Basanite	0	5.732	8.219	22.055	0	10.051	0	0
G055	Alkali basalt	0	3.475	10.176	24.54	0	9.94	0	0
G058	Melanephelinite	0	7.47	3.97	12.332	0	16.703	0	0
G064	Melanephelinite	0	5.106	2.006	13.632	0	14.751	0	0
G069	Nephelinite	0	5.657	0	7.851	3.84	22.393	0	0
G072	Nephelinite	0	5.67	0	9.426	4.636	20.124	0	0
G077	Alkali basalt	0	3.694	21.292	28.06	0	2.639	0	0
G079	Alkali basalt	0	4.964	24.729	27.313	0	2.418	0	0
G081	Alkali basalt	0	4.018	25.762	26.556	0	1.671	0	0
G084	Alkali basalt	0	3.315	20.532	26.24	0	1.731	0	0
G085	Benmoreite	1.08	17.835	49.467	11.026	0	0	0	0
G086	Hawaiite	0	5.088	29.579	32.855	0	3.004	0	0
G087	Hawaiite	0	6.087	37.433	18.351	0	2.861	0	0
G088	Alkali basalt	0	3.546	28.504	30.182	0	2.216	0	0
G089	Hawaiite	0	4.858	35.435	23.522	0	1.179	0	0
G090	Tholeiitic basalt	0	4.58	21.484	18.454	0	0	0	0
G091	Phonotephrite	3.233	49.623	6.295	22.405	0	0	2.746	0
G092	Phonotephrite	0	50.734	5.227	28.407	0	0.198	0	0
G093	Tholeiitic basalt	0	5.395	24.843	23.82	0	0	0	0
G094	Alkali basalt	0	7.452	28.14	22.897	0	0.107	0	0
G095	Alkali basalt	0	9.402	18.177	22.836	0	4.313	0	0
G096	Basanite	0	7.706	7.255	17.928	0	13.585	0	0
G097	Melanephelinite	0	8.226	3.543	12.871	0	18.86	0	0
G098	Melanephelinite	0	7.765	4.403	13.57	0	18.339	0	0
G099	Basanite	0	7.346	5.902	12.94	0	18.434	0	0
G100	Melanephelinite	0	4.804	2.624	17.666	0	11.862	0	0
G101	Shoshonite	0	13.982	32.594	16.762	0	0	0	0
G102	Picrobasalt	0	3.073	13.369	30.429	0	1.577	0	0
G103	Basanite	0	18.178	8.46	25.106	0	9.361	0	0
G104	Mugearite	0	11.996	37.231	15.032	0	0	0	0
G105	Phonotephrite	0	15.814	39.299	11.412	0	7.447	0	0
G106	Alkali basalt	0	4.61	22.507	20.83	0	1.453	0	0
G107	Potassic	0	12.404	25.776	17.065	0	1.824	0	0
G108	Tholeiitic basalt	0	6.849	24.395	20.613	0	0	0	0
G109	Tholeiitic basalt	0	7.032	26.189	27.106	0	0	0	0
G110	Alkali basalt	0	5.413	24.844	20.131	0	0.508	0	0
G111	Basanite	0	10.105	21.714	21.15	0	6.568	0	0
G112	Alkali basalt	0	6.276	17.756	22.249	0	5.178	0	0
G115	Potassic	0	15.241	33.142	19.032	0	1.078	0	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
A156	29.545	0	9.551	2.821	0	4.45	1.541	0	0	0
A165	19.483	0	16.359	2.94	0	3.497	0.966	0	0	0
A174	19.61	0	12.714	3.965	0	5.128	2.243	0	0	0
A177	24.923	0	12.122	2.888	0	4.37	1.286	0	0	0
A186	22.556	0	13.476	4.142	0	5.335	1.872	0	0	0
A188	15.768	0	9.717	4.036	0	5.269	1.612	0	0	0
A189	25.697	0	17.111	2.943	0	3.837	1.277	0	0	0
A190	23.653	0	16.182	4.148	0	4.382	1.196	0	0	0
G032	23.72	0	15.892	4.267	0	5.474	1.796	0	0	0
G037	21.555	0	18.852	3.007	0	5.307	1.645	0	0	0
G044	21.274	0	20.654	3.13	0	5.03	1.638	0	0	0
G053	28.645	0	17.37	2.86	0	4.087	0.978	0	0	0
G055	30.531	0	14.463	2.94	0	3.244	0.688	0	0	0
G058	26.827	0	22.561	3.114	0	4.95	2.074	0	0	0
G064	27.456	0	27.587	3.168	0	4.969	1.325	0	0	0
G069	30.09	0	16.808	3.445	0	7.117	2.796	0	0	0
G072	28.881	0	17.896	3.43	0	7.047	2.889	0	0	0
G077	23.971	0	12.678	2.842	0	3.785	1.038	0	0	0
G079	19.952	0	12.775	2.731	0	4.086	1.029	0	0	0
G081	18.246	0	16.36	2.746	0	3.664	0.975	0	0	0
G084	15.904	0	26.224	2.856	0	2.769	0.426	0	0	0
G085	8.107	6.082	0	3.284	0	2.233	0.883	0	0	0
G086	13.651	0	6.528	3.105	0	5.538	0.649	0	0	0
G087	11.497	0	12.851	4.039	0	5.892	0.989	0	0	0
G088	17.125	0	10.496	2.462	0	4.798	0.672	0	0	0
G089	13.747	0	10.875	3.83	0	5.635	0.917	0	0	0
G090	20.342	25.218	1.645	3.171	0	4.397	0.709	0	0	0
G091	0	3.928	0	0	1.249	7.622	1.981	0.919	0	0
G092	6.1	0	0	0	0.803	4.938	1.455	0	2.138	0
G093	14.158	4.751	18.182	2.971	0	4.75	1.131	0	0	0
G094	12.189	0	19.046	3.06	0	5.457	1.652	0	0	0
G095	16.235	0	19.411	2.904	0	4.938	1.784	0	0	0
G096	27.334	0	16.938	2.775	0	4.858	1.617	0	0	0
G097	27.868	0	17.841	2.907	0	5.442	2.442	0	0	0
G098	27.439	0	17.581	2.934	0	5.521	2.444	0	0	0
G099	26.997	0	17.441	2.907	0	5.459	2.574	0	0	0
G100	29.2	0	23.409	2.963	0	5.345	2.124	0	0	0
G101	12.554	6.722	4.792	4.301	0	5.645	2.648	0	0	0
G102	23.488	0	15.206	2.646	0	9.776	0.433	0	0	0
G103	14.746	0	11.005	4.47	0	6.439	2.236	0	0	0
G104	12.355	9.333	2.712	4.435	0	5.022	1.881	0	0	0
G105	7.372	0	8.854	3.887	0	4.274	1.64	0	0	0
G106	19.567	0	22.376	3.076	0	4.484	1.094	0	0	0
G107	14.091	0	18.108	3.956	0	4.934	1.842	0	0	0
G108	17.779	5.859	15.232	2.966	0	4.832	1.474	0	0	0
G109	15.502	4.223	10.766	2.781	0	4.999	1.402	0	0	0
G110	17.945	0	21.343	3.02	0	5.005	1.789	0	0	0
G111	12.987	0	15.641	3.117	0	7.113	1.603	0	0	0
G112	21.616	0	17.575	2.928	0	5.25	1.17	0	0	0
G115	7.89	0	12.249	4.561	0	3.334	3.471	0	0	0

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
G116	Tholeiitic basalt	0	2.529	26.121	23.993	0	0	0	0
G117	Alkali basalt	0	6.595	14.468	22.586	0	8.288	0	0
G118	Alkali basalt	0	6.778	14.423	22.598	0	8.056	0	0
G121	Alkali basalt	0	5.283	22.137	21.77	0	5.244	0	0
G122	Basanite	0	10.519	31.044	18.43	0	6.112	0	0
G123	Basanite	0	10.956	31.361	19.412	0	5.271	0	0
G124	Alkali basalt	0	9.993	9.703	19.259	0	9.866	0	0
G125	Tholeiitic basalt	0.189	4.485	27.374	24.965	0	0	0	0
G126	Alkali basalt	0	8.929	12.54	20.081	0	7.958	0	0
G127	Nephelinite	0	8.235	0	13.223	0.688	22.338	0	0
G128	Basanite	0	12.026	13.673	18.82	0	9.398	0	0
G129	Potassic	0	10.182	20.771	20.102	0	5.012	0	0
G130	Potassic	0	9.727	21.789	15.647	0	4.226	0	0
G131	Tholeiitic basalt	0.066	2.003	25.461	26.29	0	0	0	0
G132	Basanite	0	11.453	11.93	15.332	0	10.507	0	0
G133	Basanite	0	6.761	20.215	23.639	0	4.029	0	0
G134	Alkali basalt	0	7.405	22.056	22.66	0	4.196	0	0
G135	Basanite	0	9.887	23.934	18.189	0	7.662	0	0
G136	Alkali basalt	0	7.712	22.406	23.942	0	1.825	0	0
G137	Alkali basalt	0	1.891	17.067	32.902	0	5.386	0	0
G138	Hawaiite	0	9.851	25.138	21.243	0	4.012	0	0
G139	Basanite	0	4.131	15.757	18.427	0	12.348	0	0
G140	Alkali basalt	0	5.945	20.12	18.879	0	2.508	0	0
G141	Alkali basalt	0	5.697	21.623	19.754	0	1.217	0	0
G142	Alkali basalt	0	7.641	23.437	19.981	0	2.188	0	0
G143	Potassic	0	10.472	24.588	20.664	0	3.874	0	0
G144	Trachyte	0	33.968	52.553	2.225	0	0.542	0	0
G145	Hawaiite	0	11.039	37.824	17.396	0	2.828	0	0
G146	Alkali basalt	0	8.102	16.711	18.745	0	7.27	0	0
G147	Basanite	0	7.003	17.251	18.368	0	10.343	0	0
G148	Alkali basalt	0	6.075	21.715	23.44	0	4.01	0	0
G149	Basanite	0	5.803	17.77	19.025	0	9.754	0	0
G150	Basanite	0	12.54	11.199	10.142	0	17.994	0	0
G151	Basanite	0	9.97	16.798	20.107	0	11.491	0	0
G152	Basanite	0	9.432	12.782	16.676	0	11.64	0	0
G153	Basanite	0	8.853	17.931	16.539	0	9.222	0	0
G154	Alkali basalt	0	6.43	19.427	19.91	0	6.29	0	0
G155	Tholeiitic basalt	0	6.737	30.564	24.955	0	0	0	0
G156	Hawaiite	0	9.993	21.282	19.01	0	6.687	0	0
G157	Alkali basalt	0	5.868	21.266	24.262	0	5.67	0	0
G158	Dolerite	0	1.856	24.81	25.056	0	0	0	0
G159	Dolerite	0	2.458	25.19	24.773	0	0	0	0
G160	Dolerite	0	2.045	25.385	25.469	0	0	0	0
G161	Hawaiite	0	9.798	25.446	22.752	0	3.318	0	0
G162	Tholeiitic basalt	0	7.889	22.584	25.818	0	0	0	0
G163	Hawaiite	0	8.835	31.773	21.297	0	1.935	0	0
G164	Alkali basalt	0	7.824	22.712	26.369	0	0.77	0	0
G165	Alkali basalt	0	6.512	24	25.471	0	0.815	0	0
G166	Hawaiite	0	9.113	23.499	21.202	0	5.642	0	0
G167	Hawaiite	0	6.4	21.593	20.926	0	7.504	0	0
G168	Alkali basalt	0	3.049	21.561	24.718	0	2.704	0	0
G169	Alkali basalt	0	4.527	18.534	22.512	0	5.646	0	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
G116	17.491	10.683	12.314	2.888	0	3.483	0.496	0	0	0
G117	26.789	0	12.622	2.808	0	4.562	1.281	0	0	0
G118	26.331	0	12.96	2.846	0	4.68	1.328	0	0	0
G121	18.662	0	17.379	2.991	0	5.248	1.286	0	0	0
G122	8.731	0	13.205	4.112	0	5.926	1.921	0	0	0
G123	7.369	0	13.652	4.114	0	5.916	1.946	0	0	0
G124	28.993	0	13.431	2.604	0	4.708	1.441	0	0	0
G125	19.13	16.224	0	2.563	0	4.249	0.82	0	0	0
G126	22.065	0	18.689	2.918	0	5.273	1.548	0	0	0
G127	40.136	0	5.99	3.359	0	4.484	1.548	0	0	0
G128	20.42	0	16.006	2.924	0	4.857	1.877	0	0	0
G129	17.28	0	16.877	3.893	0	4.395	1.487	0	0	0
G130	19.773	0	18.226	4.149	0	4.864	1.596	0	0	0
G131	16.018	23.545	0	2.688	0	3.453	0.475	0	0	0
G132	22.146	0	16.182	3.274	0	6.737	2.437	0	0	0
G133	13.937	0	19.547	3.375	0	6.872	1.624	0	0	0
G134	12.331	0	19.282	3.381	0	6.767	1.921	0	0	0
G135	13.874	0	14.85	4.186	0	5.369	2.046	0	0	0
G136	12.193	0	20.167	3.294	0	6.494	1.967	0	0	0
G137	26.899	0	10.159	2.059	0	3.493	0.144	0	0	0
G138	14.057	0	14.502	4.126	0	5.149	1.918	0	0	0
G139	23.452	0	15.296	3.155	0	5.86	1.573	0	0	0
G140	20.972	0	23.693	2.91	0	4.114	0.857	0	0	0
G141	20.547	0	23.242	2.914	0	4.15	0.855	0	0	0
G142	17.429	0	19.69	3.13	0	4.969	1.534	0	0	0
G143	13.208	0	13.936	4.464	0	6.788	2.004	0	0	0
G144	4.101	0	2.987	2.499	0	0.91	0.213	0	0	0
G145	5.082	0	14.154	4.114	0	5.292	2.27	0	0	0
G146	18.968	0	21.742	2.955	0	4.391	1.114	0	0	0
G147	19.056	0	17.31	2.955	0	6.163	1.552	0	0	0
G148	20.5	0	14.79	2.871	0	4.545	2.053	0	0	0
G149	19.611	0	17.37	2.92	0	6.165	1.58	0	0	0
G150	19.618	0	13.934	4.036	0	5.996	4.539	0	0	0
G151	19.585	0	10.212	3.811	0	5.269	2.755	0	0	0
G152	20.024	0	18.308	2.968	0	5.831	2.34	0	0	0
G153	19.398	0	17.005	2.843	0	5.673	2.535	0	0	0
G154	19.699	0	18.739	3.023	0	5.033	1.448	0	0	0
G155	15.562	3.433	10.265	2.669	0	4.426	1.39	0	0	0
G156	16.752	0	16.494	3.887	0	4.547	1.346	0	0	0
G157	21.023	0	12.204	2.844	0	4.889	1.972	0	0	0
G158	9.845	9.165	23.484	2.917	0	2.625	0.243	0	0	0
G159	16.256	13.357	11.019	2.92	0	3.434	0.588	0	0	0
G160	15.756	17.375	7.1	2.901	0	3.381	0.588	0	0	0
G161	11.148	0	15.766	4.056	0	5.314	2.4	0	0	0
G162	9.213	9.989	12.559	3.133	0	6.435	2.379	0	0	0
G163	9.444	0	14.97	4.132	0	5.464	2.15	0	0	0
G164	11.162	0	19.154	3.266	0	6.617	2.124	0	0	0
G165	11.79	0	19.85	3.102	0	6.534	1.925	0	0	0
G166	15.244	0	14.749	3.896	0	5.466	1.191	0	0	0
G167	19.948	0	12.499	4.093	0	5.141	1.893	0	0	0
G168	19.708	0	18.947	3.044	0	5.094	1.172	0	0	0
G169	22.265	0	17.27	2.959	0	5.102	1.184	0	0	0

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
G170	Basanite	0	10.289	21.545	21.637	0	6.637	0	0
G171	Alkali basalt	0	9.325	16.434	19.3	0	6.591	0	0
G172	Alkali basalt	0	7.156	15.627	20.854	0	6.799	0	0
G173	Alkali basalt	0	7.818	18.826	24.36	0	0.573	0	0
G174	Alkali basalt	0	8.386	17.976	22.219	0	1.836	0	0
G175	Tholeiitic basalt	0	4.219	23.718	24.398	0	0	0	0
G176	Alkali basalt	0	6.471	15.961	25.984	0	0.475	0	0
G177	Alkali basalt	0	5.289	22.309	19.793	0	4.82	0	0
G178	Alkali basalt	0	10.336	17.724	22.75	0	3.041	0	0
G179	Alkali basalt	0	5.011	15.437	19.238	0	5.825	0	0
G180	Alkali basalt	0	4.799	15.495	18.735	0	6.307	0	0
G181	Alkali basalt	0	10.094	24.532	20.641	0	0.682	0	0
G183	Alkali basalt	0	7.257	23.255	22.498	0	0.828	0	0
G184	Basanite	0	8.427	20.388	16.813	0	8.707	0	0
G185	Basanite	0	7.824	20.788	16.385	0	9.137	0	0
G186	Alkali basalt	0	8.202	23.822	22.923	0	0.159	0	0
G187	Hawaiite	0	11.742	36.236	16.998	0	2.464	0	0
G189	Basanite	0	11.016	22.03	20.671	0	5.833	0	0
G190	Alkali basalt	0	5.703	18.151	18.812	0	6.39	0	0
G192	Alkali basalt	0	6.826	25.315	22.266	0	0.836	0	0
G193	Alkali basalt	0	4.793	18.823	19.346	0	6.672	0	0
G194	Alkali basalt	0	4.125	24.478	26.174	0	0.276	0	0
G195	Mugearite	0	14.49	31.606	17.154	0	4.977	0	0
G197	Basanite	0	6.607	17.839	16.888	0	10.441	0	0
G198	Hawaiite	0	10.933	29.167	18.619	0	3.552	0	0
G199	Tholeiitic basalt	0	7.121	29.54	24.575	0	0	0	0
G200	Tholeiitic basalt	0	7.316	30.098	25.499	0	0	0	0
G201	Tholeiitic basalt	0	8.492	18.683	25.144	0	0	0	0
G202	Alkali basalt	0	8.226	17.724	19.207	0	5.525	0	0
G203	Hawaiite	0	11.021	28.911	16.748	0	5.658	0	0
G204	Tholeiitic basalt	8.477	6.79	18.709	28.081	0	0	2.536	0
G205	Basanite	0	13.214	13.465	14.696	0	11.335	0	0
G206	Nephelinite	0	0	0	3.946	8.007	22.521	0	0
G208	Nephelinite	0	3.683	0	17.954	1.94	12.23	0	0
G211	Hawaiite	0	9.828	26.952	18.574	0	5.129	0	0
G212	Basanite	0	11.039	17.756	18.016	0	9.042	0	0
G213	Basanite	0	10.673	14.594	14.955	0	12.524	0	0
G214	Basanite	0	11.606	10.633	15.7	0	12.53	0	0
G215	Basanite	0	9.627	12.376	14.148	0	13.309	0	0
G216	Basanite	0	9.485	12.78	15.204	0	12.237	0	0
G217	Basanite	0	11.364	15.095	17.269	0	9.164	0	0
G218	Tephrite	0	10.094	18.048	14.004	0	11.204	0	0
G219	Potassic	0	10.2	19.961	19.844	0	5.927	0	0
G220	Basanite	0	5.035	15.983	17.662	0	10.126	0	0
G221	Alkali basalt	0	5.289	7.654	23.56	0	9.72	0	0
G222	Alkali basalt	0	6.122	17.223	20.571	0	7.144	0	0
G223	Alkali basalt	0	5.36	16	16.226	0	9.682	0	0
G224	Hawaiite	0	8.392	21.96	16.814	0	6.123	0	0
G225	Mugearite	0	14.301	39.711	15.428	0	0	2.653	0
G226	Mugearite	1.822	13.196	36.538	16.033	0	0	3.454	0
G227	Shoshonite	0	16.884	35.818	10.331	0	0	4.57	0
G228	Shoshonite	0	19.573	39.575	9.805	0	0	4.913	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
G170	11.75	0	16.275	3.124	0	7.081	1.661	0	0	0
G171	21.317	0	17.925	2.65	0	5.176	1.281	0	0	0
G172	21.165	0	18.708	2.879	0	5.176	1.636	0	0	0
G173	18.447	0	19.582	2.747	0	6.393	1.251	0	0	0
G174	18.527	0	21.693	2.62	0	5.508	1.232	0	0	0
G175	15.688	16.412	6.693	2.844	0	5.284	0.741	0	0	0
G176	20.761	0	21.531	2.791	0	4.879	1.147	0	0	0
G177	18.157	0	16.569	2.659	0	6.555	3.848	0	0	0
G178	15.593	0	18.22	2.583	0	6.767	2.984	0	0	0
G179	24.75	0	19.608	2.634	0	5.335	2.162	0	0	0
G180	25.036	0	19.658	2.662	0	5.278	2.03	0	0	0
G181	18.388	0	15.674	2.833	0	5.689	1.466	0	0	0
G183	15.038	0	21.65	2.637	0	5.084	1.752	0	0	0
G184	17.215	0	16.816	2.747	0	5.994	2.891	0	0	0
G185	16.968	0	17.145	2.772	0	5.935	3.044	0	0	0
G186	15.066	0	19.098	2.939	0	6.184	1.608	0	0	0
G187	8.326	0	11.658	3.7	0	6.424	2.449	0	0	0
G189	14.272	0	13.977	2.953	0	6.819	2.428	0	0	0
G190	18.285	0	23.178	2.736	0	4.967	1.779	0	0	0
G192	14.527	0	22.299	2.7	0	4.27	0.964	0	0	0
G193	19.047	0	20.939	2.717	0	5.35	2.312	0	0	0
G194	16.014	0	17.031	2.96	0	5.956	2.986	0	0	0
G195	9.42	0	11.496	4.035	0	4.917	1.902	0	0	0
G197	22.634	0	13.61	2.847	0	6.813	2.319	0	0	0
G198	11.299	0	15.351	3.582	0	5.03	2.465	0	0	0
G199	15.088	2.266	13.121	2.492	0	4.737	1.059	0	0	0
G200	15.579	8.288	4.659	2.679	0	4.883	0.996	0	0	0
G201	16.441	5.469	16.285	2.907	0	5.058	1.518	0	0	0
G202	24.221	0	16.043	2.559	0	5.368	1.124	0	0	0
G203	12.322	0	13.739	3.559	0	5.352	2.688	0	0	0
G204	0	21.598	0	2.936	0	7.884	2.989	0	0	0
G205	22.059	0	13.478	3.603	0	5.875	2.275	0	0	0
G206	24.707	0	20.695	3.111	0	6.802	4.655	0	0	5.556
G208	35.04	0	14.954	3.121	0	7.309	3.767	0	0	0
G211	14.973	0	12.419	3.755	0	5.43	2.938	0	0	0
G212	19.185	0	13.445	2.776	0	6.224	2.514	0	0	0
G213	23.098	0	11.896	3.579	0	5.392	3.288	0	0	0
G214	22.723	0	15.123	2.881	0	6.395	2.407	0	0	0
G215	21.047	0	16.483	2.863	0	6.249	3.897	0	0	0
G216	20.41	0	16.968	2.85	0	6.177	3.888	0	0	0
G217	19.819	0	15.681	2.756	0	6.178	2.674	0	0	0
G218	24.557	0	8.314	3.74	0	7.252	2.785	0	0	0
G219	18.321	0	13.857	3.893	0	5.69	2.305	0	0	0
G220	24.778	0	12.406	2.831	0	7.035	4.142	0	0	0
G221	34.813	0	11.478	2.736	0	4.106	0.642	0	0	0
G222	26.372	0	14.847	2.679	0	4.367	0.672	0	0	0
G223	24.333	0	16.928	2.75	0	6.124	2.597	0	0	0
G224	17.579	0	15.374	3.807	0	7.104	2.847	0	0	0
G225	0	22.478	0.032	3.165	0	1.99	0.243	0	0	0
G226	0	23.715	0	2.998	0	2	0.243	0	0	0
G227	0	25.796	1.348	3.196	0	1.808	0.246	0	0	0
G228	0	11.933	9.07	2.976	0	1.909	0.246	0	0	0

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
G229	Benmoreite	3.496	15.471	41.124	15.423	0	0	2.059	0
G230	Latite	1.216	18.905	36.994	8.129	0	0	5.451	0
G231	Tholeiitic basalt	0	6.17	22.093	31.65	0	0	0	0
G232	Mugearite	3.953	7.6	39.008	6.579	0	0	5.658	0
G233	Alkali basalt	0	2.506	34.966	29.998	0	0.008	0.698	0
G234	Mugearite	0	11.778	44.441	10.479	0	0	0	0
G235	Mugearite	0.83	10.761	42.486	11.086	0	0	0	0
G236	Mugearite	1.11	11.713	42.461	11.072	0	0	0.069	0
G237	Tholeiitic basalt	0	3.433	32.467	29.617	0	0	0.683	0
G238	Shoshonite	1.748	18.745	36.673	12.829	0	0	0	0
G239	Shoshonite	0	26.333	30.762	14.215	0	1.497	0	0
G240	Phonotephrite	0	33.141	20.364	11.791	0	3.623	0	0
G241	Shoshonite	0	22.522	23.227	24.77	0	0	0	0
G242	Mugearite	0	10.543	45.913	15.694	0	0	0	0
G243	Shoshonite	0	23.621	18.243	12.777	0	0	0.832	0
G244	Shoshonite	0	17.735	37.87	18.802	0	0.168	0	0
G245	Mugearite	0	9.71	38.814	18.255	0	2.347	0	0
G246	Mugearite	0	14.591	40.947	14.342	0	1.049	0	0
G247	Shoshonite	0	22.699	31.511	18.682	0	0	0	0
G248	Mugearite	0	13.048	43.798	13.967	0	0	0	0
G249	Potassic	0	14.81	25.673	23.381	0	0	0.337	0
G250	Benmoreite	0.514	12.806	44.652	14.265	0	0	0	0
G251	Andesite	18.776	15.2	32.027	10.81	0	0	4.842	0
G252	Andesite	16.012	20.01	27.771	12.675	0	0	1.781	0
G253	Latite	7.17	32.881	27.467	10.421	0	0	0	0
G254	Trachyte	17.874	27.468	40.464	4.522	0	0	0.874	0
G255	Rhyolite	29.228	17.321	32.349	5.778	0	0	1.95	0
G256	Andesite	9.63	1.962	48.604	11.687	0	0	0	0
G257	Trachyte	0.795	17.191	52.496	5.531	0	0	0	0
G258	Benmoreite	4.421	13.509	45.482	10.235	0	0	0	0
G259	Latite	5.061	13.876	35.598	16.449	0	0	0	0
G260	Benmoreite	4.801	13.243	37.392	16.76	0	0	0	0
G261	Benmoreite	2.985	12.611	37.705	17.23	0	0	0	0
G262	Trachyte	9.041	13.929	43.484	13.822	0	0	0	0
G263	Basaltic andesite	0	10.277	29.887	18.546	0	0	0	0
G264	Benmoreite	3.243	13.397	36.521	18.993	0	0	0	0
G265	Latite	0	18.734	39.888	15.784	0	0	0	0
G266	Andesite	7.577	8.297	35.099	21.003	0	0	0	0
G267	Basanite	0	9.71	9.669	10.926	0	17.352	0	0
G268	Basanite	0	6.347	13.551	15.639	0	13.534	0	0
G269	Potassic	0	9.828	13.409	19.766	0	8.266	0	0
G270	Basanite	0	8.681	11.264	16.363	0	13.054	0	0
G271	Basanite	0	9.172	9.073	18.614	0	12.522	0	0
G272	Picrite	0	0	0	24.279	5.037	7.733	0	0
G273	Alkali basalt	0	4.196	23.323	25.418	0	2.364	0	0
G274	Hawaiite	0	7.724	31.773	14.702	0	1.655	0	0
G275	Alkali basalt	0	5.366	25.612	26.536	0	2.311	0	0
G276	Alkali basalt	0	4.491	23.92	25.324	0	0.693	0	0
G277	Basanite	0	10.011	7.743	19.135	0	12.706	0	0
G278	Alkali basalt	0	5.189	19.687	25.698	0	4.971	0	0
G279	Alkali basalt	0	6.572	14.352	22.319	0	6.761	0	0
G280	Alkali basalt	0	5.425	22.173	21.949	0	4.908	0	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
G229	0	17.317	0	3.376	0	1.493	0.243	0	0	0
G230	0	23.328	0	3.559	0	1.924	0.493	0	0	0
G231	8.368	23.46	3.715	2.032	0	1.785	0.725	0	0	0
G232	0	31.895	0	2.978	0	1.833	0.496	0	0	0
G233	0	0	25.02	2.672	0	3.544	0.588	0	0	0
G234	1.158	19.488	1.419	4.358	0	4.828	2.053	0	0	0
G235	0.27	22.884	0	4.532	0	5.198	1.951	0	0	0
G236	0	22.501	0	4.283	0	4.766	2.027	0	0	0
G237	0	7.138	19.777	2.711	0	3.533	0.637	0	0	0
G238	1.146	17.773	0	4.181	0	4.893	2.013	0	0	0
G239	4.376	0	14.109	3.193	0	3.938	1.575	0	0	0
G240	9.318	0	8.9	3.894	0	7.487	1.48	0	0	0
G241	0.277	8.595	12.341	3.458	0	3.415	1.397	0	0	0
G242	5.3	2.574	11.546	3.482	0	3.388	1.559	0	0	0
G243	0	20.179	16.715	3.491	0	2.522	1.62	0	0	0
G244	5.112	0	11.997	3.471	0	3.322	1.524	0	0	0
G245	9.264	0	13.022	3.648	0	3.343	1.596	0	0	0
G246	6.322	0	14.95	3.369	0	3.024	1.404	0	0	0
G247	1.435	7.818	9.068	3.229	0	3.476	2.083	0	0	0
G248	6.312	4.554	9.904	3.33	0	3.47	1.615	0	0	0
G249	0	20.792	5.615	3.375	0	3.835	2.18	0	0	0
G250	9.193	13.75	0	2.74	0	1.574	0.505	0	0	0
G251	0	13.418	0	2.694	0	1.635	0.6	0	0	0
G252	0	16.371	0	2.618	0	1.939	0.82	0	0	0
G253	2.48	12.72	0	2.966	0	2.744	1.149	0	0	0
G254	0	5.162	0	1.511	0	1.624	0.5	0	0	0
G255	0	10.554	0	1.554	0	0.934	0.331	0	0	0
G256	1.511	19.967	0	2.765	0	2.706	1.168	0	0	0
G257	6.364	12.273	0	2.94	0	2.059	0.348	0	0	0
G258	2.582	15.191	0	3.759	0	3.276	1.545	0	0	0
G259	9.538	14.661	0	2.723	0	1.574	0.517	0	0	0
G260	7.534	15.542	0	2.669	0	1.567	0.489	0	0	0
G261	7.727	16.828	0	2.786	0	1.616	0.512	0	0	0
G262	2.567	12.86	0	2.47	0	1.322	0.505	0	0	0
G263	21.449	12.961	2.022	2.966	0	1.519	0.371	0	0	0
G264	6.132	16.807	0	2.801	0	1.599	0.505	0	0	0
G265	5.939	11.814	3.298	2.505	0	1.652	0.385	0	0	0
G266	6.862	16.542	0	2.53	0	1.595	0.493	0	0	0
G267	24.922	0	15.483	4.239	0	5.89	1.807	0	0	0
G268	22.705	0	18.073	3.034	0	5.584	1.531	0	0	0
G269	19.051	0	19.684	4.078	0	4.815	1.1	0	0	0
G270	22.827	0	18.17	2.971	0	5.28	1.39	0	0	0
G271	22.258	0	19.553	2.889	0	4.697	1.221	0	0	0
G272	29.266	0	22.506	2.224	0	5.406	1.154	0	0	2.396
G273	21.425	0	14.903	2.958	0	4.722	0.69	0	0	0
G274	22.724	0	7.203	4.806	0	7.97	1.443	0	0	0
G275	16.555	0	16.295	2.617	0	3.935	0.772	0	0	0
G276	17.409	0	20.818	2.839	0	3.871	0.635	0	0	0
G277	22.594	0	17.744	3.01	0	5.647	1.411	0	0	0
G278	19.962	0	17.073	2.631	0	4.025	0.762	0	0	0
G279	25.777	0	16.7	2.83	0	3.951	0.739	0	0	0
G280	17.105	0	20.981	2.891	0	3.814	0.755	0	0	0

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
G281	Alkali basalt	0	5.395	21.503	21.821	0	5.33	0	0
G282	Alkali basalt	0	3.54	26.267	27.718	0	1.631	0	0
G283	Alkali basalt	0	3.516	22.589	28.004	0	2.904	0	0
G284	Alkali basalt	0	5.265	27.121	26.087	0	0.398	0	0
G285	Alkali basalt	0	5.378	27.381	25.732	0	0.418	0	0
G286	Alkali basalt	0	5.307	22.313	23.46	0	2.907	0	0
G287	Melanephelinite	0	6.128	4.232	13.62	0	17.006	0	0
G288	Melanephelinite	0	5.307	4.89	14.651	0	16.228	0	0
G289	Nephelinite	0	6.997	4.991	9.248	0	20.844	0	0
G290	Alkali basalt	0	7.346	12.946	17.59	0	8.334	0	0
G291	Alkali basalt	0	7.115	12.772	17.637	0	8.557	0	0
G292	Alkali basalt	0	7.286	12.907	17.024	0	8.648	0	0
G293	Nephelinite	0	1.666	0	8.259	1.789	22.035	0	0
G294	Basanite	0	1.54	0	14.808	1.647	16.374	0	0
G295	Nephelinite	0	7.788	0	6.861	1.822	21.861	0	0
G296	Nephelinite	0	4.916	0	10.538	0.788	20.816	0	0
G297	Tholeiitic basalt	10.776	3.422	18.142	8.529	0	0	9.291	0
G298	Basanite	0	18.19	8.446	25.061	0	9.378	0	0
G299	Mugearite	0	11.996	37.24	14.981	0	0	0	0
G300	Hawaiite	0	7.996	22.288	20.504	0	4.85	0	0
G301	Hawaiite	0	11.606	20.346	15.904	0	7.355	0	0
G302	Hawaiite	0	9.55	25.493	19.28	0	4.97	0	0
G303	Alkali basalt	0	6.997	26.991	20.908	0	2.549	0	0
G304	Basanite	0	11.736	14.554	12.194	0	13.477	0	0
G305	Basanite	0	10.696	19.515	15.693	0	8.694	0	0
G306	Basanite	0	12.404	15.101	13.672	0	12.612	0	0
G307	Basanite	0	11.707	22.709	14.231	0	8.234	0	0
G308	Basanite	0	12.375	14.853	13.352	0	12.325	0	0
G309	Basanite	0	11.695	16.408	13.666	0	11.629	0	0
G310	Basanite	0	9.396	13.229	15.359	0	11.87	0	0
G311	Basanite	0	11.045	15.849	19.246	0	7.504	0	0
G312	Basanite	0	9.674	20.185	15.171	0	9.707	0	0
G313	Alkali basalt	0	7.612	24.825	22.006	0	3.425	0	0
G314	Hawaiite	0	10.667	23.461	18.4	0	4.742	0	0
G315	Basanite	0	10.98	15.463	15.665	0	10.913	0	0
G316	Tephrite	0	9.219	24.077	20.074	0	8.313	0	0
G317	Hawaiite	0	7.576	24.886	21.648	0	6.261	0	0
G318	Hawaiite	0	8.811	24.942	23.51	0	5.424	0	0
G319	Basanite	0	13.574	16.689	12.738	0	14.745	0	0
G320	Alkali basalt	0	9.018	22.967	20.647	0	2.653	0	0
G321	Basanite	0	11.677	14.545	11.313	0	14.412	0	0
G322	Basanite	0	11.033	14.478	13.325	0	13.499	0	0
G323	Alkali basalt	0	8.581	18.072	17.262	0	6.382	0	0
G324	Hawaiite	0	9.987	26.711	19.142	0	4.847	0	0
G325	Basanite	0	11.24	23.846	17.084	0	7.554	0	0
G326	Potassic	0	11.731	28.685	21.42	0	0	0	0
G327	Hawaiite	0	9.296	22.026	19.642	0	6.816	0	0
G328	Hawaiite	0	10.005	21.502	17	0	8.759	0	0
G329	Basanite	0	10.478	16.844	18.965	0	9.885	0	0
G330	Basanite	0	10.75	17.629	18.766	0	10.193	0	0
G331	Hawaiite	0	8.51	21.973	21.465	0	5.089	0	0
G332	Hawaiite	0	8.734	23.239	21.766	0	4.742	0	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
G281	18.046	0	20.287	2.959	0	3.88	0.776	0	0	0
G282	21.271	0	12.668	2.67	0	3.694	0.54	0	0	0
G283	24.942	0	11.014	2.704	0	3.78	0.547	0	0	0
G284	18.222	0	16.327	2.504	0	3.392	0.681	0	0	0
G285	17.763	0	16.584	2.552	0	3.489	0.702	0	0	0
G286	18.585	0	19.889	2.788	0	3.979	0.772	0	0	0
G287	30.806	0	16.268	3.256	0	6.718	1.965	0	0	0
G288	30.042	0	16.833	3.282	0	6.76	2.006	0	0	0
G289	29.315	0	15.349	4.538	0	6.705	2.011	0	0	0
G290	28.013	0	17.401	2.807	0	4.444	1.119	0	0	0
G291	30.222	0	15.574	2.813	0	4.283	1.026	0	0	0
G292	28.756	0	17.023	2.83	0	4.452	1.07	0	0	0
G293	34.908	0	20.968	2.975	0	5.544	1.856	0	0	0
G294	35.585	0	19.638	2.982	0	5.478	1.946	0	0	0
G295	32.042	0	17.015	4.357	0	6.237	2.018	0	0	0
G296	33.527	0	18.592	2.988	0	5.937	1.895	0	0	0
G297	0	34.669	0	3.793	0	10.895	0.482	0	0	0
G298	14.801	0	10.977	4.465	0	6.442	2.238	0	0	0
G299	12.404	9.536	2.515	4.42	0	5.024	1.881	0	0	0
G300	16.467	0	18.387	3.73	0	4.365	1.413	0	0	0
G301	14.98	0	19.079	3.417	0	4.716	2.592	0	0	0
G302	12.1	0	16.718	3.729	0	5.098	3.063	0	0	0
G303	16.768	0	16.226	2.505	0	4.925	2.129	0	0	0
G304	18.641	0	15.189	3.434	0	5.138	5.635	0	0	0
G305	16.49	0	15.721	3.561	0	5.362	4.265	0	0	0
G306	20.238	0	13.931	3.313	0	5.406	3.322	0	0	0
G307	14.915	0	17.022	3.224	0	5.132	2.824	0	0	0
G308	20.615	0	13.861	3.352	0	5.223	4.043	0	0	0
G309	18.186	0	15.065	3.378	0	4.8	5.174	0	0	0
G310	22.888	0	16.58	2.621	0	5.003	3.051	0	0	0
G311	17.751	0	16.664	2.457	0	4.912	4.571	0	0	0
G312	17.821	0	14.878	3.727	0	5.774	3.063	0	0	0
G313	13.951	0	18.127	2.736	0	4.969	2.349	0	0	0
G314	14.882	0	16.532	3.275	0	5.174	2.868	0	0	0
G315	21.594	0	13.492	3.32	0	5.244	3.329	0	0	0
G316	16.799	0	9.715	3.558	0	5.193	3.049	0	0	0
G317	16.63	0	10.683	3.729	0	5.26	3.327	0	0	0
G318	14.642	0	10.837	3.633	0	5.166	3.035	0	0	0
G319	16.004	0	13.267	3.382	0	5.084	4.516	0	0	0
G320	16.15	0	18.751	2.473	0	5.402	1.937	0	0	0
G321	20.394	0	14.066	3.31	0	5.119	5.164	0	0	0
G322	20.635	0	14.079	3.287	0	4.91	4.752	0	0	0
G323	17.217	0	22.086	2.623	0	4.933	2.843	0	0	0
G324	11.431	0	15.978	3.639	0	5.2	3.065	0	0	0
G325	11.997	0	15.298	3.668	0	5.778	3.536	0	0	0
G326	7.964	3.984	13.132	3.545	0	5.762	3.774	0	0	0
G327	18.673	0	12.627	3.535	0	5.031	2.352	0	0	0
G328	20.241	0	11.295	3.477	0	5.105	2.613	0	0	0
G329	19.783	0	12.638	2.569	0	5.535	3.304	0	0	0
G330	19.355	0	10.721	3.611	0	5.641	3.334	0	0	0
G331	18.984	0	11.691	3.619	0	5.354	3.313	0	0	0
G332	17.984	0	11.58	3.581	0	5.303	3.07	0	0	0

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
G333	Alkali basalt	0	7.032	26.252	25.327	0	2.51	0	0
G334	Hawaiite	0	7.156	27.149	25.203	0	2.968	0	0
G335	Hawaiite	0	9.26	20.151	23.157	0	7.282	0	0
G336	Hawaiite	0	8.616	24.709	19.965	0	5.266	0	0
G337	Tholeiitic basalt	0	8.545	21.366	28.57	0	0	0	0
G338	Alkali basalt	0	7.907	26.703	23.143	0	0.285	0	0
G339	Alkali basalt	0	7.186	21.184	18.229	0	4.774	0	0
G340	Hawaiite	0	8.037	14.655	17.552	0	8.852	0	0
G341	Alkali basalt	0	7.629	19.098	22.153	0	4.9	0	0
G342	Alkali basalt	0	7.316	17.851	22.959	0	6.337	0	0
G343	Alkali basalt	0	7.47	19.416	23.821	0	4.081	0	0
G344	Alkali basalt	0	7.824	18.011	23.436	0	3.94	0	0
G345	Alkali basalt	0	7.742	19.069	19.502	0	4.489	0	0
G346	Alkali basalt	0	6.53	25.192	21.23	0	1.36	0	0
G347	Alkali basalt	0	7.464	23.86	23.363	0	1.807	0	0
G348	Alkali basalt	0	6.577	16.533	21.117	0	8.275	0	0
G349	Alkali basalt	0	8.008	20.674	22.435	0	3.24	0	0
G350	Alkali basalt	0	7.671	16.248	23.616	0	5.097	0	0
G351	Alkali basalt	0	6.997	16.641	24.731	0	5.571	0	0
G352	Alkali basalt	0	6.388	18.642	22.898	0	4.332	0	0
G353	Alkali basalt	0	6.37	21.003	23.496	0	3.827	0	0
G354	Alkali basalt	0	7.428	16.032	23.103	0	5.933	0	0
G355	Alkali basalt	0	6.82	17.085	23.537	0	5.33	0	0
G356	Alkali basalt	0	7.021	16.498	21.74	0	6.295	0	0
G357	Alkali basalt	0	6.554	17.106	18.641	0	8.304	0	0
G360	Tholeiitic basalt	0.236	4.243	23.456	24.619	0	0	0	0
G361	Basanite	0	7.162	14.764	22.058	0	5.126	0	0
G362	Basanite	0	11.075	15.163	14.791	0	9.342	0	0
G363	Tephrite	0	6.264	20.549	15.758	0	9.051	0	0
G364	Basanite	0	8.114	18.609	16.694	0	7.824	0	0
G365	Tholeiitic basalt	1.758	6.211	26.409	27.692	0	0	0	0
G366	Tholeiitic basalt	6.551	7.239	23.659	24.861	0	0	0	0
G367	Tholeiitic basalt	2.385	7.109	26.333	24.345	0	0	0	0
G368	Basaltic andesite	6.894	6.808	26.908	20.537	0	0	0	0
G369	Basaltic andesite	5.655	11.394	27.069	22.452	0	0	0	0
G370	Phonotephrite	0	19.147	28.298	12.068	0	10.359	0	0
G374	Alkali basalt	0	6.164	26.706	24.901	0	2.892	0	0
G375	Alkali basalt	0	9.095	22.333	25.38	0	0.938	0	0
G376	Tholeiitic basalt	0	5.59	22.889	28.871	0	0	0	0
G377	Tholeiitic basalt	0	4.562	28.863	25.542	0	0	0	0
G378	Tholeiitic basalt	0	5.845	26.155	24.28	0	0	0	0
G379	Alkali basalt	0	4.775	20.654	27.668	0	2.769	0	0
G380	Alkali basalt	0	5.963	22.316	29.019	0	0.498	0	0
G381	Tholeiitic basalt	0	4.054	29.946	25.311	0	0	0	0
G382	Basanite	0	4.202	8.698	23.472	0	6.716	0	0
G383	Alkali basalt	0	5.141	27.171	23.781	0	1.274	0	0
G385	Basanite	0	7.901	16.619	21.542	0	6.316	0	0
G387	Basanite	0	10.95	17.54	15.77	0	11.529	0	0
G388	Hawaiite	0	8.581	24.23	21.011	0	6.984	0	0
G389	Hawaiite	0	9.585	25.639	17.877	0	5.982	0	0
G390	Alkali basalt	0	5.283	23.302	24.669	0	0.459	0	0
G391	Hawaiite	0	8.888	30.503	22.564	0	1.49	0	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
G333	16.621	0	13.079	2.54	0	4.752	1.884	0	0	0
G334	16.647	0	10.81	3.387	0	4.792	1.886	0	0	0
G335	21.566	0	7.89	3.445	0	5.555	1.694	0	0	0
G336	17.134	0	12.691	3.494	0	5.075	3.049	0	0	0
G337	12.06	15.884	3.495	2.499	0	5.221	2.358	0	0	0
G338	11.846	0	16.955	7.185	0	4.482	1.492	0	0	0
G339	20.32	0	17.101	4.497	0	5.538	1.17	0	0	0
G340	26.727	0	10.729	6.826	0	6.127	0.493	0	0	0
G341	19.568	0	14.163	5.016	0	6.298	1.172	0	0	0
G342	16.93	0	16.42	5.326	0	5.495	1.365	0	0	0
G343	18.071	0	15.232	4.841	0	5.95	1.119	0	0	0
G344	20.664	0	13.979	5.85	0	5.557	0.737	0	0	0
G345	22.521	0	14.194	5.799	0	5.926	0.758	0	0	0
G346	15.073	0	18.851	5.664	0	4.864	1.232	0	0	0
G347	15.331	0	15.787	5.909	0	5.168	1.309	0	0	0
G348	20.341	0	15.954	6.027	0	4.23	0.945	0	0	0
G349	19.108	0	15.645	5.603	0	4.169	1.119	0	0	0
G350	18.601	0	17.902	5.977	0	4.241	0.649	0	0	0
G351	17.167	0	17.811	6.045	0	4.342	0.693	0	0	0
G352	21.43	0	15.434	5.841	0	4.184	0.85	0	0	0
G353	21.548	0	13.023	5.942	0	4.273	0.514	0	0	0
G354	20.278	0	16.433	5.693	0	4.182	0.915	0	0	0
G355	19.746	0	16.652	5.758	0	4.226	0.843	0	0	0
G356	23.081	0	13.972	6.177	0	4.372	0.846	0	0	0
G357	25.834	0	12.956	5.694	0	4.03	0.88	0	0	0
G360	14.717	20.096	0	7.344	0	4.526	0.762	0	0	0
G361	22.068	0	13.567	9.786	0	4.087	1.381	0	0	0
G362	21.618	0	11.548	9.007	0	5.592	1.865	0	0	0
G363	20.664	0	9.614	10.047	0	6.116	1.937	0	0	0
G364	20.027	0	15.2	6.731	0	5.235	1.566	0	0	0
G365	4.886	21.818	0	4.51	0	4.304	2.41	0	0	0
G366	3.327	21.117	0	4.964	0	5.031	3.25	0	0	0
G367	4.995	21.542	0	4.948	0	5.122	3.22	0	0	0
G368	7.906	17.946	0	5.028	0	5.707	2.266	0	0	0
G369	5.104	17.821	0	4.214	0	4.215	2.076	0	0	0
G370	15.395	0	6.258	3.797	0	3.852	0.827	0	0	0
G374	16.982	0	12.464	2.852	0	5.115	1.923	0	0	0
G375	20.506	0	13.671	3.053	0	4.22	0.802	0	0	0
G376	16.473	1.74	15.279	2.731	0	4.591	1.835	0	0	0
G377	17.189	2.954	13.055	2.849	0	4.281	0.704	0	0	0
G378	15.855	5.648	13.971	2.814	0	4.403	1.026	0	0	0
G379	24.928	0	10.617	2.853	0	4.368	1.367	0	0	0
G380	24.212	0	9.418	2.781	0	4.444	1.348	0	0	0
G381	16.053	5.266	11.683	3.092	0	3.964	0.63	0	0	0
G382	28.265	0	21.188	2.869	0	3.229	1.36	0	0	0
G383	17.109	0	17.577	2.891	0	4.198	0.857	0	0	0
G385	17.379	0	18.856	3.007	0	5.664	2.715	0	0	0
G387	19.435	0	11.634	3.839	0	6.156	3.144	0	0	0
G388	17.069	0	10.374	3.882	0	5.345	2.523	0	0	0
G389	12.888	0	16.133	3.974	0	5.229	2.69	0	0	0
G390	15.444	0	22.094	3.036	0	4.2	1.513	0	0	0
G391	15.25	0	10.758	3.975	0	4.648	1.923	0	0	0

ID	Rock type	Q	Or	Ab	An	Lc	Ne	Co	Ac
G392	Basanite	0	9.934	19.687	16.395	0	8.973	0	0
G393	Basanite	0	7.86	12.374	16.215	0	12.609	0	0
G394	Alkali basalt	0	7.883	19.725	22.797	0	5.289	0	0
G395	Hawaiite	0	7.156	26.182	21.767	0	4.922	0	0
G396	Basanite	0	7.44	7.836	17.836	0	9.906	0	0
G397	Alkali basalt	0	6.146	21.764	22.864	0	4.396	0	0
G398	Alkali basalt	0	7.552	19.575	22.324	0	5.348	0	0
G399	Basanite	0	6.323	12.212	20.792	0	10.593	0	0

ID	Di	Hy	Ol	Mt	He	Il	Ap	Ru	Per	Cs
G392	18.809	0	14.334	2.768	0	5.981	3.121	0	0	0
G393	22.564	0	15.852	5.843	0	5.012	1.67	0	0	0
G394	19.272	0	15.493	4.692	0	3.65	1.2	0	0	0
G395	18.044	0	12.19	4.549	0	3.949	1.24	0	0	0
G396	25.974	0	18.906	5.815	0	4.591	1.694	0	0	0
G397	19.895	0	16.323	3.974	0	3.362	1.274	0	0	0
G398	19.85	0	16.186	4.287	0	3.686	1.188	0	0	0
G399	20.756	0	19.125	4.155	0	4.503	1.543	0	0	0

Trace element analyses database

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
A001	XRF	Th <4, U <3	Y	25		197	274		61
A002	XRF	Th <4, U <3	Y	22		182	288		60
A003	XRF	Th <4, U <3	Y	21		187	326		62
A004	XRF	Th <4, U <3	Y	26		193	295		61
A005	XRF	Th <4, U <3	Y	20		189	268		55
A006	XRF	Th <4, U <3	Y	22		211	319		63
A007	XRF	Th <4, U <3	Y	21		180	290		61
A008	XRF	Th <4, U <3	Y	19		201	278		61
A009	XRF	Th <4, U <3	Y	22		198	289		63
A010	XRF	U <3	Y	17		181	263		58
A011	XRF	Th <4, U <3	Y	22		216	316		59
A012	XRF	Th <4, U <3	Y	24		192	282		56
A013	XRF	Average	Y	21.5		195.5	272		54.5
A013a	XRF	93/30.1, Th <4, U <3	N	20		195	273		53
A013b	XRF	93/30.2, U <3	N	23		196	271		56
A015	ICP-MS		Y	23.12	1.92	207.34	321.16	0.17	53.56
A015	XRF	Average	N	22		195.5	281		57.5
A015a	XRF	93/35.1, Th <4, U <3	N	20		196	280		57
A015b	XRF	93/35.2, U <3	N	24		195	282		58
A017	XRF	Th <4, U <3	Y	22		201	289		59
A018	XRF	Th <4, U <3	Y	25		218	207		51
A019	XRF		Y	19		193	166		52
A020	ICP-MS		Y	19.51	2.63	196.82	212.09	0.16	48.42
A020	XRF		N	19		192	178		48
A021	XRF		Y	23		205	182		54
A022	XRF		Y	29		218	208		43
A023	ICP-MS		Y	21.00	1.72	185.05	368.17	0.16	55.66
A023	XRF		N	19		174	312		56
A024	XRF		Y	28		228	217		45
A025	XRF		Y	17		222	237		54
A026	XRF		Y	21		180	295		60
A027	XRF		Y	23		197	311		57
A028	XRF		Y	26		215	215		43
A029	XRF		Y	26		219	204		48
A030	XRF		Y	23		197	190		48
A031	XRF		Y	22		188	315		58
A032	XRF		Y	28		199	288		55
A033	XRF		Y	23		215	316		55
A034	XRF		Y	19		200	287		55
A035	XRF		Y	28		251	183		51
A036	XRF		Y	24		215	259		48
A037	XRF		Y	26		202	350		58
A038	XRF		Y	23		212	208		42
A039	XRF		Y	25		227	329		49
A040	XRF		Y	23		204	164		40
A041	XRF		Y	23		215	113		39
A042	XRF		Y	25		220	233		45
A043	XRF		Y	24		201	108		43
A044	XRF		Y	21		233	139		45
A045	XRF		Y	24		176	309		56
A046	ICP-MS		Y	20.27	1.57	187.76	334.71	0.16	57.97
A046	XRF		N	20		173	278		58
A047	XRF		Y	23		202	296		60
A048	XRF		Y	20		209	303		61
A049	XRF		Y	22		186	304		61
A050	XRF		Y	26		213	320		59
A051	XRF		Y	25		222	421		57
A052	XRF		Y	24		214	286		50
A053	XRF		Y	21		201	312		58
A055	ICP-MS		Y	22.79	1.93	229.23	283.30	0.17	52.80
A060	ICP-MS		Y	22.32	1.75	236.23	314.42	0.16	53.60
A061	ICP-MS		Y	19.59	1.89	187.02	271.90	0.31	52.70
A062	ICP-MS		Y	16.33	1.21	134.02	60.71	0.13	25.14
A066	ICP-MS		Y	23.22	1.70	215.11	310.50	0.15	42.87
A067	ICP-MS		Y	21.16	1.96	228.66	291.83	0.17	55.44
A068	ICP-MS		Y	21.69	1.77	201.97	256.78	0.15	42.70
A071	ICP-MS		Y	23.00	1.59	214.52	300.16	0.15	46.70
A072	ICP-MS		Y	21.79	1.75	211.52	271.92	0.19	71.10
A075	ICP-MS		Y	26.23	2.19	225.20	256.00	0.20	49.54

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
A001	233	63	109	21	7.7	517	18.2	101	17.6	
A002	227	66	100	19	9.2	678	17.6	97	17.1	
A003	229	61	103	20	8	665	18.4	96	17.7	
A004	231	66	102	21	8.6	700	16.8	98	18.9	
A005	210	53	92	20	13.8	874	17.9	124	30.5	
A006	241	62	107	20	13.8	644	18.9	131	31.1	
A007	234	72	102	20	7.1	515	18.4	99	17.8	
A008	221	67	103	21	9.6	547	17.5	104	19.3	
A009	226	71	103	20	7.3	531	18.3	106	20.3	
A010	205	68	102	21	9.2	558	19	103	18.7	
A011	211	53	102	20	13.6	656	18.5	132	31.6	
A012	213	76	100	20	14.5	1025	18.4	125	32.1	
A013	212	68.5	94	21	12.8	646	19.45	138	26.65	
A013a	211	69	93	21	12.6	646	19.1	137	27	
A013b	213	68	95	21	13	646	19.8	139	26.3	
A015	210.59	55.68	111.42	19.89	15.27	418.36	25.62	183.01	29.15	0.06
A015	198	56.5	93.5	22	15.4	417.5	26.35	180.5	25.15	
A015a	198	56	91	22	15.4	413	26	179	24.8	
A015b	198	57	96	22	15.4	422	26.7	182	25.5	
A017	235	70	91	21	16.1	424	24.3	141	22.3	
A018	71	54	98	22	9.4	408	24.5	134	17.4	
A019	168	46	119	22	16.6	905.1	23.5	221	60.5	
A020	173.06	33.47	127.46	21.24	17.67	843.94	22.61	218.71	64.90	0.42
A020	168	38	115	22	17.8	857.3	24.6	215	59	
A021	179	48	124	23	24.2	864.1	24.3	230	62.8	
A022	69	31	293	23	9.5	450.9	26.4	144	17.9	
A023	232.08	52.25	104.51	18.23	8.87	394.12	19.45	119.22	18.06	0.04
A023	223	52	105	19	9.2	395.5	19.7	121	15.3	
A024	70	54	106	23	9.7	422.1	24.2	135	16.3	
A025	223	60	146	25	32.6	1141.9	28.9	342	96.7	
A026	225	75	107	20	7.5	562.9	18.8	108	18.4	
A027	226	68	107	22	13.8	581.1	19.9	141	27.5	
A028	68	34	99	23	8.9	437.4	24.8	138	16.3	
A029	87	58	100	23	11.6	647.5	24.4	170	26.2	
A030	85	40	96	24	11.2	659.7	22.9	159	24.3	
A031	239	64	106	19	7.7	333.1	20.1	122	14.4	
A032	181	59	120	22	3	343.6	23.1	123	13.7	
A033	171	61	109	20	4.7	376.1	21.9	115	11.3	
A034	213	66	97	21	12.1	469.3	23.2	132	21.2	
A035	98	58	115	24	14.1	638.5	29.5	188	34.2	
A036	103	49	103	23	8.2	547.5	22.7	147	20.7	
A037	209	73	108	18	6.9	450.4	23.1	138	15	
A038	66	58	96	23	9.5	456.2	23.5	132	17.6	
A039	166	78	114	21	8.3	380.2	24.7	132	17	
A040	51	47	91	25	9.6	609.3	23.2	137	21.4	
A041	43	40	105	24	11.5	571.5	27.9	205	35.4	
A042	73	44	112	22	5.8	521.5	22.9	135	21.7	
A043	54	42	111	23	10.3	560.4	22.5	145	22.2	
A044	49	53	113	23	9.4	556.3	23	144	21.6	
A045	212	64	109	20	7.5	766.3	22.8	117	14.5	
A046	238.15	64.19	116.90	19.16	7.79	546.30	17.25	106.05	20.38	0.10
A046	231	66	100	21	9	551.8	17.7	104	17.6	
A047	223	58	112	21	12.8	675.9	18.7	138	30.4	
A048	218	77	108	22	12.2	630.7	18.6	133	29	
A049	232	69	119	21	9.2	556.2	19.5	109	18.1	
A050	226	62	110	21	12.5	681	19.5	141	34.5	
A051	266	62	125	21	8.6	460.4	23.9	160	21.6	
A052	169	59	118	20	9.3	340.1	21.4	123	14.2	
A053	195	56	117	23	7.9	326.9	22.9	118	11.6	
A055	205.35	56.72	108.12	18.85	10.93	497.35	21.06	147.22	26.57	0.14
A060	180.40	69.57	111.05	19.39	7.58	386.20	25.39	107.83	17.05	0.08
A061	232.66	40.90	93.98	17.85	19.42	618.07	19.32	147.60	29.23	0.19
A062	46.46	29.79	91.86	19.29	20.15	528.07	17.10	139.86	16.08	0.27
A066	132.13	56.12	107.45	18.30	8.71	497.19	22.70	130.83	26.36	0.04
A067	221.01	54.07	102.82	19.25	13.64	651.03	17.98	135.11	37.59	0.18
A068	136.77	44.88	220.31	19.07	7.54	484.72	21.80	144.10	26.29	0.07
A071	182.06	36.41	96.87	18.75	6.28	304.93	20.53	115.08	14.45	0.08
A072	401.26	46.88	109.66	16.11	7.63	273.73	18.64	114.45	16.68	0.06
A075	83.36	52.54	127.25	22.61	10.97	557.50	26.11	165.11	30.60	0.11

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
A001	172										
A002	374										
A003	420										
A004	544										
A005	1184										
A006	253										
A007	331										
A008	196										
A009	189										
A010	446										
A011	284										
A012	381										
A013	515										
A013a	513										
A013b	517										
A015	368.13	22.72	47.14	6.30	26.00	5.54	1.82	5.63	0.86	4.72	0.90
A015	394.5										
A015a	395										
A015b	394										
A017	316										
A018	152										
A019	384										
A020	355.12	33.47	65.95	8.53	34.66	7.12	2.43	6.81	0.94	4.70	0.81
A020	392										
A021	374										
A022	210										
A023	195.15	12.30	26.10	3.63	15.83	3.78	1.36	4.22	0.65	3.61	0.67
A023	200										
A024	172										
A025	686										
A026	488										
A027	898										
A028	301										
A029	396										
A030	260										
A031	138										
A032	202										
A033	495										
A034	221										
A035	532										
A036	478										
A037	2020										
A038	426										
A039	135										
A040	441										
A041	363										
A042	196										
A043	229										
A044	260										
A045	172										
A046	321.14	15.20	31.33	4.21	17.94	4.01	1.42	4.13	0.60	3.31	0.61
A046	506										
A047	322										
A048	253										
A049	325										
A050	384										
A051	279										
A052	162										
A053	169										
A055	219.08	16.69	33.65	4.64	19.82	4.58	1.64	4.80	0.72	3.98	0.76
A060	191.31	14.24	28.41	4.21	18.76	4.56	1.63	5.18	0.80	4.46	0.86
A061	419.82	19.95	41.28	5.55	23.36	4.97	1.72	4.79	0.70	3.69	0.68
A062	429.93	27.20	56.51	7.45	29.93	5.42	1.64	4.35	0.59	3.10	0.59
A066	295.51	21.77	44.32	5.91	24.75	5.28	1.80	5.31	0.79	4.29	0.81
A067	380.25	22.26	43.84	5.71	23.58	4.94	1.69	4.76	0.68	3.55	0.64
A068	222.78	19.05	40.79	5.61	23.91	5.29	1.77	5.26	0.78	4.18	0.79
A071	196.13	10.93	23.63	3.33	14.88	3.83	1.41	4.30	0.68	3.84	0.74
A072	162.66	11.62	24.91	3.47	15.26	3.67	1.32	3.94	0.62	3.43	0.65
A075	263.60	21.90	45.26	6.06	26.32	5.81	2.01	5.86	0.89	4.83	0.90

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
A001							6	3	2	P & W-T 1993
A002							5	3	2	P & W-T 1993
A003							5	3	2	P & W-T 1993
A004							4	3	2	P & W-T 1993
A005							12	3	2	P & W-T 1993
A006							48	3	2	P & W-T 1993
A007							7	3	2	P & W-T 1993
A008							6	3	2	P & W-T 1993
A009							8	3	2	P & W-T 1993
A010							13	4	2	P & W-T 1993
A011							26	3	2	P & W-T 1993
A012							4	3	2	P & W-T 1993
A013							7	3	2	P & W-T 1993
A013a							8	3	2	P & W-T 1993
A013b							6	4	2	P & W-T 1993
A015	2.31	0.35	2.10	0.32	4.17	1.78	4.45	2.54	0.41	This study
A015							4	3	2	P & W-T 1993
A015a							5	3	2	P & W-T 1993
A015b							3	4	2	P & W-T 1993
A017							4	3	2	P & W-T 1993
A018							5	3	2	P & W-T 1993
A019							8	8		P & W-T 2001
A020	1.88	0.27	1.46	0.22	4.88	3.88	2.43	4.08	1.07	This study
A020							4	5		P & W-T 2001
A021							8	3		P & W-T 2001
A022							25	2		P & W-T 2001
A023	1.71	0.27	1.51	0.23	2.88	1.20	1.07	1.38	0.40	This study
A023							10	2		P & W-T 2001
A024							4	4	4	P & W-T 2001
A025							3	4		P & W-T 2001
A026							5	3		P & W-T 2001
A027							4	4		P & W-T 2001
A028							4	4	1	P & W-T 2001
A029							5		2	P & W-T 2001
A030							4	2		P & W-T 2001
A031							3	2		P & W-T 2001
A032							2	4		P & W-T 2001
A033							5	6		P & W-T 2001
A034							4	5		P & W-T 2001
A035							6	4	3	P & W-T 2001
A036							5	1		P & W-T 2001
A037							4	2	2	P & W-T 2001
A038							4	1	1	P & W-T 2001
A039							4	3	1	P & W-T 2001
A040							6	4	1	P & W-T 2001
A041							4	2		P & W-T 2001
A042							4	4		P & W-T 2001
A043							4	2	2	P & W-T 2001
A044							6	3		P & W-T 2001
A045							4	2	1	P & W-T 2001
A046	1.53	0.24	1.33	0.21	2.57	1.17	42.61	1.57	0.47	This study
A046							5	1	2	P & W-T 2001
A047							87	2	1	P & W-T 2001
A048							47	3		P & W-T 2001
A049							6	4		P & W-T 2001
A050							6	4		P & W-T 2001
A051							5	4	2	P & W-T 2001
A052							3	3		P & W-T 2001
A053							1	1	1	P & W-T 2001
A055	1.86	0.29	1.61	0.25	3.45	1.68	1.63	1.83	0.61	This study
A060	2.13	0.32	1.77	0.28	2.67	0.97	2.38	1.35	0.39	This study
A061	1.63	0.25	1.36	0.21	3.35	1.75	2.43	2.06	0.63	This study
A062	1.43	0.22	1.25	0.19	3.31	0.90	11.26	3.46	0.83	This study
A066	1.96	0.30	1.66	0.25	2.99	1.45	2.17	2.02	0.34	This study
A067	1.51	0.23	1.25	0.19	3.13	2.11	1.90	2.46	0.68	This study
A068	1.87	0.28	1.58	0.24	3.36	1.53	1.87	1.82	0.39	This study
A071	1.82	0.28	1.57	0.24	2.84	0.92	1.20	1.25	0.40	This study
A072	1.63	0.25	1.42	0.22	2.73	1.07	1.02	1.22	0.34	This study
A075	2.28	0.33	1.97	0.31	3.98	1.64	1.88	1.97	0.55	This study

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
A076	ICP-MS		Y	18.88	2.89	213.80	96.83	0.17	39.94
A078	ICP-MS		Y	21.51	2.66	205.76	273.54	0.18	50.49
A080	ICP-MS	Average	Y	19.75	1.44	179.52	262.34	0.13	43.62
A080a	ICP-MS		N	19.69	1.47	181.63	256.69	0.13	43.76
A080b	ICP-MS		N	19.81	1.41	177.42	268.00	0.13	43.48
A081	ICP-MS		Y	24.00	1.72	206.43	298.27	0.17	43.88
A082	ICP-MS		Y	21.50	1.49	183.31	310.68	0.18	58.93
A083	ICP-MS		Y	22.32	1.41	193.52	279.15	0.16	51.80
A088	ICP-MS		Y	23.09	1.35	200.50	295.95	0.16	50.77
A088W	ICP-MS	Weathered section	N	22.96	1.44	200.15	276.95	0.16	49.45
A089	ICP-MS		Y	21.62	2.73	249.26	45.15	0.19	39.97
A092	ICP-MS		Y	20.59	2.00	224.90	207.31	0.16	43.57
A093	ICP-MS		Y	20.71	2.05	222.50	79.46	0.16	37.46
A094	ICP-MS		Y	19.96	1.87	205.75	173.22	0.16	41.92
A095	ICP-MS		Y	21.29	2.01	218.99	140.26	0.16	41.41
A096	ICP-MS		Y	21.64	1.71	195.57	276.51	0.16	48.04
A101	ICP-MS		Y	20.53	1.51	176.18	258.84	0.17	52.91
A104	ICP-MS		Y	26.51	2.11	250.14	269.79	0.18	46.13
A105	ICP-MS		Y	27.79	2.06	247.08	237.37	0.18	50.13
A106	ICP-MS		Y	26.05	2.25	240.92	279.61	0.17	54.10
A108	ICP-MS		Y	25.83	1.80	212.16	468.59	0.19	69.21
A109	ICP-MS		Y	25.56	1.95	214.68	331.26	0.19	66.20
A115	ICP-MS		Y	22.75	1.64	202.80	192.61	0.15	42.11
A116	ICP-MS		Y	23.98	1.70	207.74	297.20	0.16	52.16
A120	ICP-MS		Y	22.80	1.74	197.29	260.08	0.15	41.34
A122	ICP-MS		Y	25.86	2.64	256.58	165.91	0.19	48.16
A126	ICP-MS		Y	24.36	1.99	203.97	318.50	0.18	56.78
A127	ICP-MS		Y	24.67	2.84	246.64	233.67	0.18	52.88
A128	ICP-MS		Y	26.17	2.25	236.30	221.33	0.17	47.77
A129	ICP-MS		Y	22.74	3.00	211.69	208.79	0.18	53.61
A132	ICP-MS		Y	18.57	1.35	172.49	210.15	0.16	52.74
A134	ICP-MS		Y	22.54	2.17	216.72	198.79	0.16	45.24
A135	ICP-MS		Y	20.31	2.09	200.77	181.81	0.15	43.00
A138	ICP-MS		Y	21.74	1.46	202.98	276.30	0.16	48.14
A139	ICP-MS		Y	25.55	1.88	217.98	324.10	0.18	54.36
A140	ICP-MS		Y	23.05	1.90	236.59	95.32	0.16	38.09
A141	ICP-MS		Y	21.44	1.59	196.47	255.52	0.17	55.03
A142	ICP-MS		Y	22.37	2.19	218.46	117.70	0.17	40.60
A143	ICP-MS		Y	22.42	1.39	196.17	295.36	0.16	53.08
A144	ICP-MS		Y	20.91	1.50	197.19	272.45	0.16	56.07
A148	ICP-MS		Y	20.51	1.64	192.13	306.56	0.16	52.22
A149	ICP-MS		Y	19.74	1.49	179.50	274.20	0.16	54.34
A150	ICP-MS		Y	22.90	1.81	197.97	302.87	0.17	60.51
A152	ICP-MS		Y	22.21	1.61	200.48	298.09	0.16	52.17
A153	ICP-MS		Y	25.55	1.93	242.49	388.50	0.16	57.68
A154	ICP-MS		Y	21.51	1.57	190.76	279.86	0.16	50.84
A156	XRF	Th <5	Y						
A157	XRF	Th <5	Y						
A158	XRF	Th <5	Y						
A159	XRF	Th <5	Y						
A160	XRF	Th <5	Y						
A161	XRF	Th <5	Y						
A162	XRF	Th <5	Y						
A163	XRF	Th <5	Y						
A164	XRF	Th <5	Y						
A165	XRF	Th <5	Y						
A166	XRF	Th <5	Y						
A167	XRF	Th <5	Y						
A168	XRF	Th <5	Y						
A169	XRF	Th <5	Y						
A170	XRF	Th <5	Y						
A171	XRF	Th <5	Y						
A172	XRF	Th <5	Y						
A173	XRF	Th <5	Y						
A174	XRF	Th <5	Y						
A175	XRF	Th <5	Y						
A176	XRF	Th <5	Y						
A177	XRF	Th <5	Y						
A178	XRF	Th <5	Y						
A179	XRF	Th <5	Y						
A180	XRF	Th <5	Y						
A181	XRF	Th <5	Y						

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
A076	104.16	46.23	105.27	20.82	17.81	1180.07	28.24	233.66	53.17	0.21
A078	207.59	48.72	119.27	19.09	19.29	1014.44	26.36	237.13	61.77	0.13
A080	188.26	92.27	99.90	16.82	10.30	316.78	19.11	117.77	16.10	0.06
A080a	186.90	90.52	120.28	16.81	10.21	317.20	19.15	118.77	16.15	0.06
A080b	189.61	94.03	79.51	16.83	10.38	316.36	19.06	116.76	16.05	0.06
A081	74.69	41.02	98.38	19.53	9.17	507.83	23.10	148.03	27.97	0.10
A082	274.19	48.37	102.67	17.19	4.11	278.55	18.57	102.45	12.54	0.07
A083	175.32	51.24	101.62	17.95	6.70	290.41	18.80	95.80	10.98	0.11
A088	160.39	53.89	89.01	18.97	7.36	292.94	19.86	98.30	10.83	0.10
A088W	159.23	53.45	88.83	19.23	8.31	298.58	20.19	101.89	11.50	0.11
A089	39.36	52.78	133.76	24.44	12.57	657.09	27.91	217.51	41.39	0.09
A092	63.64	44.56	104.69	20.09	6.80	507.66	21.92	176.22	35.92	0.05
A093	46.54	43.07	107.13	21.40	10.82	567.86	25.36	181.64	32.94	0.07
A094	87.12	42.10	104.51	19.96	11.98	513.14	23.27	166.02	28.51	0.09
A095	71.95	43.60	105.09	21.07	9.88	555.94	25.12	176.49	30.79	0.05
A096	165.37	46.29	93.52	18.74	6.17	496.13	21.05	144.90	27.30	0.04
A101	232.09	50.23	106.42	18.20	12.91	370.56	20.59	154.80	22.61	0.11
A104	89.54	53.29	123.57	22.23	8.66	566.77	23.89	160.87	26.84	0.13
A105	103.06	29.69	121.81	21.77	8.76	404.51	22.96	149.10	18.55	0.05
A106	206.05	61.16	120.82	21.33	8.93	494.87	22.06	141.45	23.88	0.10
A108	332.68	50.85	117.43	18.62	7.93	436.26	20.44	118.00	19.76	0.08
A109	287.54	61.15	123.76	20.58	10.77	435.60	21.04	119.04	21.45	0.16
A115	81.26	46.27	103.90	19.59	5.36	330.64	21.13	126.30	14.67	0.03
A116	262.26	47.53	160.08	18.11	14.43	507.95	21.17	176.98	27.96	0.20
A120	103.12	47.02	96.72	18.71	8.88	506.14	22.06	158.55	31.12	0.11
A122	90.39	70.40	128.04	23.18	18.98	651.38	27.97	198.56	40.69	0.21
A126	256.94	59.47	118.97	20.64	14.00	440.74	23.06	173.31	25.10	0.18
A127	108.19	52.70	119.43	21.75	9.77	719.95	21.86	160.19	28.52	0.12
A128	86.30	50.84	114.69	22.10	8.90	433.52	23.65	141.86	20.15	0.10
A129	210.96	45.36	135.91	24.11	13.82	1036.42	24.31	227.89	68.84	4.15
A132	250.07	70.77	81.49	16.40	9.70	399.31	15.78	95.61	21.57	0.15
A134	97.80	47.67	104.32	19.51	9.92	645.32	21.02	152.73	26.20	0.09
A135	107.61	51.05	247.00	19.61	9.96	615.97	20.84	151.93	26.64	0.10
A138	251.38	43.17	108.52	17.62	6.95	331.00	19.65	107.26	15.59	0.04
A139	227.18	29.92	115.25	19.87	7.50	408.94	20.46	112.40	16.07	0.03
A140	39.48	35.64	87.57	20.52	9.70	639.82	22.93	166.66	33.35	0.08
A141	235.44	57.30	98.95	18.00	7.55	296.98	20.54	118.08	15.72	0.03
A142	57.71	34.13	109.47	21.93	9.14	590.82	23.70	172.05	34.49	0.04
A143	194.88	60.26	102.97	17.51	6.95	310.64	19.14	104.86	13.77	0.04
A144	252.36	49.34	78.74	17.56	7.46	318.75	18.86	112.63	16.15	0.03
A148	257.14	57.45	111.27	18.14	8.22	560.81	20.36	157.95	33.71	0.09
A149	241.16	46.42	102.03	17.70	5.95	269.37	18.76	108.78	13.72	0.09
A150	287.80	58.34	120.96	19.14	8.60	331.80	20.00	111.36	14.26	0.04
A152	231.38	70.30	86.66	18.27	6.90	301.06	20.40	116.78	16.47	0.02
A153	264.17	51.76	134.15	20.51	4.81	341.61	21.00	117.40	14.08	0.07
A154	210.55	54.14	98.43	17.89	8.58	323.79	20.18	118.48	16.71	0.05
A156	47	45	102	21	10	571	26	204	36	
A157	49	49	111	19	7	609	24	204	37	
A158	58	40	99	21	12	536	23	193	34	
A159	51	39	108	24	11	575	25	204	35	
A160	37	22	109	18	11	610	25	204	34	
A161	31	45	115	22	9	536	26	211	36	
A162	38	39	112	23	11	556	25	209	36	
A163	50	34	102	22	11	558	23	197	35	
A164	54	41	109	22	13	579	26	203	36	
A165	154	51	108	18	9	419	20	135	20	
A166	234	60	109	19	7	453	19	145	21	
A167	92	57	107	22	11	421	22	160	23	
A168	219	47	102	18	12	452	23	145	22	
A169	132	53	92	18	8	433	21	123	19	
A170	124	52	102	18	10	447	21	146	21	
A171	197	57	107	16	10	455	21	141	20	
A172	108	52	105	20	10	475	24	141	19	
A173	214	58	111	19	11	462	19	151	19	
A174	106	51	123	20	14	1125	26	244	46	
A175	112	51	111	21	17	1122	23	230	43	
A176	104	50	116	22	18	1133	23	244	46	
A177	82	51	109	20	10	539	25	189	31	
A178	125	42	112	21	9	513	23	178	30	
A179	122	48	102	19	9	503	24	165	26	
A180	98	35	105	20	8	543	24	179	30	
A181	95	45	107	19	9	627	26	181	30	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
A076	1038.25	44.96	90.27	12.24	49.04	9.20	2.92	7.92	1.07	5.42	0.98
A078	718.16	41.99	89.59	12.21	50.43	9.48	2.93	8.01	1.09	5.41	0.94
A080	151.49	11.62	25.07	3.53	15.39	3.74	1.30	4.02	0.63	3.53	0.68
A080a	150.40	11.68	25.33	3.55	15.49	3.74	1.32	3.99	0.63	3.53	0.68
A080b	152.59	11.55	24.80	3.52	15.29	3.73	1.29	4.05	0.64	3.53	0.68
A081	207.93	20.05	42.34	5.72	24.23	5.25	1.82	5.20	0.79	4.31	0.81
A082	116.52	9.69	21.06	2.97	13.32	3.44	1.30	3.92	0.62	3.44	0.67
A083	133.80	10.27	23.10	3.33	14.89	3.59	1.29	3.89	0.61	3.44	0.67
A088	162.96	10.62	23.99	3.47	15.43	3.72	1.35	4.04	0.64	3.57	0.70
A088W	192.08	10.91	24.61	3.54	15.87	3.83	1.39	4.18	0.66	3.65	0.72
A089	402.67	29.98	62.90	8.37	35.63	7.44	2.50	7.19	1.03	5.49	1.01
A092	361.19	20.69	46.03	6.37	27.41	5.94	1.96	5.67	0.84	4.43	0.82
A093	261.45	25.09	52.70	7.09	29.51	6.36	2.11	6.16	0.92	4.90	0.90
A094	231.14	21.79	45.85	6.19	25.93	5.64	1.88	5.57	0.83	4.49	0.84
A095	340.00	24.31	50.91	6.88	28.92	6.24	2.05	6.04	0.90	4.80	0.89
A096	198.24	18.65	39.71	5.51	23.47	5.13	1.76	5.19	0.76	4.09	0.76
A101	205.87	17.11	35.83	4.95	20.68	4.52	1.58	4.52	0.68	3.76	0.72
A104	337.92	19.91	43.06	5.87	25.69	5.73	1.97	5.76	0.86	4.66	0.88
A105	196.45	14.30	31.42	4.37	19.51	4.52	1.69	4.84	0.76	4.30	0.84
A106	764.93	16.05	33.90	4.59	20.47	4.76	1.72	5.12	0.78	4.26	0.80
A108	352.05	15.90	33.46	4.46	19.80	4.48	1.58	4.61	0.72	3.92	0.75
A109	203.72	13.26	28.62	3.96	17.68	4.19	1.49	4.56	0.70	3.95	0.77
A115	112.60	12.52	28.33	4.06	18.11	4.28	1.54	4.66	0.72	4.01	0.76
A116	230.58	21.27	44.53	6.04	25.29	5.43	1.83	5.18	0.76	4.11	0.77
A120	336.78	20.06	42.63	5.91	25.15	5.49	1.84	5.35	0.79	4.25	0.79
A122	438.29	30.28	63.57	8.42	36.26	7.59	2.51	7.31	1.05	5.52	1.02
A126	304.57	18.94	39.92	5.37	22.96	5.08	1.74	5.16	0.77	4.29	0.82
A127	1292.11	18.29	40.86	5.72	25.32	5.59	1.97	5.57	0.80	4.29	0.79
A128	175.49	14.05	31.55	4.41	20.07	4.88	1.76	5.31	0.82	4.56	0.87
A129	1093.99	37.15	73.45	9.40	39.36	8.18	2.73	7.59	1.05	5.22	0.90
A132	324.67	14.42	28.28	3.71	15.34	3.43	1.20	3.54	0.54	2.98	0.57
A134	405.11	18.17	39.86	5.66	24.38	5.41	1.89	5.28	0.77	4.10	0.76
A135	292.36	18.58	40.80	5.73	24.54	5.36	1.89	5.15	0.76	4.00	0.75
A138	600.69	11.69	24.94	3.51	15.49	3.83	1.39	4.21	0.66	3.67	0.71
A139	837.91	11.70	25.37	3.50	15.81	3.90	1.44	4.42	0.69	3.85	0.75
A140	928.19	20.98	45.68	6.44	27.45	5.95	2.01	5.81	0.84	4.43	0.82
A141	612.47	11.18	23.92	3.38	14.96	3.81	1.39	4.28	0.67	3.75	0.73
A142	394.86	21.51	46.83	6.49	28.32	6.07	2.08	5.94	0.87	4.66	0.87
A143	971.29	10.25	22.25	3.09	13.49	3.38	1.25	3.96	0.62	3.49	0.69
A144	243.30	11.75	25.12	3.50	15.18	3.73	1.35	4.09	0.63	3.53	0.67
A148	452.41	21.25	45.32	6.17	25.77	5.47	1.82	5.26	0.77	4.06	0.74
A149	120.73	10.23	22.23	3.12	13.83	3.56	1.34	4.11	0.64	3.59	0.68
A150	663.14	10.53	22.92	3.16	14.67	3.79	1.40	4.35	0.67	3.79	0.73
A152	124.96	11.84	25.36	3.56	15.72	3.90	1.40	4.40	0.67	3.78	0.72
A153	110.34	10.52	22.80	3.23	15.06	3.91	1.50	4.48	0.72	4.00	0.76
A154	302.91	11.93	25.65	3.56	15.61	3.79	1.38	4.26	0.66	3.72	0.72
A156											
A157											
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ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
A076	2.29	0.35	1.89	0.28	5.05	2.92	2.78	3.27	0.85	This study
A078	2.15	0.31	1.72	0.25	5.07	3.42	2.98	2.97	0.68	This study
A080	1.71	0.26	1.49	0.23	2.78	0.99	2.86	1.18	0.43	This study
A080a	1.70	0.26	1.49	0.23	2.77	0.99	2.78	1.16	0.42	This study
A080b	1.71	0.27	1.50	0.23	2.78	1.00	2.93	1.19	0.43	This study
A081	2.00	0.31	1.72	0.26	3.38	1.54	2.23	1.74	0.51	This study
A082	1.67	0.26	1.44	0.22	2.50	0.81	1.31	1.05	0.26	This study
A083	1.70	0.27	1.54	0.24	2.34	0.67	1.29	0.86	0.27	This study
A088	1.79	0.28	1.61	0.25	2.40	0.67	2.00	0.90	0.24	This study
A088W	1.82	0.28	1.62	0.25	2.47	0.72	4.17	0.93	0.26	This study
A089	2.42	0.34	2.05	0.31	4.93	2.23	3.06	2.71	0.80	This study
A092	1.96	0.30	1.65	0.25	4.06	2.02	1.81	1.89	0.47	This study
A093	2.22	0.33	1.88	0.29	4.14	1.84	2.59	2.49	0.39	This study
A094	2.04	0.31	1.74	0.26	3.81	1.65	1.97	2.34	0.66	This study
A095	2.16	0.33	1.83	0.28	4.00	1.75	2.11	2.36	0.50	This study
A096	1.86	0.28	1.53	0.23	3.32	1.56	1.45	1.75	0.36	This study
A101	1.82	0.28	1.64	0.26	3.47	1.34	2.11	1.98	0.40	This study
A104	2.16	0.31	1.82	0.28	3.82	1.45	1.62	1.75	0.69	This study
A105	2.17	0.31	1.95	0.31	3.62	1.16	2.38	1.79	0.21	This study
A106	1.95	0.28	1.69	0.26	3.49	1.38	1.67	1.67	0.63	This study
A108	1.82	0.27	1.60	0.25	2.86	1.10	1.70	1.53	0.32	This study
A109	1.92	0.28	1.75	0.28	3.04	1.28	1.43	1.60	0.47	This study
A115	1.91	0.29	1.62	0.25	2.95	0.84	1.29	1.04	0.23	This study
A116	1.91	0.28	1.61	0.25	4.01	1.67	2.21	2.27	0.65	This study
A120	1.89	0.28	1.58	0.24	3.62	1.76	1.75	1.96	0.37	This study
A122	2.40	0.33	2.01	0.31	4.56	2.17	2.25	2.95	0.82	This study
A126	2.05	0.30	1.86	0.30	4.02	1.44	2.36	2.18	0.59	This study
A127	1.95	0.27	1.67	0.26	3.86	1.67	1.97	1.48	0.49	This study
A128	2.14	0.30	1.82	0.28	3.48	1.20	1.56	1.31	0.38	This study
A129	2.05	0.27	1.55	0.24	5.38	3.98	2.48	4.44	1.10	This study
A132	1.41	0.21	1.21	0.19	2.32	1.28	2.13	1.62	0.60	This study
A134	1.85	0.27	1.55	0.24	3.50	1.55	1.87	1.53	0.37	This study
A135	1.85	0.28	1.54	0.24	3.48	1.58	1.93	1.59	0.40	This study
A138	1.76	0.27	1.53	0.24	2.70	0.97	1.90	1.24	0.30	This study
A139	1.87	0.27	1.64	0.26	2.90	0.98	1.49	1.28	0.25	This study
A140	2.00	0.30	1.66	0.26	3.96	1.89	2.20	2.15	0.73	This study
A141	1.82	0.28	1.59	0.25	2.84	0.98	2.62	1.27	0.28	This study
A142	2.12	0.30	1.83	0.28	4.13	1.85	2.48	2.12	0.34	This study
A143	1.72	0.27	1.51	0.24	2.52	0.85	1.65	1.16	0.37	This study
A144	1.67	0.26	1.44	0.23	2.74	1.03	1.74	1.28	0.41	This study
A148	1.80	0.26	1.45	0.22	3.60	1.93	1.74	2.02	0.59	This study
A149	1.70	0.26	1.47	0.22	2.68	0.88	1.13	1.14	0.37	This study
A150	1.85	0.26	1.59	0.24	2.86	0.87	1.26	1.19	0.43	This study
A152	1.80	0.28	1.57	0.25	2.84	1.06	1.17	1.32	0.43	This study
A153	1.91	0.27	1.64	0.26	3.04	0.90	1.39	1.21	0.49	This study
A154	1.81	0.28	1.57	0.24	2.85	1.03	1.05	1.30	0.31	This study
A156								5		W-T n.d.
A157								5		W-T n.d.
A158								5		W-T n.d.
A159								5		W-T n.d.
A160								5		W-T n.d.
A161								5		W-T n.d.
A162								5		W-T n.d.
A163								5		W-T n.d.
A164								5		W-T n.d.
A165								5		W-T n.d.
A166								5		W-T n.d.
A167								5		W-T n.d.
A168								5		W-T n.d.
A169								5		W-T n.d.
A170								5		W-T n.d.
A171								5		W-T n.d.
A172								5		W-T n.d.
A173								5		W-T n.d.
A174								5		W-T n.d.
A175								5		W-T n.d.
A176								5		W-T n.d.
A177								5		W-T n.d.
A178								5		W-T n.d.
A179								5		W-T n.d.
A180								5		W-T n.d.
A181								5		W-T n.d.

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
A182	XRF	Th <5	Y						
A183	XRF	Th <5	Y						
A184	XRF	Th <5	Y						
A185	XRF	Th <5	Y						
A186	XRF	Th <5	Y						
A187	XRF		Y						
A188	XRF	Ni <19, Th <5	Y						
A189	XRF	Th <5	Y						
A190	XRF	Th <5	Y						
A191	XRF	Th <3	Y						
G001	ICP-MS		Y	22.97	1.81	206.03	351.94	0.18	62.99
G001	XRF	Th <4, U <3	N	23		185	315		60
G002	XRF	Th <4, U <3	Y	18		195	245		53
G003	XRF	Th <4, U <3	Y	21		195	278		57
G004	XRF	U <3	Y	16		255	84		49
G005	ICP-MS		Y	21.56	2.01	211.02	289.36	0.19	64.60
G005	XRF	Th <4, U <3	N	21		196	228		59
G006	XRF	Th <4, U <3	Y	21		188	269		61
G007	XRF	Th <4, U <3	Y	22		219	184		52
G008	ICP-MS		Y	25.36	2.91	247.29	180.79	0.15	42.63
G008	XRF		N	23		239	156		54
G009	XRF	U <3	N	20		224	213		54
G009	ICP-MS	Average	Y	21.52	2.31	224.45	231.50	0.17	49.64
G009a	ICP-MS		N	21.28	2.18	223.10	217.41	0.17	48.47
G009b	ICP-MS		N	21.05	2.37	221.33	257.75	0.17	49.74
G009c	ICP-MS		N	20.48	2.07	213.50	209.75	0.16	47.01
G009d	ICP-MS		N	23.28	2.61	239.87	241.09	0.18	53.36
G010	XRF	U <3	Y	21		244	213		51
G011	XRF	U <3	Y	18		202	163		55
G012	XRF	U <3	Y	19		209	164		55
G013	XRF	U <3	Y	21		201	164		54
G014	XRF	U <3	Y	16		202	138		58
G015	XRF	U <3	Y	15		198	161		61
G016	XRF	Th <4, U <3	Y	22		212	246		60
G017	XRF	Average	Y	20.5		208.5	230		59.5
G017a	XRF	93/17.1, U <3	N	18		212	230		59
G017b	XRF	93/17.2, Th <4, U <3	N	23		205	230		60
G018	ICP-MS		Y	18.901	2.55	197.759	515.878	0.173	63.008
G018	XRF	Th <4, U <3	N	15		203	388		64
G019	ICP-MS		Y	25.026	2.418	249.83	239.644	0.172	52.361
G019	XRF	Average	N	24		230.5	229		50
G019a	XRF	93/33.1, Th <4, U <3	N	24		225	215		50
G019b	XRF	93/33.2, Th <4, U <3	N	24		236	243		50
G020	XRF	U <3	Y	21		211	283		55
G021	XRF		Y	27		193	326		54
G022	XRF		Y	24		217	208		49
G023	XRF		Y	23		192	259		47
G024	XRF		Y	23		200	208		43
G025	ICP-MS		Y	21.71	1.93	201.13	257.43	0.17	46.94
G025	XRF		N	23		201	242		49
G026	XRF		Y	22		198	232		44
G027	XRF		Y	25		195	265		55
G028	XRF		Y	23		190	274		58
G029	ICP-MS		Y	19.24	2.77	189.76	174.17	0.16	45.20
G032	ICP-MS		Y	19.74	3.05	203.46	182.55	0.19	55.98
G035	ICP-MS		Y	19.88	2.90	196.52	177.25	0.17	51.87
G035W	ICP-MS	Weathered section	N	19.49	2.60	187.21	171.85	0.17	50.20
G037	ICP-MS		Y	18.65	2.58	182.52	162.25	0.16	49.46
G044	ICP-MS		Y	20.11	2.88	214.77	292.78	0.20	60.40
G048	ICP-MS		Y	21.53	2.11	202.88	306.72	0.18	55.08
G053	ICP-MS		Y	22.03	2.26	224.77	332.27	0.18	63.32
G055	ICP-MS		Y	21.29	1.66	199.88	299.65	0.17	62.09
G058	ICP-MS		Y	21.45	2.83	211.64	437.50	0.21	63.09
G064	ICP-MS		Y	24.76	2.79	237.78	578.76	0.21	72.88
G069	ICP-MS		Y	15.84	3.69	226.26	140.71	0.19	50.04
G072	ICP-MS	Average	Y	14.30	3.61	195.97	147.22	0.19	48.55
G072a	ICP-MS		N	14.20	3.53	193.19	161.69	0.18	47.80
G072b	ICP-MS		N	14.40	3.69	198.76	132.75	0.19	49.30

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
A182	83	45	111	21	10	544	24	190	32	
A183	38	55	112	24	12	557	25	192	28	
A184	59	59	110	21	11	546	26	189	29	
A185	68	49	117	19	11	536	25	191	31	
A186	143	51	113	19	14	994	22	211	37	
A187	141	57	121	17	14	911	23	190	34	
A188	19	26	124	23	14	676	29	253	43	
A189	194	48	110	19	8	509	22	163	26	
A190	185	61	117	22	18	595	17	177	36	
A191	124	148	69	11	3	29	9	11	3	
G001	281.87	74.09	120.96	21.57	9.13	605.91	19.04	116.64	23.45	0.21
G001	219	75	103	20	8.8	580	19.6	109	20.8	
G002	190	68	93	19	12.8	747	20.4	139	34.3	
G003	212	60	89	20	12.3	658	19.1	129	28.4	
G004	99	95	116	23	20.3	742	29.4	211	51.8	
G005	337.57	70.60	114.32	21.08	11.13	601.60	21.06	143.48	34.25	0.16
G005	253	72	96	21	10.6	572	20.7	136	30.3	
G006	237	78	99	19	9.8	562	21.2	115	26.6	
G007	88	43	97	21	9.6	693	22.9	146	26.3	
G008	60.59	64.57	128.85	21.03	12.51	804.81	26.55	187.27	34.13	0.13
G008	253	72	96	21	12.1	806	27.4	182	30	
G009	141	68	112	20	14.9	761	25.6	174	35.3	
G009	147.51	64.59	111.28	19.23	14.70	758.34	23.68	176.45	37.70	0.27
G009a	148.34	63.07	109.14	18.90	14.32	748.77	23.24	173.09	37.07	0.27
G009b	138.26	65.54	118.78	19.32	14.95	764.08	24.13	179.66	38.61	0.26
G009c	141.96	61.59	100.12	18.19	14.10	740.19	22.70	169.10	36.20	0.26
G009d	161.48	68.18	117.10	20.52	15.44	780.32	24.66	183.95	38.91	0.29
G010	152	37	119	23	12.2	1201	29.3	227	55.2	
G011	168	59	114	23	12.9	1562	24.7	202	58.2	
G012	159	58	112	21	6.5	888	24.5	215	60.3	
G013	154	48	117	21	23.4	900	24.6	206	58.8	
G014	153	57	118	24	22.1	965	24.8	251	65.3	
G015	160	52	137	24	29	1062	23.4	214	61.6	
G016	237	70	115	22	14.2	874	25.7	207	60.9	
G017	215.5	65	111	20.5	11.55	844	24.4	200	59.6	
G017a	218	66	110	21	12.1	845	23.7	201	59.8	
G017b	213	64	112	20	11	843	25.1	199	59.4	
G018	374.203	52.518	123.795	20.576	11.399	869.875	20.345	182.014	57.526	0.258
G018	335	57	108	21	12.4	896	22.9	177	49.4	
G019	133.519	70.197	113.834	22.489	19.859	506.633	20.618	144.294	31.827	0.166
G019	115	71	91	22.5	20.2	494	21.3	139.5	28.3	
G019a	114	69	91	23	20.5	493	21.1	138	27.8	
G019b	116	73	91	22	19.9	495	21.5	141	28.8	
G020	174	65	86	22	21	445	19.5	124	24.9	
G021	205	61	115	21	7.5	494.8	23.6	162	26.7	
G022	90	50	102	20	8	550.8	25.8	162	22.2	
G023	110	57	98	22	7.4	572.8	25.3	156	23.2	
G024	82	53	99	24	11.3	553.8	26.5	165	23.3	
G025	112.51	50.15	113.60	20.59	8.53	508.68	23.91	159.90	27.30	0.07
G025	112	55	104	22	8.6	518.9	25.7	166	24.6	
G026	105	60	92	23	8.6	536.7	22.7	153	21.8	
G027	207	61	123	21	12.5	966.6	25	184	35.7	
G028	215	61	125	22	13.4	838.4	24.9	184	35.8	
G029	163.24	42.84	114.52	20.93	23.69	912.51	23.17	211.53	64.30	0.43
G032	203.10	48.97	140.68	24.55	25.58	1095.01	24.84	247.05	77.22	0.35
G035	195.17	46.89	114.92	21.44	20.03	837.33	22.47	207.35	63.42	0.25
G035W	187.16	45.80	107.52	21.05	19.80	854.72	22.50	207.53	62.74	0.27
G037	181.34	49.64	136.86	21.13	21.74	886.17	22.43	214.02	65.57	0.36
G044	255.92	57.55	145.18	24.60	14.93	891.17	21.78	216.34	65.68	0.46
G048	276.75	60.43	110.03	20.26	11.28	686.78	19.06	158.56	46.65	0.26
G053	274.66	57.68	117.21	20.62	12.61	672.42	18.74	143.16	38.34	0.12
G055	279.32	63.22	114.68	19.98	6.84	634.00	17.31	107.43	20.37	0.08
G058	340.49	60.31	143.27	23.20	12.72	1196.44	25.21	251.29	81.91	0.33
G064	463.16	46.26	129.86	20.95	10.07	1005.16	21.06	200.21	63.01	0.28
G069	148.54	46.38	149.00	24.54	13.09	1514.43	29.57	348.35	119.62	0.44
G072	225.23	45.08	125.05	23.53	21.40	1512.88	28.72	339.67	118.45	0.44
G072a	304.85	44.46	124.02	23.02	20.95	1458.69	28.07	332.35	115.98	0.43
G072b	145.62	45.71	126.07	24.04	21.85	1567.06	29.38	346.99	120.92	0.44

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
A182											
A183											
A184											
A185											
A186											
A187											
A188											
A189											
A190											
A191											
G001	1301.97	17.41	35.90	4.73	20.45	4.52	1.56	4.61	0.68	3.66	0.68
G001	1242										
G002	1752										
G003	286										
G004	2549										
G005	451.89	23.34	45.26	5.73	23.82	5.01	1.71	4.99	0.74	3.99	0.75
G005	469										
G006	209										
G007	179										
G008	598.22	21.72	48.23	6.82	29.80	6.57	2.17	6.66	0.95	5.04	0.94
G008	585										
G009	363										
G009	371.95	28.78	60.30	8.05	33.68	6.86	2.26	6.44	0.90	4.70	0.85
G009a	371.57	28.46	59.47	7.97	33.23	6.77	2.21	6.17	0.88	4.58	0.83
G009b	369.83	29.20	61.01	8.13	33.89	6.85	2.28	6.68	0.92	4.81	0.87
G009c	359.52	27.61	57.90	7.82	32.37	6.60	2.17	6.16	0.87	4.48	0.81
G009d	386.90	29.85	62.84	8.30	35.22	7.20	2.38	6.74	0.95	4.95	0.90
G010	487										
G011	827										
G012	353										
G013	359										
G014	384										
G015	359										
G016	341										
G017	356.5										
G017a	357										
G017b	356										
G018	318.076	28.508	58.863	7.922	33.18	6.901	2.334	6.43	0.863	4.269	0.72
G018	357										
G019	548.552	16.388	34.86	4.72	20.977	4.8515	1.741	5.042	0.76	4.1345	0.765
G019	505										
G019a	507										
G019b	503										
G020	245										
G021	329										
G022	305										
G023	264										
G024	261										
G025	240.06	21.35	45.10	6.22	26.37	5.71	1.93	5.92	0.86	4.59	0.85
G025	246										
G026	313										
G027	372										
G028	357										
G029	555.05	34.76	69.04	8.86	36.47	7.46	2.49	6.86	0.95	4.76	0.82
G032	418.94	42.09	82.67	10.57	44.05	8.86	2.97	7.86	1.08	5.32	0.91
G035	349.29	33.81	66.54	8.70	35.68	7.31	2.44	6.69	0.93	4.67	0.81
G035W	500.82	33.01	65.13	8.53	34.89	7.21	2.41	6.56	0.93	4.63	0.81
G037	411.33	35.39	69.36	9.04	36.71	7.54	2.53	6.74	0.94	4.69	0.81
G044	364.58	37.58	74.90	9.61	40.23	8.06	2.70	7.21	0.98	4.84	0.80
G048	267.80	25.74	51.84	6.87	28.40	5.89	2.02	5.34	0.77	3.89	0.68
G053	1217.77	23.12	45.49	5.84	24.74	5.21	1.73	5.10	0.72	3.74	0.68
G055	2469.52	14.88	30.83	4.06	17.73	4.02	1.38	4.24	0.62	3.28	0.62
G058	461.06	48.16	95.69	12.21	50.79	10.04	3.32	8.68	1.17	5.61	0.94
G064	311.66	32.09	64.61	8.37	35.69	7.40	2.47	6.72	0.90	4.51	0.76
G069	567.40	67.89	132.70	17.26	69.62	13.39	4.29	11.01	1.44	6.68	1.06
G072	595.98	66.49	129.96	16.96	67.94	13.02	4.17	10.92	1.41	6.56	1.04
G072a	575.54	64.79	126.51	16.49	65.91	12.65	4.04	10.62	1.36	6.39	1.01
G072b	616.43	68.20	133.41	17.44	69.97	13.38	4.29	11.22	1.46	6.73	1.07

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
A182								5		W-T n.d.
A183								5		W-T n.d.
A184								5		W-T n.d.
A185								5		W-T n.d.
A186								5		W-T n.d.
A187								6		W-T n.d.
A188								5		W-T n.d.
A189								5		W-T n.d.
A190								5		W-T n.d.
A191								3		W-T n.d.
G001	1.69	0.25	1.46	0.23	2.84	1.22	1.92	1.79	0.62	This study
G001							7	3	2	P & W-T 1993
G002							4	3	2	P & W-T 1993
G003							6	3	2	P & W-T 1993
G004							5	4	2	P & W-T 1993
G005	1.87	0.26	1.62	0.25	3.37	1.81	2.77	2.73	0.68	This study
G005							5	3	2	P & W-T 1993
G006							7	3	2	P & W-T 1993
G007							5	3	2	P & W-T 1993
G008	2.28	0.34	1.94	0.30	4.35	2.01	2.31	1.81	0.77	This study
G008							5	5	2	P & W-T 1993
G009							5	4	2	P & W-T 1993
G009	2.03	0.30	1.66	0.25	3.98	2.15	3.52	2.46	1.02	This study
G009a	1.98	0.29	1.62	0.24	3.82	2.11	5.24	2.41	1.00	This study
G009b	2.09	0.31	1.70	0.25	4.08	2.22	2.77	2.53	1.04	This study
G009c	1.94	0.29	1.57	0.24	3.80	2.08	2.88	2.37	0.98	This study
G009d	2.12	0.29	1.74	0.27	4.22	2.18	3.20	2.54	1.07	This study
G010							4	6	2	P & W-T 1993
G011							4	4	2	P & W-T 1993
G012							7	6	2	P & W-T 1993
G013							7	5	2	P & W-T 1993
G014							9	5	2	P & W-T 1993
G015							6	4	2	P & W-T 1993
G016							5	3	2	P & W-T 1993
G017							6.5	5	2	P & W-T 1993
G017a							8	6	2	P & W-T 1993
G017b							5	3	2	P & W-T 1993
G018	1.6435	0.225	1.2445	0.174	4.142	3.438	2.057	3.414	0.89	This study
G018							1	3	2	P & W-T 1993
G019	1.857	0.265	1.597	0.245	3.6325	2.161	1.598	2.49	0.641	This study
G019							4	3	2	P & W-T 1993
G019a							4	3	2	P & W-T 1993
G019b							4	3	2	P & W-T 1993
G020							4	4	2	P & W-T 1993
G021							5	4		P & W-T 2001
G022							5	5	2	P & W-T 2001
G023							5	2	3	P & W-T 2001
G024							4	4		P & W-T 2001
G025	2.13	0.32	1.82	0.28	3.73	1.52	1.47	2.00	0.53	This study
G025							2	2		P & W-T 2001
G026							5	6	2	P & W-T 2001
G027							4	6	1	P & W-T 2001
G028							3	1		P & W-T 2001
G029	1.88	0.26	1.45	0.21	4.72	3.92	4.04	4.22	1.18	This study
G032	2.02	0.26	1.48	0.22	5.57	4.37	2.73	5.02	0.99	This study
G035	1.84	0.26	1.44	0.21	4.63	3.87	2.05	4.18	0.91	This study
G035W	1.85	0.27	1.42	0.21	4.60	3.80	2.27	4.20	0.93	This study
G037	1.82	0.26	1.38	0.20	4.73	3.93	2.36	4.24	1.17	This study
G044	1.75	0.23	1.30	0.19	4.99	3.76	2.45	4.28	1.23	This study
G048	1.58	0.23	1.23	0.18	3.58	2.86	1.76	2.86	0.82	This study
G053	1.61	0.22	1.35	0.21	3.41	2.04	2.11	2.64	0.48	This study
G055	1.54	0.22	1.35	0.21	2.60	1.10	1.62	1.49	1.08	This study
G058	2.02	0.25	1.46	0.21	5.67	4.52	3.04	5.33	1.45	This study
G064	1.72	0.22	1.29	0.19	4.81	3.52	2.02	3.70	0.98	This study
G069	2.14	0.27	1.38	0.19	7.34	6.83	3.31	6.87	1.23	This study
G072	2.13	0.27	1.35	0.18	7.13	6.82	3.64	6.98	1.40	This study
G072a	2.08	0.27	1.33	0.18	6.96	6.65	3.15	6.80	1.37	This study
G072b	2.18	0.28	1.38	0.19	7.30	6.99	4.14	7.15	1.43	This study

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G072W	ICP-MS	Weathered section. Average	N	14.03	3.52	197.84	134.33	0.19	48.58
G072Wa	ICP-MS	Weathered section	N	14.36	3.54	201.90	140.47	0.19	49.65
G072Wb	ICP-MS	Weathered section	N	13.70	3.51	193.78	128.18	0.18	47.51
G077	ICP-MS		Y	24.32	2.10	199.71	255.85	0.18	53.61
G079	ICP-MS		Y	22.16	1.83	214.03	134.16	0.16	40.73
G081	ICP-MS		Y	22.86	1.73	205.94	275.13	0.17	46.61
G084	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	20		198	350		60
G085	XRF		Y	12					20
G086	XRF		Y	16		210	37		34
G087	XRF		Y	17		242	54		52
G088	XRF		Y	21		218	101		43
G089	XRF		Y	17		240	48		45
G090	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	21		186	146		60
G091	XRF		Y	16		328	12		15
G092	XRF		Y	21		247	14		14
G093	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	19		176	202		52
G094	XRF		Y	15		162	128		48
G095	XRF		Y	13		149	163		51
G096	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	19		209	267		47
G097	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	15		202	235		54
G098	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	16		192	220		50
G099	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	17		204	222		52
G100	XRF		Y	17		229	450		57
G101	XRF		Y	20		131	45		36
G102	XRF and ICP MS	ICP-MS (REE)	Y	31		479	103		60
G103	XRF and ICP MS	ICP-MS (REE)	Y	21		105	7		43
G104	XRF		Y	20		158	15		40
G105	XRF		Y			62	9		35
G106	XRF and ICP MS	ICP-MS (REE)	Y	15		195	243		61
G107	XRF and ICP MS	ICP-MS (REE)	Y	16		133	250		53
G108	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	21		139	183		60
G109	XRF		Y	18		204	68		40
G110	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	15		159	173		57
G111	ICP-MS		Y	13		200	60		45
G112	ICP-MS		Y	20		225	252		50
G113	XRF		Y	15		92	132		32
G114	XRF		Y	12		108	158		39
G115	XRF		Y	13		14	2		37
G116	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	14		164	205		53
G117	XRF		Y	17		149	135		42
G118	XRF		Y	15		155	139		49
G119	XRF		Y	15		95	12		30
G120	XRF		Y	19		108	94		36
G121	XRF		Y	19		198	175		53
G122	XRF		Y	12		118	29		42

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G072W	146.30	45.34	148.18	23.91	28.78	1531.67	29.09	343.77	120.08	0.47
G072Wa	149.41	45.99	148.75	24.17	28.69	1530.50	29.41	347.06	121.12	0.48
G072Wb	143.19	44.68	145.08	23.66	28.87	1532.84	28.78	340.48	119.04	0.47
G077	148.17	52.81	114.59	21.94	5.23	525.36	23.69	158.14	26.29	0.04
G079	68.48	40.51	105.22	20.73	9.25	556.55	23.08	157.80	26.12	0.07
G081	126.02	49.14	95.89	20.07	5.33	516.12	21.78	144.09	24.39	0.03
G084	273	63	87		10	388	19	74	16	
G085	2	15	133		62	674	47	502	109	
G086	36	50	82		12	1007	17	113	23	
G087	41	33	88		16	584	26	195	34	
G088	52	41	86		9	649	19	114	21	
G089	32	26	106		17	794	24	187	33	
G090	125	32	115		17	392	25	165	24	
G091	7	9	1183		58	66	38	346	66	
G092	12	21	266		59	74	35	272	48	
G093	181	65	99		17	599	22	151	38	
G094	116	52	106		18	774	27	204	53	
G095	162	59	97		36	955	21	201	71	
G096	190	71	94		31	885	24	188	81	
G097	200	59	101		18	1113	27	238	100	
G098	188	63	101		24	1138	27	236	101	
G099	186	61	102		16	1095	24	233	102	
G100	340	64	95		12	838	25	201	88	
G101	24	25	80		35	531	25	178	40	
G102	88	49	72		8	648	11	49	12	
G103	8	32	117		36	346	31	309	63	
G104	8	24	110		37	531	34	277	50	
G105	16	21	164		57	1044	17	587	106	
G106	221	63	109		17	615	22	160	38	
G107	242	52	148		43	1165	23	426	79	
G108	185	60	120		10	624	21	183	39	
G109	52	58	101		15	997	28	216	50	
G110	197	57	123		8	724	24	204	49	
G111	52	50	94		26	830	30	273	59	
G112	162	65	96		14	636	24	188	47	
G113	175	28	104		17	567	23	273	64	
G114	195	32	116		20	419	26	303	70	
G115	2	21	116		39	458	40	469	85	
G116	187	68	102		8	288	21	96	15	
G117	118	51	95		19	805	23	179	44	
G118	116	52	92		20	760	23	178	45	
G119	50	33	84		1	157	16	112	27	
G120	81	32	51		22	294	21	121	30	
G121	139	59	102		8	693	26	220	54	
G122	30	44	91		32	1073	31	275	73	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G072W	647.68	66.67	130.01	16.89	68.10	13.13	4.19	10.95	1.42	6.62	1.04
G072Wa	653.41	66.79	130.06	16.91	68.42	13.18	4.21	11.09	1.43	6.66	1.05
G072Wb	641.95	66.55	129.97	16.86	67.78	13.09	4.17	10.81	1.40	6.57	1.04
G077	257.83	20.76	44.76	6.07	26.25	5.73	2.00	5.61	0.84	4.58	0.86
G079	209.60	21.48	45.53	6.19	26.02	5.62	1.93	5.52	0.83	4.47	0.83
G081	308.58	18.86	40.72	5.58	24.06	5.29	1.80	5.17	0.78	4.18	0.78
G084	178	9	26	3.01	15	3.42	1.1	4.04	0.54	3.43	0.69
G085	780	75	162		73						
G086	194	14	39		22						
G087	254	23	67		34						
G088	195	13	40		23						
G089	255	21	59		31						
G090	179	17	47	5.62	26	5.8	1.89	7.08	0.93	4.99	0.98
G091	32										
G092	72										
G093	315	23	54	6.88	29	5.91	2.14	7.64	1.03	4.86	0.98
G094	483	33	83		40						
G095	660	45	99		41						
G096	633	52	108	11.42	44	8.23	2.59	9.26	1.06	5.28	0.94
G097	686	66	131	14.37	57	8.71	3.26	9.02	1.2	5.82	0.86
G098	699	64	134	10.64	55	7.73	2.05	9.93	1.29	4.41	0.19
G099	676	65	136	15.01	55	9.2	3.34	9.62	1.28	5.85	0.98
G100	704	57	119		50						
G101	1117										
G102	1796	9.6	20.9		13.3	3.29	1.33		0.57		
G103	371	28.62	65.49	8.23	35.29	7.34	2.07	6.98	0.94	5.2	0.26
G104	503										
G105	652										
G106	291	27.81	58.89	7.36	31.19	7.17	2.36	8.84	1.12	5.84	0.99
G107	512	52.99	107.16	13.18	50.56	9.68	3.1	9.72	1.34	5.11	0.55
G108	231	27	63	7.4	33	6.26	2.44	6.8	1	5.06	0.94
G109	287	26	70		36						
G110	247	31	75	8.21	37	7.37	2.43	8.36	1.02	4.91	0.91
G111	418	38	93		47						
G112	360	28	66	7.93	34	6.88	2.32	7.74	0.94	5.1	0.95
G113	307	55	129		58						
G114	320										
G115	508	66	153		72						
G116	110	7	25	3.41	16	3.95	1.52	4.03	0.7	3.63	0.76
G117	322	28	70		35						
G118	316	26	70		35						
G119	32										
G120	93										
G121	381	31	75		38						
G122	496	40	105		53						

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G072W	2.13	0.28	1.37	0.19	7.21	6.83	3.34	7.03	1.42	This study
G072Wa	2.15	0.28	1.38	0.19	7.28	6.91	3.39	7.07	1.44	This study
G072Wb	2.12	0.27	1.35	0.18	7.15	6.75	3.29	6.98	1.41	This study
G077	2.12	0.30	1.80	0.28	3.73	1.38	1.16	1.88	0.52	This study
G079	2.06	0.31	1.72	0.27	3.63	1.45	1.58	2.12	0.38	This study
G081	1.91	0.29	1.62	0.24	3.31	1.35	1.32	1.64	0.31	This study
G084	1.99	0.3	1.76	0.3						Laws 1997
G085										Laws 1997
G086										Laws 1997
G087										Laws 1997
G088										Laws 1997
G089										Laws 1997
G090	2.61	0.34	2.09	0.32						Laws 1997
G091										Laws 1997
G092										Laws 1997
G093	2.28	0.37	1.84	0.39						Laws 1997
G094										Laws 1997
G095										Laws 1997
G096	2.54	0.35	2.05	0.31						Laws 1997
G097	2.73	0.3	1.82	0.35						Laws 1997
G098	1.84	0.56	0.72	0.33						Laws 1997
G099	2.53	0.29	1.88	0.3						Laws 1997
G100										Laws 1997
G101										Laws 1997
G102			0.91	0.13	2.35	0.99				Laws 1997
G103	2.3	0.61	1.34	0.58						Laws 1997
G104										Laws 1997
G105										Laws 1997
G106	2.84	0.39	2.09	0.32						Laws 1997
G107	1.93	0.23	1.26	0.18						Laws 1997
G108	2.24	0.27	1.75	0.27						Laws 1997
G109										Laws 1997
G110	2.13	0.32	1.67	0.25						Laws 1997
G111										Laws 1997
G112	2.29	0.33	1.91	0.31						Laws 1997
G113							5	16		Laws 1997
G114							2	11		Laws 1997
G115										Laws 1997
G116	1.72	0.25	1.65	0.27						Laws 1997
G117										Laws 1997
G118										Laws 1997
G119							4	8		Laws 1997
G120							4	7		Laws 1997
G121										Laws 1997
G122										Laws 1997

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G123	XRF		Y	11		117	29		39
G124	XRF		Y	15		168	181		44
G125	XRF		Y	18		184	111		42
G126	XRF		Y	18		206	288		51
G127	XRF		Y	17		130	90		42
G128	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	11		180	205		51
G129	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	12		152	247		47
G130	XRF		Y	17		164	179		52
G131	XRF and ICP MS	ICP-MS (REE)	Y	21		145	212		56
G132	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	10		167	170		51
G133	XRF		Y	21		228	93		59
G134	XRF		Y	20		209	88		52
G135	XRF		Y	13		155	94		52
G136	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	17		184	116		56
G137	XRF		N	27		230	118		37
G138	XRF		Y	17		152	110		47
G139	XRF		Y	16		187	151		55
G140	XRF		Y	20		200	309		56
G141	XRF		Y	22		182	320		57
G142	XRF		Y	11		155	145		55
G143	XRF		Y	15		159	62		49
G144	XRF		Y				4		11
G145	XRF		Y	11		93	27		43
G146	XRF		Y	20		178	268		58
G147	XRF		Y	19		198	162		55
G148	XRF		Y	22		195	151		46
G149	XRF		Y	15		197	157		55
G150	XRF		Y	16		152	46		47
G151	XRF		Y	14		212	30		43
G152	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	15		169	143		51
G153	XRF		Y	17		166	138		48
G154	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	16		176	174		55
G155	XRF		Y	19		212	65		37
G156	XRF and ICP MS	XRF (inc La, Ce and Nd) ICP-MS (REE)	Y	18		160	164		48
G157	XRF		Y	24		201	61		43
G158	ICP-MS		Y	17.6		190	489		70
G159	ICP-MS		Y	24.4		155	290		134
G160	ICP-MS		Y	23		170	280		98
G161	ICP-MS		Y	16.1		165	127		50
G162	ICP-MS		Y	21.6		200	160		62
G163	ICP-MS		Y	13.7		157	61		64
G164	ICP-MS		Y	20.2		230	141		58
G165	ICP-MS		Y	20.2		160	160		57
G166	ICP-MS		Y	18.1		235	102		53
G167	ICP-MS		Y	20.1		190	350		55
G168	ICP-MS		Y	21.9		185	420		57
G169	ICP-MS		Y	18.5		225	198		52
G170	ICP-MS		Y	16.5		175	160		45
G171	ICP-MS		Y	22.6		20	275		58
G172	ICP-MS		Y	22.2		220	280		50
G173	XRF, NAA and ICP-MS		Y			242	242		49
G174	XRF, NAA and ICP-MS		Y			223	335		56
G175	XRF, NAA and ICP-MS		Y			174	262		56
G176	XRF, NAA and ICP-MS		Y			215	383		59

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G123	30	41	90		31	1054	30	274	71	
G124	177	50	93		24	780	22	256	62	
G125	73	40	93		15	421	26	146	26	
G126	186	68	94		29	724	25	220	63	
G127	98	35	83		36	851	25	248	64	
G128	165	52	94		48	730	29	275	91	
G129	175	60	96		36	699	26	262	67	
G130	191	62	111		21	596	23	190	42	
G131	208	24	103		7	270	17	89	12	
G132	153	48	144		37	1226	28	326	91	
G133	105	50	104		18	836	26	221	50	
G134	86	45	100		18	803	27	224	52	
G135	80	54	99		21	785	30	287	74	
G136	92	44	94		22	854	26	219	53	
G137	60	40	47		4	746	8	21	1	
G138	77	46	99		33	999	30	300	76	
G139	109	52	100		10	922	28	240	65	
G140	303	62	104		16	522	23	148	32	
G141	310	62	101		15	499	22	147	31	
G142	162	54	119		22	917	24	176	49	
G143	65	43	111		32	1002	31	378	86	
G144	6	8	95		80	44	39	655	138	
G145	21	35	102		32	898	26	368	69	
G146	235	64	105		17	711	17	144	47	
G147	170	55	94		9	908	21	229	63	
G148	94	52	103		16	772	24	184	47	
G149	160	46	96		9	873	19	223	60	
G150	99	46	131		26	2051	28	345	136	
G151	45	54	108		23	1356	30	242	86	
G152	166	64	108		18	1211	23	224	60	
G153	157	58	115		17	1344	22	239	66	
G154	167	61	103		15	806	23	176	38	
G155	43	47	90		16	626	29	184	39	
G156	163	60	92		17	861	23	216	39	
G157	48	62	105		13	845	28	242	64	
G158	220	41	86		7.4	171	13	68	6.6	
G159	230	8	112		7.1	299	27	89	14.4	
G160	225	78	115		6.9	274	18	93	14.9	
G161	85	17	108		29	803	31	303	73.8	
G162	95	10	120		23	904	29	243	56.4	
G163	55	34	140		22.4	810	37	318	67.5	
G164	90	36	97		20.9	966	24	234	55	
G165	100	44	125		18.8	785	25	217	51.4	
G166	60	59	116		24.1	827	27	263	54.9	
G167	320	66	110		27.1	670	22	245	60	
G168	200	74	135		20.2	702	23	220	58.8	
G169	100	40	91		22.9	927	22	220	51.1	
G170	90	50	110		19.5	871	27	310	72.4	
G171	180	68	115		6.5	765	22	197	46.9	
G172	165	70	115		5.8	665	21	201	47	
G173	209	43			12	1006	21	237	48	
G174	251	53			24	655	21	194	42	
G175	261	24			10	496	17	129	22	
G176	274	51			19	724	20	162	42	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G123	504	41	104		51						
G124	500	39	90		41						
G125	205	18	42		23						
G126	412	34	86		40						
G127	495	31	67		34						
G128	782	55	118	12.23	49	8.31	2.67	9.12	1.12	5.49	1
G129	480	42	94	10.46	44	7.01	2.65	7.29	1.04	5.56	1.08
G130	233	27	68		36						
G131	104	9.63	21.43	3.04	13.68	3.96	1.39	4.93	0.71	3.89	0.77
G132	1923	60	135	15.69	65	11.37	4.12	10.03	1.36	5.98	1.08
G133	397	30	81		42						
G134	427	33	86		45						
G135	473	47	110		50						
G136	443	34	86	7.59	47	6.74	2.34	6.78	0.87	4.66	0.18
G137	111		7		5						
G138	510	49	113		49						
G139	454	39	97		47						
G140	250	19	45		25						
G141	258	16	48		27						
G142	545										
G143	3246										
G144	602										
G145	674										
G146	293										
G147	386										
G148	344										
G149	396										
G150	992	100	209		87						
G151	664	61	139		62						
G152	475	42	103	12.53	51	9.02	3.35	9.13	1.15	5.7	0.94
G153	616	49	117		57						
G154	322	29	73	8.77	40	6.79	2.42	6.73	1.03	4.68	0.87
G155	298	28	68		36						
G156	257	24	62	6.83	30	5.25	2.11	6.07	0.97	4.91	0.82
G157	333	36	93		47						
G158	445	5.3	12.3	1.8	8.1	2.22	0.83	3	0.43	2.57	0.51
G159	109	9.9	21.7	2.8	13.1	3.4	1.28	3.8	0.63	3.64	0.69
G160	99	10.1	22	2.8	12.9	3.39	1.31	4	0.64	3.77	0.72
G161	472	50	104.3	12.3	47.7	8.51	2.62	7.5	1.11	5.71	1.04
G162	627	34.9	75.7	9.6	39.6	7.8	2.81	7.2	1.03	5.23	0.94
G163	421	39.9	88.1	10	45.6	9.24	3.06	8.9	1.3	6.6	1.18
G164	412	33.2	73.1	9.2	37.8	7.47	2.59	6.7	0.95	4.8	0.85
G165	405	32.8	71.5	8.6	36.3	7.16	2.74	6.7	0.96	5.2	0.94
G166	403	33	70.7	8.6	35.1	7.08	2.55	6.7	0.98	5.15	0.95
G167	439	39	77.2	8.8	34.8	6.8	2.14	6.2	0.9	4.7	0.84
G168	368	38	77.4	9	36.6	7.18	2.31	6.6	0.98	5.18	0.93
G169	398	31.3	67.3	8.5	34.6	6.93	2.25	6.3	0.93	4.71	0.86
G170	435	50.1	103	11.7	46	8.44	2.72	7.5	1.1	5.82	1.07
G171	340	30.4	63.1	7.5	30.7	6.3	2.06	6	0.89	4.85	0.89
G172	341	30.3	64.2	7.8	33.1	6.86	2.36	7	0.98	5.21	0.95
G173	332										
G174	311										
G175	217										
G176	502										

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G123										Laws 1997
G124										Laws 1997
G125										Laws 1997
G126										Laws 1997
G127										Laws 1997
G128	2.56	0.35	2.2	0.35						Laws 1997
G129	2.81	0.4	2.37	0.37						Laws 1997
G130										Laws 1997
G131	2.02	0.25	1.74	0.24						Laws 1997
G132	2.34	0.37	1.64	0.33				13		Laws 1997
G133										Laws 1997
G134										Laws 1997
G135										Laws 1997
G136	2.05	0.37	1.48	0.37						Laws 1997
G137										Laws 1997
G138										Laws 1997
G139										Laws 1997
G140										Laws 1997
G141										Laws 1997
G142										Laws 1997
G143										Laws 1997
G144										Laws 1997
G145										Laws 1997
G146										Laws 1997
G147										Laws 1997
G148										Laws 1997
G149										Laws 1997
G150										Laws 1997
G151										Laws 1997
G152	2.38	0.29	1.79	0.27						Laws 1997
G153										Laws 1997
G154	2.43	0.28	1.67	0.35						Laws 1997
G155										Laws 1997
G156	2.26	0.3	1.8	0.31						Laws 1997
G157										Laws 1997
G158	1.36	0.19	1.22	0.19	1.9	0.43	1.85	0.71	0.22	Wilson et al 2000
G159	1.78	0.23	1.46	0.21	2.4	0.8	1.84	1.26	0.36	Wilson et al 2000
G160	1.84	0.24	1.5	0.22	2.5	0.83	1.19	1.27	0.37	Wilson et al 2000
G161	2.68	0.35	2.31	0.36	6.1	4.11	3.89	5.56	1.85	Wilson et al 2000
G162	2.36	0.29	1.91	0.28	5.2	3.01	2.76	3.58	1.11	Wilson et al 2000
G163	2.92	0.38	2.42	0.34	7.2	3.8	3.34	4.51	1.51	Wilson et al 2000
G164	2.07	0.26	1.64	0.25	4.5	2.64	3.9	2.8	0.9	Wilson et al 2000
G165	2.29	0.3	1.88	0.28	5.3	2.99	3.22	3.43	1.04	Wilson et al 2000
G166	2.38	0.32	2.1	0.32	6	3.15	2.8	3.88	1.31	Wilson et al 2000
G167	2.08	0.28	1.7	0.26	5.4	3.34	3.17	4.81	1.47	Wilson et al 2000
G168	2.28	0.3	1.82	0.27	5	3.3	3.05	4.52	1.35	Wilson et al 2000
G169	2.12	0.27	1.71	0.26	4.7	2.72	2.71	2.88	0.93	Wilson et al 2000
G170	2.77	0.38	2.42	0.37	6.7	4.16	4.59	5.87	1.87	Wilson et al 2000
G171	2.25	0.29	1.84	0.27	4.4	2.56	2.62	3.39	1	Wilson et al 2000
G172	2.34	0.29	1.91	0.28	4.6	2.58		3.39	1.04	Wilson et al 2000
G173										Weinstein 2000
G174										Weinstein 2000
G175										Weinstein 2000
G176										Weinstein 2000

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G177	XRF, NAA and ICP-MS		Y			189	139		38
G178	XRF, NAA and ICP-MS		Y			205	132		40
G179	XRF, NAA and ICP-MS		Y			227	304		56
G180	XRF, NAA and ICP-MS		Y			212	294		55
G181	XRF, NAA and ICP-MS		Y			209	260		49
G182	XRF, NAA and ICP-MS		Y						
G183	XRF, NAA and ICP-MS		Y			202	254		51
G184	XRF, NAA and ICP-MS		Y			191	168		44
G185	XRF, NAA and ICP-MS		Y			177	174		44
G186	XRF, NAA and ICP-MS		Y			195	195		52
G187	XRF, NAA and ICP-MS		Y			110	48		31
G188	XRF, NAA and ICP-MS		Y			219	203		47
G189	XRF, NAA and ICP-MS		Y			196	95		38
G190	XRF, NAA and ICP-MS		Y			200	321		61
G191	XRF, NAA and ICP-MS		Y						
G192	XRF, NAA and ICP-MS		Y			204	317		60
G193	XRF, NAA and ICP-MS		Y			214	302		51
G194	XRF, NAA and ICP-MS		Y			227	267		44
G195	XRF, NAA and ICP-MS		Y			117	88		33
G196	XRF, NAA and ICP-MS		Y						
G197	XRF, NAA and ICP-MS		Y			191	125		40
G198	XRF, NAA and ICP-MS		Y			122	126		43
G199	XRF, NAA and ICP-MS		Y			199	187		40
G200	XRF, NAA and ICP-MS		Y			234	205		34
G201	XRF, NAA and ICP-MS		Y			168	229		52
G202	XRF, NAA and ICP-MS		Y			232	348		50
G203	XRF, NAA and ICP-MS		Y			153	116		40
G204	XRF, NAA and ICP-MS		Y			188	116		47
G205	XRF, NAA and ICP-MS		Y			205	157		42
G206	XRF, NAA and ICP-MS		Y			249	163		51
G207	XRF, NAA and ICP-MS		Y			188	182		38
G208	XRF, NAA and ICP-MS		Y			256	153		49
G209	XRF, NAA and ICP-MS		Y			186	167		40
G210	XRF, NAA and ICP-MS		Y			201	165		36
G211	XRF, NAA and ICP-MS		Y			154	155		37
G212	XRF, NAA and ICP-MS		Y			191	161		44

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G177	127	31			10	1965	27	298	111	
G178	147	37			22	1427	26	288	88	
G179	260	50			11	1207	24	255	65	
G180	271	52			8	1272	25	272	69	
G181	206	38			26	1233	20	239	61	
G182										
G183	211	39			27	1268	20	242	61	
G184	142	31			19	1239	24	274	81	
G185	144	27			18	1264	24	281	83	
G186	192	41			16	939	18	210	51	
G187	66	31			25	1371	18	315	75	
G188	150	14			16	1403	29	348	95	
G189	93	25			23	1305	24	289	69	
G190	331	56			9	886	21	180	48	
G191										
G192	230	48			18	610	18	147	32	
G193	268	53			7	1032	22	204	58	
G194	234	42			7	1330	26	250	74	
G195	87	36			33	1319	22	356	75	
G196										
G197	117	39			14	1901	28	296	100	
G198	138	33			24	1956	21	292	82	
G199	70	18			18	729	23	198	40	
G200	84	14			17	656	22	195	38	
G201	177	41			16	1192	23	230	46	
G202	225	51			22	711	21	195	41	
G203	102	34			23	1223	23	347	78	
G204	113	30			6	1053	25	369	112	
G205	135	35			34	1352	24	309	78	
G206	155	47			26	1748	34	348	126	
G207	145	38			33	1326	28	309	97	
G208	176	38			18	1453	30	327	125	
G209	135	38			24	1121	23	291	70	
G210	125	43			26	1195	25	297	72	
G211	115	37			22	1282	26	332	87	
G212	139	46			28	1165	24	279	76	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G177	601	67.3	125.1		63.6	11.4	3.92	10.71	1.46		
G178	881	55.7	102.5		49.2	9.42	3.34	9.53	1.17		0.93
G179	528	53	97.8		50.5	9.08	3.06	8.62	1.31		1.03
G180	541	52.5	96.1		45.4	8.91	3.08		1.32		
G181	409	32	62.4		33.6	6.62	2.49		1		
G182		38.8	73.4		35.6	7.44	2.72	7.2	1.11		
G183	423	35.4	66.2		35	6.85	2.47	7.24	1.09		
G184	559										
G185	543	53.1	97.9		47.3	8.89	3.03	7.94	1.1		1.07
G186	276	24.6	51.3		27.5	6.09	2.27	6.83	0.93		0.91
G187	419	38.5	76.4		39.5	7.89	2.91	8.06	0.96		
G188	587	54.4	113.4	13.8	56.2	12.27	3.58	12.15	1.28	6.13	1.02
G189	449	42	80.6		39.6	8.01	2.85	8.18	1.02		0.9
G190	322	33.4	64.5		32	6.2	2.16		0.76		0.68
G191		20.9	41.4		21.7	4.71	1.76	4.62	0.74		0.83
G192	230	18.5	38.1		19.8	4.22	1.63		0.65		0.6
G193	387	44.3	81.9		41.2	7.65	2.55	6.78	0.91		
G194	521	60.8	106.8		49.1	9.07	3	8.21	1.15		
G195	491	39.5	75.6		36.5	7.05	2.56	6.12	0.82		
G196		56.5	102.9		51.7	9.66	3.19	7.59	1.22		1.19
G197	609	59.7	108.7		52.4	9.81	3.23	9.06	1.21		1.12
G198	447	45.8	83.2		39.2	7.53	2.66	6.95	0.85		
G199	262	23.1	54.5	6.2	27.6	5.65	1.8	4.66	0.66	3.89	0.7
G200	255										
G201	1483	71.1	142.8	14.9	63.3	10.49	3.31	8.11	1.09	5.05	0.83
G202	338										
G203	497										
G204	739										
G205	593										
G206	588	86.9	170.2	19.6	76.6	17.3	4.77	16.3	1.61	7.49	1.19
G207	750										
G208	491										
G209	471										
G210	733										
G211	580										
G212	465										

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G177			1.69	0.21	6.41	6.09		6.53	1.56	Weinstein 2000
G178			1.45	0.21	6.03	4.91		5.71	1.36	Weinstein 2000
G179			1.58	0.22	5.44	3.54		5.57	1.42	Weinstein 2000
G180			1.64	0.22	5.62	3.84		5.35	1.61	Weinstein 2000
G181			1.32	0.16	5.25	3.63		3.57	0.99	Weinstein 2000
G182			1.49	0.18	4.97	3.5		3.99	0.76	Weinstein 2000
G183			1.5	0.19	4.48	3.38		3.73	1.03	Weinstein 2000
G184										Weinstein 2000
G185			1.4	0.19	5.53	4.61		5.63	1.88	Weinstein 2000
G186		0.24	1.12	0.16	4.72	3.16		2.4	0.76	Weinstein 2000
G187			1.01	0.12	6.31	4.39		3.96	1.15	Weinstein 2000
G188	2.44	0.28	1.73	0.24	6.1		3.4	5.51	1.62	Weinstein 2000
G189		0.31	1.46	0.18	5.57	3.83		4.01	0.63	Weinstein 2000
G190			1.19	0.14	3.67	2.52		3.12	0.9	Weinstein 2000
G191			1.2	0.16	3.22	2.04		2.07	0.61	Weinstein 2000
G192			1.13	0.15	3.18	1.83		1.87	0.59	Weinstein 2000
G193		0.23	1.19	0.17	4.09	3.04		4.31	1.28	Weinstein 2000
G194			1.42	0.2	4.93	3.78		6.1	1.76	Weinstein 2000
G195			1.45	0.19	6.91	4.33		4.21	1.07	Weinstein 2000
G196		0.34	1.79	0.25	6.29	5.34		5.92	1.43	Weinstein 2000
G197			1.85	0.25	6.2	5.37		6.58	1.73	Weinstein 2000
G198		0.25	1.25	0.16	5.37	4.09		4.45	1.12	Weinstein 2000
G199	1.81	0.24	1.55	0.21	4.4	3.49	2.24	2.89	0.64	Weinstein 2000
G200										Weinstein 2000
G201	2.03	0.28	1.64	0.26	5.01	4.46	3.56	8.07	1.62	Weinstein 2000
G202										Weinstein 2000
G203										Weinstein 2000
G204										Weinstein 2000
G205										Weinstein 2000
G206	2.79	0.33	1.81	0.25	5.02		0.43	10.84	3.1	Weinstein 2000
G207										Weinstein 2000
G208										Weinstein 2000
G209										Weinstein 2000
G210										Weinstein 2000
G211										Weinstein 2000
G212										Weinstein 2000

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G213	XRF, NAA and ICP-MS		Y			167	127		37
G214	XRF, NAA and ICP-MS		Y			193	149		41
G215	XRF, NAA and ICP-MS		Y			191	162		47
G216	XRF, NAA and ICP-MS		Y			196	173		45
G217	XRF, NAA and ICP-MS		Y			182	162		43
G218	XRF, NAA and ICP-MS		Y			190	95		40
G219	XRF, NAA and ICP-MS		Y			168	159		46
G220	XRF, NAA and ICP-MS		Y			241	181		44
G221	XRF, NAA and ICP-MS		Y			190	280		50
G222	XRF, NAA and ICP-MS		Y			205	287		54
G223	XRF, NAA and ICP-MS		Y			203	196		50
G224	XRF, NAA and ICP-MS		Y			170	164		45
G225	NAA and ICP-AES	ICP-AES (Sr and Ni)	Y	23			36		28
G226	NAA and ICP-AES	ICP-AES (Sr and Ni)	Y	23			48		26
G227	NAA and ICP-AES	ICP-AES (Sr and Ni)	Y	24			53		28
G228	NAA and ICP-AES	ICP-AES (Sr and Ni)	Y	25			50		28
G229	NAA and ICP-AES	ICP-AES (Sr and Ni), Rb <10	Y	27			500		25
G230	NAA and ICP-AES	ICP-AES (Sr and Ni), U >1	Y	23			65		32
G231	NAA and ICP-AES	ICP-AES (Sr and Ni), Rb <10, Cs <0.2, U <1	Y	32			415		41
G232	NAA and ICP-AES	ICP-AES (Sr and Ni)	Y	32			430		33
G233	XRF		Y	27		206	42		55
G234	XRF		Y	24		192	21		47
G235	XRF		Y	25		208	27		49
G236	XRF		Y	24		208	29		44
G237	XRF		Y	27		204	51		56
G238	XRF		Y	21		206	25		45
G239	XRF		Y	23		201	174		47
G240	XRF		Y	21		339	76		68
G241	XRF		Y	24		204	111		
G242	XRF		Y	22		227	161		
G243	XRF		Y	29		151	314		
G244	XRF		Y	23		222	179		
G245	XRF		Y	24		207	159		
G246	XRF		Y	24		204	178		
G247	XRF		Y	22		215	154		
G248	XRF		Y	23		229	213		
G249	XRF		Y	21		250	156		
G250	XRF		Y	23		167	252		31
G251	XRF		Y	27		172	23		45
G252	XRF		Y	17		125	61		22
G253	XRF		Y	18		153	15		27
G254	XRF		Y	8		69	13		
G255	XRF		Y	9		74	53		
G256	XRF		Y	9		164	143		
G257	XRF		Y	15		143	48		
G258	XRF		Y	22		217	125		
G259	XRF		Y	21		153	289		29
G260	XRF		Y	22		158	279		29
G261	XRF		Y	21		173	259		32
G262	XRF		Y	17		134	157		24

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G213	101	33			27	1602	31	346	104	
G214	107	43			28	1204	29	270	88	
G215	119	45			22	1934	28	314	103	
G216	133	38			21	1646	28	312	102	
G217	118	35			31	1265	27	299	93	
G218	103	38			19	1417	26	328	92	
G219	148	32			22	1186	22	259	69	
G220	133	38			7	1490	32	282	112	
G221	210	47			14	467	17	114	26	
G222	216	55			17	510	18	142	36	
G223	175	51			17	1306	25	292	76	
G224	140	36			14	1465	25	328	95	
G225	24				62	540	20.9	99		5.24
G226	23				44	400	22	114		3.99
G227	25				63	325	20.8	101		8.32
G228	26				71	270	18.6	117		5
G229	160				10	180	15	73		3.19
G230	35				85	750	21.6	110		3.04
G231	120				10	720	22.3	125		0.2
G232	110				12	370	21.8	120		0.42
G233	62	39	88	21	11	577	32	161	9	
G234	12	16	139	24	36	379	52	338	26	
G235	15	17	138	26	35	382	51	327	24	
G236	13	17	136	24	39	428	52	336	24	
G237	59	40	95	20	15	631	32	167	7	
G238	15	10	225	25	67	328	53	339	21	
G239	110	15	64	18	57	319	32	180	14	
G240	83	91	191	22	97	496	35	250	33	
G241	49	30	171	21	100	602	29	232	16	
G242	53	10	125	21	43	464	35	263	18	
G243	128	39	98	12	56	725	25	161	14	
G244	61	35	112	21	76	745	32	252	15	
G245	58	16	126	22	47	623	36	275	16	
G246	64	15	97	19	60	721	30	217	14	
G247	65	123	118	20	104	818	29	252	13	
G248	68	10	44	20	47	824	29	14	13	
G249	66	12	106	21	55	932	35	297	21	
G250	54	21	72	19	45	492	24	163	7	
G251	13	17	121	23	31	496	54	315	22	
G252	30	14	82	19	82	305	30	167	12	
G253	10	307	87	21	106	169	30	201	10	
G254	5	97	67	17	116	376	37	437	23	
G255	14	7	80	18	70	517	22	292	12	
G256	62	61	78	17	6	453	25	207	14	
G257	11	32	175	13	49	539	25	224	15	
G258	47	28	98	17	4	365	33	253	17	
G259	62	12	74	18	57	508	21	160	8	
G260	56	46	68	18	51	557	21	153	6	
G261	59	20	75	18	49	589	23	154	8	
G262	39	10	63	19	52	633	11	176	8	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G213	1181										
G214	512	48.7	104.7	12	51.8	9.51	2.88	7.35	0.96	5.18	0.89
G215	582	65	153.4	15.6	65.7	11.38	3.43	8.41	1.03	5.3	0.87
G216	567										
G217	527	55.1	117	13.1	54.4	9.56	3.06	8.16	1.02	5.41	0.99
G218	759										
G219	464	36.3	81.3	9.4	41.9	7.93	2.57	6.14	0.8	4.2	0.68
G220	730										
G221	234										
G222	296	13.1	32.4	3.8	18.4	4.05	1.42	3.58	0.52	3.07	0.55
G223	562	55.5	105.4		51.8	9.78	3.24	9.01	1.13		0.78
G224	629	60.2	117.8		59.5	10.9	3.6	8.63	1.13		
G225	640	20.3	40.7			4.7	1.4	0.77		4.1	
G226	700	19.2	38.6			4.7	1.36	0.7		4.1	
G227	570	17.6	38.8			4.9	1.5	0.9		3.5	
G228	920	17.8	38.4			4.9	1.36	0.81		3.8	
G229	830	14.4	31.5			3.9	1.06	0.54		2.7	
G230	805	20.2	40.6			4.7	1.44	0.81		3.8	
G231	360	16.8	36.1			4.4	1.35	0.66		4.2	
G232	375	18.4	37.8			4.6	1.44	0.66		3.5	
G233	242										
G234	697										
G235	589										
G236	715										
G237	239										
G238	1051										
G239	890										
G240	4328										
G241	1140										
G242	712										
G243	1227										
G244	823										
G245	578										
G246	889										
G247	2083										
G248	1016										
G249	1019										
G250	647										
G251	1159										
G252	631										
G253	1355										
G254	1378										
G255	592										
G256	128										
G257	871										
G258	878										
G259	781										
G260	723										
G261	645										
G262	735										

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G213										Weinstein 2000
G214	2.27	0.28	1.81	0.25	5.68	2.08	2.77	5.2	1.25	Weinstein 2000
G215	2.12	0.25	1.53	0.2	5.87	2.37	4.43	7.12	1.71	Weinstein 2000
G216										Weinstein 2000
G217	2.43	0.3	1.94	0.25	6.12	5.19	3.38	6.17	1.56	Weinstein 2000
G218										Weinstein 2000
G219	1.69	0.19	1.19	0.15	5.39	5.3	2.54	3.96	0.79	Weinstein 2000
G220										Weinstein 2000
G221										Weinstein 2000
G222	1.41	0.17	1.15	0.16	3.41	2.5	1.28	2.25	0.57	Weinstein 2000
G223		0.25	1.4	0.19	5.48	3.76		4.69	1.35	Weinstein 2000
G224			1.36	0.21	6.68	5.08		4.96	1.41	Weinstein 2000
G225			2.4	0.46	4.03	0.34		3.32	1.5	Bogoch et al. 1993
G226			1.6	0.39	3.91	0.32		3.2	1.7	Bogoch et al. 1993
G227			1.7	0.5	3.9	0.37		3.21	5.1	Bogoch et al. 1993
G228			2	0.5	4.13	0.48		3.36	4.8	Bogoch et al. 1993
G229			1.5	0.39	2.86	0.3		2.49	4.7	Bogoch et al. 1993
G230			2.4	0.44	3.97	0.37		3.8	1	Bogoch et al. 1993
G231			1.8	0.41	3.1	0.24		2.7	1	Bogoch et al. 1993
G232			1.8	0.45	3.11	0.32		3.11	1.1	Bogoch et al. 1993
G233			3.56				6			Jarrar et al. 1992
G234			4.86				9			Jarrar et al. 1992
G235			4.56				11			Jarrar et al. 1992
G236			4.67				10			Jarrar et al. 1992
G237			3.58				7			Jarrar et al. 1992
G238			4.26				17			Jarrar et al. 1992
G239			2.95				15			Jarrar et al. 1992
G240			3.85				22			Jarrar et al. 1992
G241							17			Jarrar et al. 1992
G242							10			Jarrar et al. 1992
G243							19			Jarrar et al. 1992
G244							14			Jarrar et al. 1992
G245							11			Jarrar et al. 1992
G246							10			Jarrar et al. 1992
G247							11			Jarrar et al. 1992
G248							11			Jarrar et al. 1992
G249							11			Jarrar et al. 1992
G250			2.69				10			Jarrar et al. 1992
G251			4.99				10			Jarrar et al. 1992
G252			2.95				15			Jarrar et al. 1992
G253			3.02				20			Jarrar et al. 1992
G254							27			Jarrar et al. 1992
G255							12			Jarrar et al. 1992
G256							10			Jarrar et al. 1992
G257							28			Jarrar et al. 1992
G258							10			Jarrar et al. 1992
G259			2.38				13			Jarrar et al. 1992
G260			2.37				12			Jarrar et al. 1992
G261			2.67				11			Jarrar et al. 1992
G262			1.88				11			Jarrar et al. 1992

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G263	XRF		Y	27		185	832		45
G264	XRF		Y	23		167	265		30
G265	XRF		Y	23		176	161		30
G266	XRF		Y	21		163	322		31
G267	XRF		Y	18		190	161		62
G268	XRF		Y	21		195	163		47
G269	XRF		Y	25		206	226		64
G270	XRF		Y	21		204	180		60
G271	XRF		Y	25		208	237		64
G272	XRF		Y	20		162	407		66
G273	XRF		Y	22		220	286		61
G274	XRF		Y	30		303	57		49
G275	XRF		Y	31		230	246		54
G276	XRF		Y	26		225	397		67
G277	XRF		Y	23		199	193		96
G278	XRF		Y	26		225	260		55
G279	XRF		Y	23		210	320		63
G280	XRF		Y	22		189	299		71
G281	XRF		Y	27		189	314		72
G282	XRF		Y	33		258	200		57
G283	XRF		Y	31		252	197		56
G284	XRF		Y	28		211	299		52
G285	XRF		Y	26		204	297		53
G286	XRF		Y	31		213	356		68
G287	XRF		Y	18		208	165		63
G288	XRF		Y	19		213	180		62
G289	XRF		Y	16		214	184		67
G290	XRF		Y	22		212	343		66
G291	XRF		Y	22		212	346		66
G292	XRF		Y	21		223	347		65
G293	XRF		Y	17		225	578		71
G294	XRF		Y	16		211	494		63
G295	XRF		Y	20		211	392		70
G296	XRF		Y	19		200	335		63
G297	XRF		Y	31		497	103		60
G298	XRF		Y	21		105	7		43
G299	XRF		Y	20		158	15		40
G300	ICP-AES and AAS		Y			186	304		59
G301	ICP-AES and AAS		Y			150	254		55
G302	ICP-AES and AAS		Y			175	194		56
G303	ICP-AES and AAS		Y			191	237		57
G304	ICP-AES and AAS		Y			186	209		57
G305	ICP-AES and AAS		Y			185	232		58
G306	ICP-AES and AAS		Y			183	216		58
G307	ICP-AES and AAS		Y			173	383		61
G308	ICP-AES and AAS		Y			161	221		54
G309	ICP-AES and AAS		Y			182	227		54
G310	ICP-AES and AAS		Y			208	260		63
G311	ICP-AES and AAS		Y			186	564		56
G312	ICP-AES and AAS		Y			188	178		55
G313	ICP-AES and AAS		Y			186	194		59
G314	ICP-AES and AAS		Y			174	283		51
G315	ICP-AES and AAS		Y			193	252		53
G316	ICP-AES and AAS		Y			197	36		43
G317	ICP-AES and AAS		Y			217	89		46

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G263	198	12	121	19	36	332	20	134	6	
G264	59	21	78	18	52	681	23	157	7	
G265	42	23	66	18	75	713	22	147	7	
G266	68	5	75	18	36	618	21	151	7	
G267	159	49	130		24	983	20	243	75	
G268	157	54	125		24	924	15	214	63	
G269	196	52	102		24	658	15	160	46	
G270	168	65	113		21	803	19	197	60	
G271	184	66	96		27	663	18	194	44	
G272	386	58	79		13	802	11	178	40	
G273	91	48	106		12	498	12	125	18	
G274	23	88	140		20	458	33	237	44	
G275	114	53	97		14	563	18	140	22	
G276	200	71	100		13	349	26	129	19	
G277	160	56	98		21	791	20	246	46	
G278	86	48	90		11	508	16	156	29	
G279	199	60	98		20	456	15	121	24	
G280	263	76	106		14	556	9	149	26	
G281	264	79	108		11	499	18	157	20	
G282	58	60	91		10	450	9	125	12	
G283	56	65	91		8	443	19	135	2	
G284	102	67	91		18	489	16	133	24	
G285	106	40	92		17	477	16	124	18	
G286	194	62	95		19	480	16	137	28	
G287	161	63	140		13	1213	27	288	88	
G288	161	61	144		7	1133	23	297	88	
G289	163	57	145		25		19	306	86	
G290	253	74	106		21	616	15	161	39	
G291	253	74	106		19	608	24	157	37	
G292	261	73	103		19	620	17	161	37	
G293	364	64	117		2	952	14	202	74	
G294	300	56	112		13	1203	23	209	79	
G295	250	73	144		27	1092	25	288	85	
G296	234	62	135		11	1066	15	254	92	
G297	88	49				648	11	49	121	
G298	8	32				346	31	309	63	
G299	8	24				531	34	277	50	
G300	246	193	112		14	763	19			
G301	217	44	100		21	1121	19			
G302	148	44	130		19	1129	21			
G303	155	48	113		15	922	23			
G304	158	52	128		27	1835	25			
G305	159	42	125		22	1685	23			
G306	168	41	122		24	1698	23			
G307	266	40	129		22	1425	22			
G308	164	40	104		24	1492	22			
G309	169	49	123		25	1765	25			
G310	213	58	126		12	1450	23			
G311	190	46	134		21	1754	26			
G312	153	44	125			1274	21			
G313	147	53	113			913	19			
G314	208	35	100			1400	20			
G315	158	40	104			1632	22			
G316	25	34	117		15	1264	24			
G317	24	45	124		16	1424	26			

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G263	532										
G264	776										
G265	945										
G266	576										
G267	385	41	77								
G268	381	34	59								
G269	319	24	61								
G270	381	30	67								
G271	315	24	55								
G272	278	16	40								
G273	229		45								
G274	325	18	60								
G275	242	14	49								
G276	226	8	48								
G277	389	32	68								
G278	230	15	48								
G279	561		35								
G280	401	13	33								
G281	221	7	45								
G282	138		25								
G283	156		29								
G284	235		42								
G285	252	10	44								
G286	237	15	47								
G287	543	38	84								
G288	530	44	94								
G289	544	38	96								
G290	314	6	42								
G291	595	20	54								
G292	350	25	55								
G293	474	39	94								
G294	476	46	82								
G295	487	47	88								
G296	472	51	95								
G297	796										
G298	371										
G299	503										
G300	350	30	59				1.6				
G301	595	58	105				2.2				
G302	485	53	100				2.5				
G303	355	42	80				2.1				
G304	880	112	185				3.6				
G305	820	93	154				3.1				
G306	920	95	155				3.2				
G307	735	78	131				2.7				
G308	720	84	140				2.8				
G309	839	108	174				3.4				
G310	589	66	118				2.8				
G311	809	111	178				3.5				
G312	565	56	107				3.3				
G313	350	39	74				2.4				
G314	750	72	128				2.7				
G315	820	86	150				3.2				
G316	512	60	107				2.4				
G317	562	65	118				2.8				

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G263			2.57				35			Jarrar et al. 1992
G264			2.57				11			Jarrar et al. 1992
G265			2.47				10			Jarrar et al. 1992
G266			2.37				14			Jarrar et al. 1992
G267							14	4		Saffarini et al. 1987
G268							8			Saffarini et al. 1987
G269							9	5		Saffarini et al. 1987
G270							14			Saffarini et al. 1987
G271							19			Saffarini et al. 1987
G272							14	1		Saffarini et al. 1987
G273							13			Saffarini et al. 1987
G274							25	1		Saffarini et al. 1987
G275							15			Saffarini et al. 1987
G276							28			Saffarini et al. 1987
G277							24			Saffarini et al. 1987
G278							8			Saffarini et al. 1987
G279							20	6		Saffarini et al. 1987
G280							15			Saffarini et al. 1987
G281							19			Saffarini et al. 1987
G282							16			Saffarini et al. 1987
G283							8	3		Saffarini et al. 1987
G284							7	9		Saffarini et al. 1987
G285							13	8		Saffarini et al. 1987
G286							15			Saffarini et al. 1987
G287							10			Saffarini et al. 1987
G288							11	2		Saffarini et al. 1987
G289							13			Saffarini et al. 1987
G290							13			Saffarini et al. 1987
G291							18			Saffarini et al. 1987
G292							13	1		Saffarini et al. 1987
G293							15	5		Saffarini et al. 1987
G294							9	9		Saffarini et al. 1987
G295							18			Saffarini et al. 1987
G296							15			Saffarini et al. 1987
G297										Shawabekeh 1998
G298							5			Shawabekeh 1998
G299							5			Shawabekeh 1998
G300										Weinstein et al. 1994
G301										Weinstein et al. 1994
G302										Weinstein et al. 1994
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G313										Weinstein et al. 1994
G314										Weinstein et al. 1994
G315										Weinstein et al. 1994
G316										Weinstein et al. 1994
G317										Weinstein et al. 1994

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G318	ICP-AES and AAS		Y			239	86		47
G319	ICP-AES and AAS		Y			179	151		54
G320	ICP-AES and AAS		Y			180	323		58
G321	ICP-AES and AAS		Y			176	189		54
G322	ICP-AES and AAS		Y			187	205		57
G323	ICP-AES and AAS		Y			192	364		67
G324	ICP-AES and AAS		Y			179	167		54
G325	ICP-AES and AAS		Y			184	126		57
G326	ICP-AES and AAS		Y			159	106		51
G327	ICP-AES and AAS		Y			179	213		46
G328	ICP-AES and AAS		Y			196	231		50
G329	ICP-AES and AAS		Y			212	238		56
G330	ICP-AES and AAS		Y			210	128		49
G331	ICP-AES and AAS		Y			199	141		47
G332	ICP-AES and AAS		Y			189	109		44
G333	ICP-AES and AAS		Y			230	147		50
G334	ICP-AES and AAS		Y			227	110		47
G335	ICP-AES and AAS		Y			209	49		43
G336	ICP-AES and AAS		Y			217	246		54
G337	ICP-AES and AAS		Y			238	221		88
G338	ICP-AES		Y				217		50
G339	ICP-AES		Y				253		47
G340	ICP-AES		Y				167		39
G341	ICP-AES		Y				236		46
G342	ICP-AES		Y				201		52
G343	ICP-AES		Y				233		47
G344	ICP-AES		Y				192		45
G345	ICP-AES		Y				172		30
G346	ICP-AES		Y				210		48
G347	ICP-AES		Y				239		40
G348	ICP-AES		Y				173		59
G349	ICP-AES		Y				170		65
G350	ICP-AES		Y				166		54
G351	ICP-AES		Y				148		79
G352	ICP-AES		Y				164		63
G353	ICP-AES		Y				164		33
G354	ICP-AES		Y				147		34
G355	ICP-AES		Y				152		62
G356	ICP-AES		Y				187		54
G357	ICP-AES		Y				192		38
G358	ICP-AES		Y						
G359	ICP-AES		Y						
G360	Not reported		Y	20.8		191.6	216.3		38.8
G361	Not reported		Y	22.6		207.2	255.6		38.1
G362	NAA		Y	17.5			161		49
G363	NAA		Y	17.2			142		50.5
G364	NAA		Y	17			242		51.1
G365	ICP-OES	Average	Y	20		325	81		
G366	ICP-OES	Average	Y	20		370	49		
G367	ICP-OES	Average	Y	18		362	33		
G368	ICP-OES	Average	Y	21		424	51		
G369	ICP-OES	Average	Y	20		281	50		
G370	ICP-OES	Average	Y	13		249	15		

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G318	40	48	136		18	1460	29			
G319	117	67	140		28	1780	25			
G320	254	53	124		21	1481	21			
G321	155	44	120		25	1791	24			
G322	158	50	126		27	1831	25			
G323	165	45	106			1260	20			
G324	120	41	122			1178	21			
G325	102	38	131			1350	22			
G326	96	40	120			1311	21			
G327	115	52	107		16	1116	23			
G328	111	71	127		21	1173	24			
G329	100	60	139		21	1437	28			
G330	80	53	120		19	1501	26			
G331	90	55	117		15	1569	24			
G332	100	57	109		16	1422	26			
G333	96	50	104			873	23			
G334	58	47	103			877	24			
G335	42	42			9	1222	25			
G336	93	53	115			1090	23			
G337	123	51	145			1166	27			
G338	185	46			26	1090	28	265	65	
G339	210	39			22	960	27	247	53	
G340	161	72			30	1048	26	265	68	
G341	220	40			29	1064	28	258	64	
G342	180	61			26	1010	27	249	58	
G343	201	41			24	1015	25	251	61	
G344	215	58			30	1120	27	260	62	
G345	175	63			29	1083	24	260	62	
G346	330	46			27	1084	26	253	59	
G347	220	32			25	1010	27	248	58	
G348	341	76			20	1040	26	224	36	
G349	215	52			18	993	25	215	43	
G350	216	48			20	973	26	218	39	
G351	206	39			19	957	25	212	46	
G352	196	48			17	970	27	214	39	
G353	195	67			20	960	25	210	47	
G354	194	57			21	990	26	209	45	
G355	193	59			19	946	26	208	34	
G356	189	45			17	816	26	204	42	
G357	197	41			16	785	25	196	34	
G358										
G359										
G360	215.1	64.5	88.4		12.3	560.5	19.1	118.2	25.4	
G361	207.3	72.2	100.8		16.6	748.3	19.4	170.2	47.8	
G362					26.2	1000		218		0.529
G363					20	1100		208		0.339
G364					15.2	896		220		0.297
G365	52				35	556	25	112	35	
G366	46				33	477	30	159	40	
G367	60				35	526	26	132	41	
G368	34				43	525	29	168	48	
G369	26				60	637	30	260	31	
G370	33				71	381	23	177	28	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G318	719	73	124				3.4				
G319	910	107	180				3.6				
G320	710	69	119				2.6				
G321	835	107	178				3.6				
G322	860	111	182				3.6				
G323	555	61	111				3				
G324	525	59	109				3.2				
G325	605	63	118				3.6				
G326	575	61	113				3.4				
G327	500	55	101				2.4				
G328	605	60	110				2.6				
G329	790	76	133				3.2				
G330	710	75	135				3.2				
G331	675	63	114				2.7				
G332	723	66	114				2.7				
G333	410	43	79				2.2				
G334	365	43	79				2.1				
G335	615	62	113				4				
G336	515	58	103				2.5				
G337	725	63	109				2.8				
G338	410										
G339	350										
G340	442										
G341	521										
G342	518										
G343	379										
G344	425										
G345	480										
G346	512										
G347	420										
G348	300										
G349	296										
G350	296										
G351	286										
G352	288										
G353	298										
G354	290										
G355	289										
G356	272										
G357	260										
G358		43	100	10		12	2.8			7	
G359		32	84	8		5.9	2.3			8	
G360	348.5	35.7	40								
G361	282.2	46	61.5								
G362	402	40.1	74.5		37.6	7.66	2.7	7.1	0.94	5.25	
G363	377	40.7	78.4		35.7	7.8	2.76	8.3	1.01	5.06	
G364	350	32.8	64.5		32.4	6.87	2.32	6.7	0.83	4.15	
G365	398	16									
G366	465	23									
G367	468	18									
G368	399	22									
G369	592	36									
G370	470	20									

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G318										Weinstein et al. 1994
G319										Weinstein et al. 1994
G320										Weinstein et al. 1994
G321										Weinstein et al. 1994
G322										Weinstein et al. 1994
G323										Weinstein et al. 1994
G324										Weinstein et al. 1994
G325										Weinstein et al. 1994
G326										Weinstein et al. 1994
G327										Weinstein et al. 1994
G328										Weinstein et al. 1994
G329										Weinstein et al. 1994
G330										Weinstein et al. 1994
G331										Weinstein et al. 1994
G332										Weinstein et al. 1994
G333										Weinstein et al. 1994
G334										Weinstein et al. 1994
G335										Weinstein et al. 1994
G336										Weinstein et al. 1994
G337										Weinstein et al. 1994
G338										Al-Malabeh 1994
G339										Al-Malabeh 1994
G340										Al-Malabeh 1994
G341										Al-Malabeh 1994
G342										Al-Malabeh 1994
G343										Al-Malabeh 1994
G344										Al-Malabeh 1994
G345										Al-Malabeh 1994
G346										Al-Malabeh 1994
G347										Al-Malabeh 1994
G348										Al-Malabeh 1994
G349										Al-Malabeh 1994
G350										Al-Malabeh 1994
G351										Al-Malabeh 1994
G352										Al-Malabeh 1994
G353										Al-Malabeh 1994
G354										Al-Malabeh 1994
G355										Al-Malabeh 1994
G356										Al-Malabeh 1994
G357										Al-Malabeh 1994
G358	4.3		2.1	0.15						Al-Malabeh 1994
G359	4.8		1.9	0.14						Al-Malabeh 1994
G360										Khalil 1992
G361										Khalil 1992
G362			1.47	0.187	4.81	4.17		4.68	1.18	Duffield et al. 1988
G363			1.37	0.155	5.07	4.26		4.66	0.99	Duffield et al. 1988
G364			1.32	0.171	4.3	3.54		3.66	0.9	Duffield et al. 1988
G365										Jarrar 2001
G366										Jarrar 2001
G367										Jarrar 2001
G368										Jarrar 2001
G369										Jarrar 2001
G370										Jarrar 2001

ID	Analysis	Notes	Use	Sc	Ti	V	Cr	Mn	Co
G371	ICP-OES		Y						
G372	ICP-OES		Y						
G373	ICP-OES		Y						
G374	XRF		Y			278	101		45
G375	XRF		Y			259	346		50
G376	XRF		Y			284	214		47
G377	XRF		Y			196	217		47
G378	XRF		Y			256	238		48
G379	XRF		Y			306	286		48
G380	XRF		Y			259	398		49
G381	XRF		Y			243	210		49
G382	XRF		Y			223	541		53
G383	XRF		Y			226	281		47
G384	XRF		Y			229	183		51
G385	XRF		Y			214	346		49
G386	XRF		Y			262	412		87
G387	XRF		Y			197	170		47
G388	XRF		Y			248	70		43
G389	XRF		Y			175	127		75
G390	XRF		Y			221	274		50
G391	XRF		Y			278	193		48
G392	XRF		Y			255	112		45
G393	XRF		Y	18		194	217		56
G394	XRF		Y	16		190	193		52
G395	XRF		Y	24		180	120		55
G396	XRF		Y	21		219	410		58
G397	XRF		Y	19		201	252		65
G398	XRF		Y	22		183	198		51
G399	XRF		Y	25		218	254		70

ID	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs
G371										
G372										
G373										
G374	28	49	107	24	13	827	28	235	49.5	
G375	226	34	109	22	19	664	24	203	31.2	
G376	73	60	104	22	10	816	28	195	39.2	
G377	69	58	103	25	10	424	25	154	20	
G378	108	57	117	22	14	825	27	174	27.3	
G379	83	65	102	31	10	643	32	177	31.3	
G380	75	56	102	25	12	819	28	204	32.8	
G381	174	58	111	23	8	411	25	153	17.9	
G382	415	59	113	17	11	676	24	160	30.7	
G383	142	64	97	21	11	422	25	159	22	
G384	114	41	113	19	32	1367	31	336	85.8	
G385	158	50	113	21	19	1087	27	249	66.1	
G386	177	49	106	20	8	497	23	161	27.6	
G387	89	59	116	23	22	1872	25	285	61.6	
G388	34	42	106	19	16	1504	27	234	52.2	
G389	125	50	125	24	21	1187	24	272	57.5	
G390	231	61	111	22	12	872	24	177	30.5	
G391	92	33	117	26	17	1090	32	255	47.4	
G392	100	47	115	21	19	1759	23	270	65.8	
G393	222	51	116		20	900	18	223	58	
G394	188	66	111		11	630	18	151	45	
G395	70	58	136		10	424	14	148	29	
G396	290	61	120		23	1153	19	264	86	
G397	208	64	121		9	564	14	164	38	
G398	178	58	92		12	498	15	160	24	
G399	204	73	118		15	794	20	226	36	

ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
G371		12.33	30.86		19.6	6.13	1.87	3.93		4.87	
G372		27.6	63.43		37.8	11.53	3.47	8.73		7.8	
G373		16.9	39.7		23.1	6.6	2.2	4.8		4.2	
G374	532										
G375	835										
G376	816										
G377	719										
G378	428										
G379	922										
G380	815										
G381	427										
G382	834										
G383	368										
G384	1569										
G385	439										
G386	667										
G387	800										
G388	1055										
G389	846										
G390	665										
G391	1142										
G392	1425										
G393	360	37	70								
G394	298	15	35								
G395	184	12	26								
G396	489	36	91								
G397	222	18	30								
G398	232	16	33								
G399	333	19	59								

ID	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U	Analed by?
G371	2.6	0.27	2.53	0.4						Jarrar 2001
G372	3.87	0.47	3.2	0.47						Jarrar 2001
G373	1.9	0.3	1.7	0.4						Jarrar 2001
G374							4	4	3	W-T and Thorpe 1993
G375							5	4	3	W-T and Thorpe 1993
G376							5	4	3	W-T and Thorpe 1993
G377							4	3	3	W-T and Thorpe 1993
G378							4	3	3	W-T and Thorpe 1993
G379							4	3	3	W-T and Thorpe 1993
G380							5	3	3	W-T and Thorpe 1993
G381							4	3	3	W-T and Thorpe 1993
G382							6	3	3	W-T and Thorpe 1993
G383							3	3	3	W-T and Thorpe 1993
G384							5	6	4	W-T and Thorpe 1993
G385							7	5	3	W-T and Thorpe 1993
G386							4	3	3	W-T and Thorpe 1993
G387							4	4	4	W-T and Thorpe 1993
G388							6	3	3	W-T and Thorpe 1993
G389							7	3	3	W-T and Thorpe 1993
G390							5	3	3	W-T and Thorpe 1993
G391							7	6	3	W-T and Thorpe 1993
G392							4	4	3	W-T and Thorpe 1993
G393										Nasir 1990
G394										Nasir 1990
G395										Nasir 1990
G396										Nasir 1990
G397										Nasir 1990
G398										Nasir 1990
G399										Nasir 1990

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"Of making many books there is no end,
and much study wearies the body."
Ecclesiastes 12:12b (NIV)

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