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The Element Composition of Soils from Archaeological Landscapes in Boeotia, Greece

**A critical evaluation of element soil analysis in the investigation of archaeological
landscapes co-ordinated with the archaeological survey of Boeotia, Greece**

Two volumes

Volume One

Jonathan Neil RIMMINGTON

**submitted for the degree
of Doctor of Philosophy**

**University of Durham
Department of Archaeology**

1998

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17 JAN 2000

The Element Composition of Soils from Archaeological Landscapes in Boeotia, Greece

Jonathan Neil Rimmington

Soils collected from the archaeological landscape of Boeotia, Greece were analysed for their element composition using the NERC ICP-AES facility at the Royal Holloway and Bedford New College. The aim of the thesis was to establish whether element analysis could be used to indicate the nature and intensity of past human activity, in particular manuring which was the suggested cause of the ubiquitous spread of sherds across the landscape. The thesis built upon earlier studies in Boeotia which had highlighted lead, copper and zinc as possible indicators. This thesis confirmed that lead and zinc were good indicators at the site level, and also highlighted potassium, phosphorus, manganese and barium as good indicators at the site level. Barium proved to be the best indicator being stable in the soil environment and showing a clear relationship to the size of the settlement site. This thesis did not establish an element signal which reflected the intensity of sherds in the non-settlement manured landscape. The dilution of certain elements in the soil environment was as important as an increase in concentration. This was due to the addition of organic material divorcing the surface soil composition from the influence of the underlying geology. Multi-element analysis was useful in highlighting groups of elements which was particularly of use in discerning anomalies caused by the underlying geology. Sequential analysis of a selected group of samples was used to highlight whether any portion of the soil particularly influenced the changes in concentration due to human activity. Future work should concentrate on improved modelling and testing of models on historical, ethnoarchaeological and reconstructed archaeological settlements.

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CONTENTS

Chapter	Page Number
Table of contents	i
Table of figures	vi
Table of tables	xiii
Table of overlays	xix
 Chapter 1 Introduction	 1
1.1 The aim of the project	1
1.2 Introduction	1
1.3 The Boeotia survey	4
1.3.1 The archaeological survey	4
1.3.2 The climate, soils and soil erosion of the survey area	5
1.3.3 The geology of the survey area	6
1.3.4 Modern land-use of the survey area	8
 Chapter 2 Soil Chemical Analysis and Archaeological Investigation	 11
2.1 Introduction	11
2.2 Soil phosphate analysis in archaeology	12
2.2.1 Introduction	12
2.2.2 Sources of archaeological soil phosphate anomaly	13
2.2.3 Retention of phosphate in soil	14
2.2.4 Methodology of analysis	17
2.2.5 Statistical analysis of data	19
2.2.6 Phosphate analysis and complementary techniques	20
2.3 Other elemental chemical analyses of the soil	21
2.3.1 Introduction	21
2.3.2 Development of soil elemental analysis	21
2.4 Conclusion	26
 Chapter 3 Element soil analysis in Boeotia, Greece	 28
3.1 Introduction	28
3.2 Regional level sampling as a means of establishing a base level	30
3.3 Regional transects and the influences of modern and archaeological human activity	33
3.4 Sites	35
3.4.1 Major sites	35
3.4.1.1 Thespieae city	35
3.4.1.2 Hyettos plain	37
3.4.2 Minor sites	38
3.4.2.1 PP17	38
3.4.2.2 PP27	40

3.4.2.3 TPW2	41
3.4.2.4 TPW11	42
3.4.2.5 VM64	43
3.4.2.6 VM89	45
3.4.2.7 VM95	46
3.4.2.8 P4	47
3.5 Conclusions	48
Chapter 4 Retention of Trace Elements in Soils	50
4.1 Introduction	50
4.2 Soil properties and trace element retention	50
4.2.1 Soil colloids	51
4.2.1.1 Inorganic soil colloids	51
4.2.1.2 Organic soil colloids	53
4.2.2 The hydrogen potential (pH)	55
4.2.3 The reduction-oxidation potential (Eh)	55
4.3 Element retention in soil	56
4.4 Conclusion	58
Chapter 5 Field Survey and Greek Archaeology	59
5.1 Introduction	59
5.2 The origin of artefacts in the landscape	59
5.3 Survey methodology and site location	63
5.4 Site dating and interpretation of function	67
5.5 The pattern of settlement in Greece	68
5.6 Conclusion	70
Chapter 6 Classical Greek Agriculture	72
6.1 Introduction	72
6.2 Where did the farming community live?	73
6.3 The pattern of land-holding	75
6.4 Crops and cultivation strategies	76
6.5 Animals and animal husbandry	81
6.6 Conclusion	82
Chapter 7 Modelling Changes in Soil Elemental Composition Due to Human Activity	84
7.1 Introduction	84
7.2 The baseline	84
7.3 The inputs and outputs of archaeological human activities	85
7.4 Stability of Change	89
7.5 Model	90
7.6 Conclusion	91
Chapter 8 Sampling	93
8.1 Introduction	93
8.2 Archaeological site selection	93

8.3 Soil sampling.....	94
8.3.1 Surface soil sampling	94
8.3.2 Soil profile sampling	95
8.4 Rock and human occupation debris sampling.....	95
8.5 Storage	96
 Chapter 9 Element Analysis.....	97
9.1 Introduction	97
9.2 The ICP-AES	98
9.3 General sample preparation	99
9.4 Pseudo-total analysis.....	100
9.4.1 Introduction.....	100
9.4.2 Sample preparation	101
9.4.3 Sample analysis.....	102
9.4.4 Data quality	102
9.4.4.1 Detection limits	103
9.4.4.2 Analytical reproducibility	104
9.4.4.3 Instrument reproducibility.....	105
9.4.4.4 Internal standards	106
9.4.4.5 Reference materials	106
9.4.4.6 Variability due to sieving.....	107
9.4.4.7 Comparison with previously observed soil values	107
9.4.5 Summary	108
9.5 Sequential extraction of selected soil samples	108
9.5.1 Introduction.....	108
9.5.2 Methodology	109
9.5.3 Sample analysis.....	110
9.5.4 Data quality	110
9.5.5 Summary	111
 Chapter 10 Resistivity Survey	112
10.1 Introduction	112
10.2 Methodology.....	113
 Chapter 11 Complementary Soil Analyses	114
11.1 Introduction	114
11.2 Soil colour	115
11.2.1 Introduction.....	115
11.2.2 Method.....	115
11.3 Particle size analysis	116
11.3.1 introduction.....	116
11.4 Organic matter content.....	117
11.4.1 Introduction.....	117
11.4.2 Method.....	118
 Chapter 12 Results for Environmental Samples.....	119
12.1 Introduction	119
12.2 Geological samples	119

12.3 Archaeological samples	120
12.3.1 Boeotian artefacts	121
12.3.2 Castell Henllys samples	121
12.3.3 Tow Law samples	122
12.4 Modern interference	123
12.5 Summary	124
 Chapter 13 Control Areas	126
13.1 Introduction	126
13.2 Control area one	127
13.3 Control area two	130
13.4 Conclusions	132
 Chapter 14 Hyettos: A City State	133
14.1 Introduction	133
14.2 The trace element survey	134
14.3 The 1994 surface soil survey	135
14.4 The 1995 surface soil survey	137
14.5 The soil pit survey	139
14.6 Sequential extraction of Hyettos samples	140
14.7 Summary	141
 Chapter 15 Village Sites	144
15.1 Introduction	
15.2 Askra	
15.2.1 History of Askra	
15.2.2 Soil survey of Askra	
15.2.3 Results of 1994 surface soil survey	
15.2.4 Results of 1995 surface soil survey	
15.2.5 Results of 1995 soil pit sampling	
15.2.6 Summary	
15.3 VM4	
15.3.1 History of VM4	
15.3.2 Surveys of VM4	
15.3.3 Results of the surface soil sampling	
15.3.4 Summary	
15.4 Rhadon	
15.4.1 History of Rhadon	
15.4.2 Surface soil survey of Rhadon	
15.4.3 Results of surface soil sampling	
15.4.4 Summary	
 Chapter 16 Farm sites	
16.1 Introduction	
16.2 VM70	
16.2.1 Introduction	
16.2.2 Soil survey	
16.2.2.1 Surface soil survey of 1994	

16.2.2.2 Comparison of values from the 1994 and 1995 surface soil surveys.....	
16.2.2.3 Surface soil survey of 1995	
16.2.2.4 Soil pit survey	
16.2.2.5 Sequential extraction of soil pits one, two and three.....	
16.2.2.6 Summary.....	
16.3 CN11.....	
16.3.1 Introduction.....	
16.3.2 The soil survey	
16.3.3 Summary	
16.4 VM87.....	
16.4.1 Introduction.....	
16.4.2 Surface soil survey	
16.4.3 Summary	
Chapter 17 Discussion of Results.....	
17.1 Introduction	
17.2 Physical characteristics	
17.3 Element characteristics.....	
17.4 Comparison to previous studies	
17.5 Comparison to model	
17.6 Summary.....	
Chapter 18 Conclusion and Directions for Future Work	
References.....	
Appendices.....	A1
Appendix 1 Environmental samples.....	A1
Appendix 2 Control area samples.....	A2
Appendix 3 Hyettos city samples.....	A3
Appendix 4 Village samples	A4
Appendix 5 Farmstead samples	A5

TABLE OF FIGURES

Figure Number and Description	Volume, Page Number
1.1 Plot of soil lead against age of garden.....	2, 1
1.2 Location map of Boeotia and the survey areas	2, 2
1.3 a - f Sites in the survey area of south-west Boeotia	2, 3-5
1.4 Geology of the south-west Boeotia survey area	2, 7
1.5 Geology of the Hyettos survey area, including Rhadon.....	2, 9
2.1 Relationship between solution pH and the relative concentration of three soluble forms of phosphate	2, 10
2.2 Inorganic fixation of added phosphates at various pH values	2, 10
2.3 Plot of intensity of soil enrichment (total phosphate) over time (fraction II/I)	2, 12
2.4 Field VII at Butser Ancient Farm Site.....	2, 12
2.5 Histogram plot showing the variation in the concentration of 5 β -stanols across field VII at Butser Ancient Farm Site and control samples	2, 13
2.6 Histogram plots showing the relative concentrations of Al, Ca, Fe, Mn, P and K across field VII at Butser Ancient Farm Site and the control samples	2, 13
3.1 The Thespieae survey area showing the relationship between surface sherd density and the two transect soil surveys of the Thespieae region	2, 14
3.2 Thespieae transect 1	2, 16
3.3 Thespieae transect 2	2, 17
3.4 Thespieae transects 3 and 4	2, 18
3.5 a - e Comparison of Thespieae transect 1 values (2) and corresponding sample points on the Waters transects (1).....	2, 19
3.6 a - e Comparison of Thespieae transect 2 values (2) and corresponding sample points on the Waters transects (1).....	2, 21
3.7 Relationship of the two Thespieae surveys to the position of the Late Roman defensive wall	2, 23
3.8 a - c Surface soil lead, copper and zinc concentrations for the survey of Thespieae.....	2, 24
3.9 a - c Comparison of lead, copper and zinc values from the Chapman (2) and Waters (1) survey of Thespieae city.	2, 26

3.10 Hyettos Plain sherd densities and transect survey of Hyettos	2, 27
3.11 Line graph showing the soil concentration of elements with distance from the city	2, 28
3.12 Relationship of survey grids at PP17	2, 30
3.13 Interpretation of soil resistance features, tile and pottery sherd densities	2, 31
3.14 a - f Surface soil lead, copper, zinc, nickel, manganese and magnesium concentration at PP17	2, 33
3.15 Relationship of survey grids at PP27	2, 37
3.16 a Greyscale plot of twin-probe soil resistance data for PP27	2, 38
3.16 b Interpretation of twin-probe soil resistance data for PP27	2, 38
3.17 Surface soil tile distribution at PP27	2, 39
3.18 Surface soil sherd distribution at PP27	2, 39
3.19 a - c Contour plot of surface soil lead, copper and zinc concentrations at PP27	2, 41
3.20 Surface soil (a) tile (b) magnetic susceptibility and (c) magnetic viscosity surveys at TPW2	2, 43
3.21 Surface soil (a) lead and (b) copper concentrations at TPW2	2, 44
3.22 TPW11, showing the relationship between survey grids	2, 46
3.23 Visibility corrected surface sherd densities at TPW11	2, 47
3.24 The surface soil (a) magnetic susceptibility, (b) magnetic viscosity and (c) tile surveys of TPW11	2, 48
3.25 Surface soil tile densities at TPW11	2, 50
3.26 a - c Surface soil lead, copper and zinc concentration at TPW11	2, 51
3.27 Survey grid and transects at VM64	2, 54
3.28 Surface soil (a) tile, (b) magnetic susceptibility and (c) magnetic viscosity surveys at VM64	2, 55
3.29 Surface soil (a) lead and (b) copper concentration surveys at VM64	2, 56
3.30 Surface soil magnetic susceptibility and magnetic viscosity for the transect surveys at VM64	2, 57
3.31 a Surface soil lead and copper concentrations for east - west transect A	2, 58
3.31 b Surface soil lead and copper concentrations for east - west transect B	2, 58
3.32 a Surface soil lead and copper concentrations for north - south transect A	2, 59
3.32 b Surface soil lead and copper concentrations for north - south transect B	2, 59
3.33 Surface soil (a) magnetic susceptibility, (b) magnetic viscosity and (c) tile surveys at VM89	2, 61
3.34 Surface soil (a) copper and (b) lead concentration at VM89	2, 62

3.35 Surface soil (a) magnetic susceptibility, (b) magnetic viscosity, (c) tile, (d) lead and (e) copper at VM95.....	2, 64
3.36 Relationship between visibility corrected sherd densities and soil survey grid at P4....	2, 65
3.37 Surface soil magnetic susceptibility at P4	2, 67
3.38 a - c Surface soil lead, copper and zinc concentration at P4.....	2, 68
5.1 Typical Boeotian surface sherd density plot showing the decreasing density of sherds with distance away from sites	2, 71
5.2 a The influence of topography on the expression of sherd concentration	2, 72
5.2 b The influence of an obstacle on the expression of sherd concentration.....	2, 72
5.3 Surface sherd densities surrounding sites in Kurban Höyük, Turkey.....	2, 73
5.4 Site P4 and surrounding field transects showing raw counts (A) and visibility corrected counts (B)	2, 75
5.5 Comparison of results from repeating survey in part of the Biferno valley	2, 76
5.6 Histogram plot of date ranges for offsite diagnostic sherds collected from the Leondari south-east transects	2, 78
6.1 Country house near the Cave of Pan at Vari	2, 79
6.2 Small country house near Vari	2, 80
6.3 Classical country house PH76.....	2, 81
6.4 Interpreted plan of PP17 from a soil resistivity survey	2, 82
6.5 Interpretation of soil resistivity survey results at VM70 showing a (A) house, (B) high resistance features, (C) field-wall and (D) ditches	2, 83
6.6 House D at Halieis showing press room and kopron.....	2, 84
6.7 Threshing floor	2, 85
6.8 Reconstruction of a Greek oil-mill, <i>trapetum</i>	2, 86
6.9 Simple lever-press shown on a fragment of Classical pottery.....	2, 86
7.1 Simple model of element pathways in an infield / outfield subsistence farmstead.....	2, 93
8.1 Surface soil sampling at a sample point	2, 97
9.1 Inductively coupled plasma	2, 98
9.2 Sequential extraction scheme.....	2, 106

10.1 Twin-probe array resistivity meter	2, 116
10.2 Zig-zag sampling strategy for resistivity survey	2, 116
11.1 Munsell soil colour notation for a dull yellow orange soil	1, 115
12.1 Sampling strategy of the Earthwatch hut at Castell Henllys Iron Age reconstruction settlement.....	2, 120
12.2 Comparison of the element composition of fire surface and fire sub-surface samples.....	2, 121
12.3 Comparison of the indoor and outdoor surface soil concentrations from the Earthwatch hut at Castell Henllys, Wales	2, 122
12.4 a - u Element concentrations of soil samples from two transects progressing away from a road	2, 126
13.1 Relationship between surface sherd density and control area 1	2, 133
13.2 Contour plot showing the percentage of the soil below the particle size 212 μ m at control area 1	2, 134
13.3 a - ζ Contour plots of surface soil element concentrations at control area 1 and plots of surface soil element concentrations and cumulative frequency (%) for control area 1	2, 139
13.4 Relationship between surface sherd density and control area 2	2, 155
13.5 Contour plot showing the percentage of the soil below the particle size 212 μ m at control area 2.....	2, 156
13.6 a - δ Contour plots of surface soil element concentrations at control area 2 and plots of surface soil element concentrations and cumulative frequency (%) for control area 2.....	2, 161
14.1 Relationship between surveys at Hyettos city	2, 176
14.2 Map of the total counts of sherds across Hyettos city, corrected for differential visibility conditions	2, 177
14.3 Contour plot showing the percentage particle size below 212 μ m for surface soil samples of the 1994 Hyettos survey.....	2, 178
14.4 a - δ Contour plots of surface soil element concentrations for the 1994 survey of Hyettos and plots of the cumulative frequency (%) for the element concentrations of 1994 surface soil samples from Hyettos.....	2, 183

14.5 Relationship between surface soil sherd density and percentage particle size below 212 µm for 1995 samples from Hyettos city	2, 198
14.6 a - g Combined bar chart and high-low line graph showing the relationship between sherd density and the range of soil concentrations of major elements for each of the four soil sampling grids of the 1995 survey.....	2, 203
14.7 a - g Plots showing the per cent cumulative frequency of major element concentrations from the 1995 samples of Hyettos.....	2, 206
14.8 a - n Combined bar chart and high-low line graph showing the relationship between sherd density and the range of soil concentrations of minor elements for each of the four soil sampling grids of the 1995 survey.....	2, 209
14.9 a - n Plots showing the per cent cumulative frequency of minor element concentrations from the 1995 samples of Hyettos.....	2, 214
14.10 a - r Bar chart plots of soil profile element concentration for the Hyettos city survey.....	2, 219
15.1 Relationship between the soil surveys, surface sherd densities and field boundaries at Askra.....	2, 227
15.2 Percentage particle size below 212 µm for the 1994 Askra transect survey samples .	2, 228
15.3 a - p Surface soil element concentration of samples from the 1994 Askra survey transect	2, 232
15.4 Relationship between sherd density and percentage particle size below 212 µm	2, 238
15.5 a - κ Relationship between surface soil sherd density and element concentration for the 1995 survey of Askra and plot of the cumulative frequency (%) of element concentration for the surface soil samples of the 1995 survey of Askra.....	2, 243
15.6 a - p Comparison of element concentration for grid one and four soil pit profiles of the 1995 Askra survey	2, 261
15.7 Relationship of surveys to surface features at VM4	2, 267
15.8 a Greyscale plot of twin-probe resistance data for site VM4.....	2, 268
15.8 b Interpretation of twin-probe resistance data for site VM4	2, 268
15.9 Contour plot showing the percentage particle size below 212 µm at VM4.....	2, 269
15.10 a - κ Contour plot of surface soil element concentration at VM4 and plot of the cumulative frequency (%) of element concentration for surface soil VM4 samples ...	2, 274
15.11 Relationship of the soil survey transects to surface features at Rhadon	2, 292
15.12 Contour plot showing the percentage particle size below 212 µm at Rhadon	2, 293

15.13 a - o Contour plot of surface soil element concentration at Rhadon and plot of the cumulative frequency (%) of element concentration for surface soil samples from Rhadon	2, 298
16.1 The relationship between surveys carried out prior to this thesis	2, 319
16.2 Relationship between the surveys at VM70, which were carried out as part of this thesis	2, 320
16.3 Contour plot showing the topography survey of VM70	2, 321
16.4 The relationship between visibility corrected sherd densities and topography	2, 322
16.5 Rubble distribution at VM70.....	2, 323
16.6 a Tile distribution at VM70.....	2, 324
16.6 b Magnetic susceptibility at VM70.....	2, 324
16.7 a Greyscale plot of twin-probe resistance data for site VM70.....	2, 325
16.7 b Interpretation of twin-probe resistance data for site VM70.....	2, 325
16.8 Contour plot showing the percentage particle size below 212 μm for the 1994 surface soil survey of VM70	2, 326
16.9 a - κ Contour plot of surface soil element concentration at VM4 for the 1994 soil survey and plot of the cumulative frequency (%) of element concentration of surface soil samples from the 1994 soil survey of VM70.....	2, 331
16.10 a - t Comparison of 1994 and 1995 results for surface soil element concentration ..	2, 350
16.11 Contour plot showing the percentage particle size below 212 μm for the 1995 surface soil sampling of VM70.....	2, 357
16.12 a - o Contour plot of surface soil element concentration at VM4 for the 1995 soil survey and plot of the cumulative frequency (%) for the element concentration of surface soil samples from the 1995 soil survey of VM70.....	2, 362
16.13 Soil pit 1	2, 383
16.14 Soil pit 2.....	2, 384
16.15 Soil pit 3.....	2, 385
16.16 Soil pit 4.....	2, 386
16.17 Soil pit 5.....	2, 387
16.18 Organic matter content of soil pit samples at VM70 using loss-on-ignition method	2, 388
16.19 Percentage of soil particle size below 212 μm for the soil pits at VM70.....	2, 389
16.20 a - r Element concentration of the soil pits at VM70.....	2, 390
16.21 a - e Calcium concentration in sequential extract samples from VM70 soil pits.....	2, 409

16.22 a - c Lanthanum concentration in sequential extract samples from VM70 soil pits . 2, 411	2, 411
16.23 a - c Strontium concentration in sequential extract samples from VM70 soil pits ... 2, 412	2, 412
16.24 Potassium concentration in extraction 7 samples from VM70 soil pits..... 2, 413	2, 413
16.25 a - c Lead concentration in sequential extract samples from VM70 soil pits..... 2, 414	2, 414
16.26 a - e Barium concentration in sequential extract samples from VM70 soil pits 2, 415	2, 415
16.27 a - d Aluminium concentration in sequential extract samples from VM70 soil pits . 2, 417	2, 417
16.28 a - d Iron concentration in sequential extract samples from VM70 soil pits..... 2, 419	2, 419
16.29 Scandium concentration in extraction 7 samples from VM70 soil pits..... 2, 421	2, 421
16.30 a - b Copper concentration in sequential extract samples from VM70 soil pits..... 2, 422	2, 422
16.31 a - d Vanadium concentration in sequential extract samples from VM70 soil pits... 2, 423	2, 423
16.32 a - b Zinc concentration in sequential extract samples from VM70 soil pits 2, 425	2, 425
16.33 a - c Cobalt concentration in sequential extract samples from VM70 soil pits 2, 426	2, 426
16.34 a - b Chromium concentration in sequential extract samples from VM70 soil pits.. 2, 427	2, 427
16.35 a - g Manganese concentration in sequential extract samples from VM70 soil pits . 2, 428	2, 428
16.36 a - f Nickel concentration in sequential extract samples from VM70 soil pits..... 2, 431	2, 431
16.37 a - c Phosphorus concentration in sequential extract samples from VM70 soil pits. 2, 433	2, 433
16.38 a - b Cerium concentration in sequential extract samples from VM70 soil pits..... 2, 434	2, 434
16.39 Relationship of surveys at CN11	2, 435
16.40 a Greyscale plot of twin-probe resistance data for site CN11.....	2, 436
16.40 b Interpretation of twin-probe resistance data for site CN11	2, 436
16.41 Visibility corrected ceramic count for CN11	2, 437
16.42 Visibility corrected tile count for CN11	2, 437
16.43 Contour plot showing the percentage particle size below 212 μm at site CN11	2, 438
16.44 a - β Contour plot of surface soil element concentration at site CN11 and plot of surface soil aluminium concentration and cumulative frequency for CN11.....	2, 443
16.45 Relationship of surveys at VM87.....	2, 457
16.46 Visibility corrected sherd densities at VM87	2, 458
16.47 Contour plot showing the percentage particle size below 212 μm at VM87.....	2, 459
16.48 a - x Contour plot of surface soil element concentration at VM87 and plot of the cumulative frequency for element concentration of surface soil samples from VM87.....	2, 464
17.1 Comparison of lead and calcium for samples collected in 1995.....	2, 478
17.2 Possible influence of manuring on the element concentration of a soil developed over a geology with alternating beds of material	2, 480

TABLE OF TABLES

Table number and Description Volume, Page Number

1.1 Geological key for figure 1.42, 6

1.2 Geological key for figure 1.52, 8

2.1 Correlation of inorganic soil phosphate fractionation percentages with various types of
land-use2, 11

3.1 Values obtained from regional surveys to date2, 15

3.2 Diagnostic sherd date ranges for PP17.....2, 29

3.3 Comparison of the Waters and the Davies and Terzis data sets for PP172, 32

3.4 Statistical data for the Davies and Terzis survey of PP17.....2, 32

3.5 Diagnostic sherd date ranges for PP27.....2, 36

3.6 Statistical data for PP27.....2, 40

3.7 Diagnostic sherd dates for TPW22, 42

3.8 Diagnostic sherd dates for TPW112, 45

3.9 Statistical data for TPW112, 49

3.10 Diagnostic sherd date ranges at VM64.....2, 53

3.11 Diagnostic sherd date ranges for VM892, 60

3.12 Diagnostic sherd date ranges at VM95.....2, 63

3.13 Statistical data for P4.....2, 66

4.1 Form and solubility of elements in oxidised and alkaline conditions similar to those
found in Greek soils2, 70

5.1 The approximate radius of significant field scatters surrounding archaeological sites in
the Middle East.....2, 74

5.2 Mean weight and area of sherds collected on the Camel Down field-walking
survey.....2, 74

5.3 Criteria for the categorisation of site function2, 77

7.1 Element composition of two rocks in Boeotia.....2, 87

7.2 Comparison of element concentrations in different types of wastes to the element composition of a Boeotian limestone	2, 88
7.3 Comparison of element concentrations in different types of wastes to the element composition of a Boeotian ultrabasic	2, 89
7.4 Comparison of element values for different types of manure.....	2, 90
7.5 Comparison of food types with parent materials for some major elements.....	2, 91
7.6 Annual production of wastes	2, 92
7.7 Hypothetical household B.....	2, 94
7.8 Composition of a soil on a limestone parent material before application of manure and at different time intervals afterwards.....	2, 95
7.9 Composition of a soil on a ultrabasic parent material before application of manure and at different time intervals afterwards.....	2, 96
9.1 Quality control data for samples collected in 1994	2, 99
9.2 Quality control data for samples collected in 1995	2, 100
9.3 Comparison of analytical reproducibility error and instrument reproducibility error	2, 101
9.4 Comparison of values obtained for samples analysed in both 1994 and 1995	2, 102
9.5 Comparison of reference values for certified reference materials used in analyses with those obtained through analysis with a nitric acid digestion procedure	2, 103
9.6 Sub-samples of a single sample to assess variability in result due to sieving in preparation	2, 104
9.7 Comparison of 1994 and 1995 data sets with quoted soil contents.....	2, 105
9.8 Element concentrations detectable in blank extraction samples	2, 107
9.9 Quality control data for extraction 1 (exchangeable cations) of sequential extraction	2, 108
9.10 Quality control data for extraction 2 (carbonate bound metals) of sequential extraction.....	2, 109
9.11 Quality control data for extraction 3 (fulvic fraction) of sequential extraction....	2, 110
9.12 Quality control data for extraction 4 (humic fraction) of sequential extraction ...	2, 111
9.13 Quality control data for extraction 5 (secondary manganese oxides) of sequential extraction.....	2, 112
9.14 Quality control data for extraction 6 (secondary iron oxides) of sequential extraction.....	2, 113
9.15 Quality control data for extraction 7 (pseudo-total) of sequential extraction.....	2, 114

9.16 Summary table of the extractions in which elements can be readily detected and are usable in the interpretations	2, 115
11.1 The British Standards Institution grain-size classification.....	2, 117
12.1 Average composition of five geological specimens from the Boeotia survey area compared with the average soil content of 1995 soil samples.....	2, 118
12.2 Average composition for three archaeological materials found on sites in Boeotia	2, 119
12.3 Comparison of element concentrations of surface and sub-surface soil samples from two sample points	2, 123
12.4 Comparison of element concentrations in samples collected from inside and outside the remains of a charcoal clamp and pottery kiln at Castell Henllys, Wales.....	2, 124
12.5 Comparison of element concentrations in midden samples from a rare breeds farm at Tow Law	2, 125
13.1 Statistical data for particle size analysis at control area 1	2, 134
13.2 Comparison of soil values from control area 1 and reproducibility error	2, 135
13.3 Statistical data for control area 1	2, 136
13.4 Correlation coefficients for elements from control area 1	2, 137
13.5 Table showing the estimated number and range of populations of each element for the samples from control area 1.....	2, 138
13.6 Statistical data for particle size analysis at control area 2.....	2, 156
13.7 Comparison of soil values from control area 2 and reproducibility error	2, 157
13.8 Statistical data for control area 2.....	2, 158
13.9 Correlation coefficients for elements from control area 2.....	2, 159
13.10 Table showing the estimated number and range of populations of each element for the samples from control area 2	2, 160
14.1 Statistical data for the percentage particle size below 212 μm for the 1994 surface soil survey of Hyettos city	2, 178
14.2 Comparison of values from the 1994 surface soil survey of Hyettos city and reproducibility error	2, 179
14.3 Statistical data for the 1994 surface soil survey of Hyettos.....	2, 180

14.4 Correlation coefficients for the 1994 surface soil sampling of Hyettos city	2, 181
14.5 Table showing the estimated number and range of populations for each element in the 1994 surface soil survey of Hyettos city	2, 182
14.6 Comparison of values from the 1995 surface soil survey of Hyettos city and reproducibility error	2, 199
14.7 Statistical data from the 1995 soil survey of Hyettos city	2, 200
14.8 Correlation coefficients for the 1995 surface soil sampling survey of Hyettos city	2, 201
14.9 Table showing the estimated number and range of populations of each element for the 1995 surface soil survey of Hyettos city	2, 202
14.10 Results for extractions 1 to 4 of the sequential extraction scheme	2, 225
14.11 Results for extractions 5 to 7 of the sequential extraction scheme	2, 226
15.1 General information for three village sites	1, 144
15.2 Comparison of values for the 1994 surface soil survey of Askra and reproducibility error	2, 229
15.3 Statistical data for the 1994 surface soil survey of Askra	2, 230
15.4 Correlation coefficients for the 1994 surface soil transect survey of Askra	2, 231
15.5 Comparison of values for the 1995 surface soil survey of Askra and reproducibility error	2, 239
15.6 Statistical data for the 1995 surface soil survey of Askra	2, 240
15.7 Correlation coefficients for the 1995 surface soil samples from Askra	2, 241
15.8 Estimated range and number of populations for elements in samples from the 1995 surface soil survey of Askra	2, 242
15.9 Statistical data for particle size at VM4	2, 269
15.10 Comparison of values for the surface soil survey of VM4 and reproducibility error	2, 270
15.11 Statistical data for the surface soil survey of VM4	2, 271
15.12 Correlation coefficients for the surface soil survey of VM4	2, 272
15.13 Estimated range and number of populations for elements in samples from the surface soil survey of VM4	2, 273
15.14 Statistical data for particle size at Rhadon	2, 293
15.15 Comparison of values for the surface soil survey of Rhadon and reproducibility error	2, 294
15.16 Statistical data for the surface soil survey of Rhadon	2, 295

15.17 Correlation coefficients for the surface soil survey of Rhadon	2, 296
15.18 Estimated range and number of populations for elements in samples from the surface soil survey of Rhadon.....	2, 297
16.1 Dates of diagnostic sherds collected from VM70.....	2, 318
16.2 Statistical data for percentage particle size below 212 μm of samples from the 1994 surface soil survey of VM70	2, 326
16.3 Comparison of values from the 1994 surface soil survey of site VM70 and reproducibility error	2, 327
16.4 Statistical data for the 1994 surface soil survey of site VM70	2, 328
16.5 Correlation coefficients for the 1994 surface soil survey of VM70	2, 329
16.6 Table showing the estimated range and number of populations for each element for the 1994 surface soil survey of VM70	2, 330
16.7 Comparison of element values obtained from samples collected from the same sample points in both the 1994 and 1995 field season	2, 349
16.8 Statistical data for particle size of 1995 surface samples from VM70.....	2, 357
16.9 Comparison of values from the 1995 surface soil survey of site VM70 and reproducibility error	2, 358
16.10 Statistical data for the 1995 surface soil survey of site VM70	2, 359
16.11 Correlation coefficients for the 1995 surface soil survey of VM70	2, 360
16.12 Table showing the estimated range and number of populations for each element for the 1995 surface soil survey of VM70	2, 361
16.13 a Summary table of soil colour of the 1995 soil pit survey samples	2, 382
16.13 b Summary table of soil profile observations in the 1995 soil pit survey	2, 382
16.14 Values of extracts and comparison to detection limit for extracts 1, 2, 3, 4, 5, 6, and 7	2, 408
16.15 Statistical data for particle size at CN11	2, 438
16.16 Comparison of element soil results for site CN11 and the reproducibility error of analysis.....	2, 439
16.17 Statistical data for site CN11 of elements that have ranges exceeding reproducibility error	2, 440
16.18 Correlation coefficients for the surface soil survey of CN11	2, 441
16.19 Estimated range and number of populations for elements in samples from the surface soil survey of CN11	2, 442

16.20 Statistical data for particle size at VM87	2, 459
16.21 Comparison of values for the surface soil survey of VM87 and reproducibility error	2, 460
16.22 Statistical data for the surface soil sampling of VM87	2, 461
16.23 Correlation coefficients for the surface soil survey of VM87	2, 462
16.24 Estimated range and number of populations for elements in samples from the surface soil survey of VM87	2, 463
17.1 Percentage particle size below 212 μm of samples from sites sampled during this thesis	2, 476
17.2 Element populations with an archaeological association compared against populations characteristic of control areas	2, 477
17.3 Comparison of sequential extraction totals with pseudo-total digestion values....	2, 479

TABLE OF OVERLAYS

Overlay Number and Description.....	Volume, Location
1 PP17	2, Inside back cover
2 PP27.....	2, Inside back cover
3 TPW11.....	2, Inside back cover
4 P4	2, Inside back cover
5 VM4.....	2, Inside back cover
6 Rhadon	2, Inside back cover
7 Resistivity survey features.....	2, Inside back cover
8 1994 survey of VM70	2, Inside back cover
9 1995 survey of VM70.....	2, Inside back cover

CHAPTER 1

INTRODUCTION

1.1 The Aim of the Project

The primary aim of this project is to establish whether element signals can be detected in the soil which bear a relation to the archaeological landscape. The secondary aim is to ascertain the extent to which the signal reflects the intensity and nature of past human activities on archaeological sites and in the archaeological landscape.

The research was conducted in conjunction with the Cambridge-Durham Boeotia Archaeological Expedition (Expedition directors: Dr. J.L.Bintliff (Durham) and Prof. A.M.Snodgrass (Cambridge)). The research has been focused on three main areas: archaeological background, theoretical modelling of ancient impacts and field experiments in Boeotia.

1.2 Introduction

The basis for this research is the observation that past human activities have caused changes in the physical and chemical properties of the soil, which are detectable in the present day. This research is concerned with the chemical changes to the soil. It is specifically concerned with the changes that occur to the element composition of the soil due to human occupation and activity.



It is well known that the human activities of agriculture and industry can alter the element composition of soils (Shiel, 1991; Thornton, 1991). In agriculture the benefit of adding materials such as manure to improve the crop yield, thus altering the elemental composition of the soil, has long been recognised. The merits of different types of manure are described by the classical writers (White, 1970). The materials added to the soil contained the nutrients required for crop growth and maturation; nitrogen, phosphorus and potassium and other elements which are coincidentally introduced to the soil. The classic example of how agriculture can alter the soil is the plaggen soils of the Netherlands (van de Westeringh, 1988). The plaggen soils are characterised by a dark, humic topsoil fifty centimetres thick which has developed through the continued application of byre material (cow or sheep dung mixed with forest litter, heather and grass sods). The purpose of these applications was to improve the fertility of sandy soils in order to sustain arable cultivation. Elsewhere, the types of material added to the soil in order to fertilise and condition it have been diverse. In the coastal areas of Ireland calcareous sand and seaweed were added to the soil (Conry, 1971). In more recent times lime has been added, to lower the hydrogen potential of the soil and make it more suitable for cereal crops or good pasture (Goudie, 1981).

The effect of industry can be local or global. Wastes from industry are diverse and their nature will determine their effect. Solid wastes such as the gangue material from mineral extraction are dumped in one locality and slowly permeate the surrounding environment. Liquid wastes such as fine slurries from mineral processing, effluent from tanneries and dye-houses enter watercourses and are deposited in the channel and over-bank sediments of the channel (Davies, 1980). Airborne wastes from activities such as smelting can be carried long distances. Lead pollution from Greek and Roman lead smelting two millennia ago, has been detected in the Greenland ice core (Hong *et al.*, 1994).

In addition to the changes caused by agriculture and industry this research is concerned with a phenomenon called the “habitation effect” (Bintliff *et al.*, 1988). This term is defined as the change in the elemental composition of the soil due to general domestic activities. It was first observed in a study of the effect of lead pollution from industry on urban garden soils in comparison to a control sample of rural garden soils (Davies, 1978). Davies noted that some of the control samples from rural gardens had lead values which were lower than urban soils, but that could still be considered contaminated, and that the level of soil lead increased in proportion to the age of the house (figure 1.1). Thus the elevation of the lead content of the soil was most acute in the mature gardens. Davies suggested that this was due to the application of coal ash to the garden soil. In a later paper (Davies, 1980), a similar enhancement for copper, lead, zinc and nickel was “ascribed to gardening activities such as the use of soot and coal ash or municipal composts and general fallout from bonfires, vehicle emissions and industry.” Other work has highlighted the fact that the combustion of products such as dung and wood can increase indoor air and soil concentrations, and local soil concentrations of lead and copper (Davidson *et al.*, 1981).

The habitation effect could also occur through the use, wear and loss of metals and other materials adding their distinct composition to the soil. For example, lead has a long history of use. It was the first metal to be smelted from ore in about 4000 B.C. (Sutton-Goold, 1990). Lead was used by many of the great civilisations including the Egyptians, Phoenicians, Chinese, Greeks and Romans (Goodhart, 1985). In the Roman period lead was used for many small objects such as candle-holders, small bowls and girdle hangers (Sutton-Goold, 1990). It was even used as an item of exchange, the tessera, a small leaden block used to replace silver coin when the expense of maintaining armies had induced inflation (Sutton-Goold, 1990). Lead was also used in the Roman water supply system as piping and tanks for storage and it was used as a sweetener and preservative in

wine (Eisinger, 1991). With such ubiquitous use of lead it is very likely that some will have entered the soil through object loss, object wear and increased human body lead burden leading to increased lead content of excreta. Lead serves as one example, though this example may equally apply to other metals used such as iron, copper and tin, and to everyday materials such as wood, pottery and stone.

The aim of this research is to establish whether element signals can be detected in the soil which bear a relation to the archaeological landscape in terms of intensity and nature of the past human activity.

1.3 The Boeotia Survey

1.3.1 The Archaeological Survey

Boeotia is a district of Greece situated in the central mainland (figure 1.2). The archaeological survey expedition has been in operation since 1979, in which time, more than fifty square kilometres of the region in south-west Boeotia around the ancient towns of Thespieae, Askra and Haliartos, have been intensively field-walked (figure 1.2). In 1990 a further three square kilometres area around the small ancient city state of Hyettos in north Boeotia was surveyed as a control for the work in south-west Boeotia (figure 1.2). The results of this work have produced a distribution of surface sherds which highlights the general pattern of settlement in different periods of antiquity (figures 1.3a - 1.3f). These results show that the greatest number of sites and greatest dispersal of settlement occurs in the Archaic-Early Hellenistic periods and in the Late Roman period. In addition the results have shown that sherds are spread across large areas of the landscape, the result of manuring with domestic wastes which include the sherds (Bintliff, 1997).

1.3.2 Climate, Soils and Soil Erosion of the Survey Area

The climate of Boeotia is a Mediterranean type characterised by mild, moderately wet winters and hot, dry summers when compared to the rest of Europe (Rackham, 1983). The average annual precipitation of the region varies from 432mm per annum on the plains to 732mm per annum on the mountain belts. The majority of precipitation falls in the winter months. The average monthly temperatures at low altitudes range from 7°C in January to 27°C in July. Summer, daytime temperatures can reach 40°C, which combined with strong winds leads to a high evaporation rate.

The soils of the region are predominantly calcareous and oxidised. The pH of the soils is seldom outside the range of 7 to 8 (Rackham, 1983). The soils of Boeotia have been studied as part of a test of the use of Geographical Information Systems in land evaluation for sustainable agriculture (Davidson and Theocharopoulos, 1992; Davidson *et al.*, 1994; and Theocharopoulos *et al.*, 1995). Entisols and gley soils occur on former lake sediments whilst inceptisols and vertisols are associated with the fringing terraces and alluvial fans. Alfisols are found at higher levels, either on the upper stable terraces or on the upland plateau areas whilst entisols are dominant on the colluvial areas and steeper slopes (Davidson and Theocharopolos, 1992). The soils of this study are those of the upland plateau in the Valley of the Muses and Hyettos regions and therefore the soil classes likely to be encountered are alfisols and entisols (where steep slopes are close to sampling area). Alfisols are moist mineral soils with an eluviated layer beneath the A horizon and an illuvial horizon of silicate clay enrichment (Brady, 1990). Entisols are weakly developed mineral soils without subsurface horizons (Brady, 1990).

The soil studies include an assessment of soil erosion (Davidson and Theocharopolous, 1992). The assessment of erosion is based on the extent to which subsurface horizons have become exposed. On slopes less than 3 % there is a distinct lack

of erosion, of slopes between 3 and 6 % less than 30% exhibited exposed subsurface horizons. Only on slopes of greater than 6 % is erosion more probable in occurrence than not.

1.3.3 The Geology of the Survey Area

The general geology of Greece is one of limestone ridges folded along axes running north west to south east (Ager, 1980). The ridges were formed in two episodes: one at the Miocene-Pliocene boundary (5.1 million years ago), known as the Pontian movements, when the modern Mediterranean Sea began to open, and the other at the Pliocene-Quaternary boundary, known as the Villafranchian movements (Aubouin, 1977). The valleys between them are filled by "Older Fill" (middle to late Pleistocene, 250,000-10,000 B.P.) and a series of Holocene fills (typically Early Bronze Age, Classical, Late Roman to Medieval and Early Modern) (van Andel and Zangger, 1990; Bintliff, 1992).

The geology of Boeotia consists of a series of basins lying between two of the lateral horsts (trending WNW to ENE) of the Dinaric-Pindus system (Ager, 1980). The bounding horst to the north is the Kallidroman trend of the mountains Khlomon, Prophitis Elias, Ptoion and Ktipas. The southern boundary is formed by the Parnassos trend of the mountains Helikon, Kitharon, Pastra and Parnes. The intervening valley systems are filled by Tertiary deposits or Pleistocene fills.

Previous trace element studies of the soil have been carried out in the Thespieae plains region and the Hyettos region. This study was carried out in the Valley of the Muses (within the Thespieae region) and the Hyettos region (including the medieval to modern site of Rhadon). The following sub-sections describe the local geology for each of these regions.

Valley of the Muses - The geology of the Valley of the Muses, illustrated in figure 1.4, is dominated by the mountains of Helikon and Pyrgaki. Helikon is composed of older material than Pyrgaki. Helikon is composed of Upper Triassic (230-210 million years ago) crystalline limestone. Pyrgaki is of Upper Cretaceous (98-65 million years ago) pelagic limestones. At the Palaeocene-Eocene boundary (approx. 65 million years ago) these limestones were subject to a period of uplift, folding and erosion. The result was the formation of Helikon and Pyrgaki, and the creation of the undivided flysch deposits which cover the floor of the Valley of the Muses. Flysch is a homogenised material formed by the rapid erosion of rocks subject to tectonic uplift. Overlying the flysch in only a few places is a layer of Quaternary alluvium and colluvium.

Thespieae - The plain around the ancient city of Thespieae is underlain by conglomerates, sandstones, sands and red clay (figure 1.4). These were laid down in the late Tertiary and Pleistocene periods. The source of rocks of this conglomerate are carbonates, shale, sandstone and chert.

Hyettos - The acropolis at Hyettos and the upland region to the north west are underlain by Upper Cretaceous transgressive limestones (figure 1.5). The flat plain area to the east and south of the acropolis is underlain by Mesozoic (Triassic and Jurassic) deposits of marine transgression and regression (thin limestones, shales and clays) intruded by ultrabasic rocks containing peridotite, dunite and olivinite. The boundary between the Cretaceous limestones of the uplands and the other Mesozoic deposits is marked by conglomerates of the Upper Cretaceous marine transgression and chrome-nickeliferous lateritic iron-ore.

The chrome-nickeliferous lateritic iron-ore has been mined over the centuries. The occurrence of iron-ore near Hyettos is noted by Pliny (Bakhuizen, 1976). The iron ores of north-east Boeotia are residual iron ores formed from ultramafic rocks under a tropical

climate in the Lower Cretaceous period (Kreulen, 1976). The combined action of the high temperatures and heavy rainfall of a tropical climate, and the organic acids produced by the abundant vegetation, chemically weathered the ultramafic material creating laterites of one to ten metres in thickness (Kreulen, 1976). The ultramafic material consists of magnesium and iron silicates. Iron oxide, being the only insoluble component occurring in any important quantity, remains, as the other constituents are weathered and leached from the rock. The resultant ores are distinguished by an intensely dark red coloured stratum between greenish ultramafic rocks and the Upper Cretaceous limestones (Kreulen, 1976) and are characterised by the association of the elements chromium, nickel, cobalt and magnesium. After formation they were either buried by the Upper Cretaceous limestones or eroded and transported, accumulating in depressions before burial (Kreulen, 1976).

Rhadon - The village of Rhadon sits at the foot of a north-east facing slope overlooking a valley filled with Quaternary alluvium (figure 1.5). The village resides on rocks of mid to lower Jurassic age, which include *shales intercalated with marly limestone*. The hillside above the village is composed of Upper Cretaceous limestone. The junction between the rocks of the hillside and the rocks beneath the village is marked by the presence of conglomerates of Upper Cretaceous age and tuffs of basic igneous rocks.

1.3.4 Modern Land-use of the Survey Area

The source for the historical view of agricultural and industrial development in the Boeotian region is Slaughter and Kasimis (1986). The descriptions of land use in the study areas are from my own observations.

The modernisation of agriculture and the introduction of factory based industry are recent occurrences in Boeotia, mainly happening over the last three decades. The main

reason for this development occurring so recently is the turbulent history of the area. After the 1821 War of Independence attempts had been made to encourage foreign capital. The focal point of these efforts was the draining of Lake Kopais. However, the area suffered from brigandage, which meant it was not secure until the last decades of the nineteenth century. This insecurity led to the neglect of the region's infrastructure and any improvements required a large input of capital without any quick return. Also discouraging the development of agriculture was the limitation of land rights for the local peasantry. It was only in 1931 that a British company, the third company to attempt it, successfully completed the drainage of Lake Kopais. The land was offered as freehold plots, but no buyers came forward and the entire drained lands by default fell under the ownership of the British company who proceeded to exploit the position, increasing rents, mechanisation and expansion of the force of wage-labourers. Elsewhere, traditional farming practices of peasant cultivation persisted in the inter-war years. The period of the Second World War and the Civil War which followed were a time of dire poverty for Greek peasants and troubled times for the British company. The holdings of the British company were expropriated by the Greek state in 1953 and distributed among the local villages.

The introduction of modern farm machinery enabling the intensification of agriculture in the region has been the product of the last two decades, through the pressure to mechanise as labour availability has decreased, and as credit has become easier to access. The pressure to modernise has forced many to sell their holdings and as a result the remaining holdings have increased in size by amalgamation. The region has therefore only had limited impact by modern intensive agriculture.

The Valley of the Muses - The valley is agricultural. The predominant crops grown are cereals, olive, vine and rough grassland. In addition the occasional field is planted with

tomatoes or potatoes, and there are some almond trees. The vines have blue deposits on their leaves suggesting the use of blue vitriol, a fungicide containing 25 % copper.

Thespieae - The plain around the ancient city of Thespieae is very much an area devoted to cereal production, mainly wheat and maize. The other crops grown in this area are tomatoes and water-melons.

Hyettos - The plain to the east of the Acropolis is intensively used for agriculture. The main produce of the plain is cereals as it is to the east of the Acropolis. The other crop observed on the plain during fieldwork was tobacco. The feature most noticeable as absent from the plain is the presence of olive trees which are only located near to the acropolis and on the hills to the west of the Acropolis. The area to the south of the acropolis where the 1995 soil sampling was carried out is an area mainly devoted to cereal production and grazing.

Rhadon - The medieval village of Rhadon lies on the south side of a valley which is used for the production of cereal and tobacco crops as was observed to the east of the Hyettos acropolis. The village site itself lies above this intensively farmed area and is used solely for grazing.

CHAPTER 2

SOIL CHEMICAL ANALYSIS AND ARCHAEOLOGICAL INVESTIGATION

2.1 Introduction

In the past the soil has been considered only as the veil to be removed to uncover the archaeology beneath. The first observation that soils could yield information about archaeology was made by William Camden, who writing in his book “Britannia” in 1600 noted the features now called “crop marks” (Daniel, 1967). However, it has not been until the twentieth century that the analysis of soil properties, including aerial photography of crop marks has become more common in archaeological investigation. The information that soils contain can exist in a observable form, such as a change in soil colour or the improved / retarded growth of a crop due to the archaeological influence on a soil. It can also exist in an analytical observable form, such as the changes in soil chemistry, the subject of this thesis. Archaeological soil investigation covers a wide range of techniques from simple field tests to complicated analytical procedures, which are necessary to extract as much information as possible to aid in the interpretation of a site.

This chapter is concerned with reviewing only the use of soil chemical analysis to investigate the elemental constituents of the soil in relation to archaeological activity. The principal soil chemical tool, phosphate analysis, is discussed, followed by other element analysis techniques used to investigate the changes in the elemental composition of soils on and around archaeological sites.

2.2 Soil Phosphate Analysis in Archaeology

2.2.1 Introduction

Soil phosphate analysis has been in use as a tool for archaeological investigation for the majority of the twentieth century. There are two main reasons why it is of use. Phosphate is produced in significant amounts on a human activity area by a variety of processes including waste disposal, burial and construction. Under most soil conditions, once incorporated in the soil, phosphate is immobile, being bound in relatively insoluble forms. These two factors mean that over a period of continuous activity in an area the concentration of soil phosphate will be enhanced above normal soil concentration and will remain enhanced after the area is abandoned.

The first observation of a soil phosphate enhancement in association with archaeological remains was in 1911 by Hughes, a soil scientist working in Egypt. However, it is Arrhenius in the late 1920s and early 1930s who is credited as being the first to develop soil phosphate analysis as a means of archaeological investigation. His development of the technique was built on observations he made while being employed by the Swedish Sugar Manufacturing Company to map soils of southern Sweden. Here, he observed a correlation between relatively high “plant available” soil phosphate and the location of Mesolithic artefacts and medieval settlements (Eidt, 1984a).

The work of Arrhenius was followed up by numerous people in the 1930s. The most notable of these is W. Lorch. He improved the methodology by outlining a shorter laboratory method for phosphate analysis and presented thorough instructions concerning sampling and treatment (Eidt, 1984a). Since the Second World War numerous studies have refined these early techniques. There have been improvements in modelling and better

understanding of soil phosphate, improved analytical techniques and statistical analyses of the results. This chapter summarises the important aspects of this development.

2.2.2 Sources of Archaeological Soil Phosphate Anomaly

An archaeological soil phosphate anomaly is defined here as an area of soil phosphate concentration which is quantifiably distinct from normal background levels. This could mean greater than or less than the normal background soil phosphate concentration. It is common for articles to refer to three main sources of phosphate anomalies (Provan, 1971; Proudfoot, 1976):

- urine and faeces of humans and animals,
- refuse derived from bone, meat, fish, plants, together with skeletal remains in graves,
- animal manure applied as fertiliser.

These are very important sources for the enhancement of soil phosphate, but they are not the only sources for the establishment of an anomaly. Any process in which humans play a cognitive or unintentional part, resulting in an alteration to the soil phosphate concentration is a potential anomaly of significance to archaeological interpretation. Therefore, wastes from industrial processes and debris from the construction and destruction of buildings should also be included.

The enhancement of phosphate has been modelled by Cook and Heizer (1965). They estimate that a living group of 100 people would excrete 62 kg of phosphorus annually. The amount deposited as waste or garbage, they estimate to be the same as human excrement. Here they add the caveat that the amount produced as waste is extremely hard to judge incorporating food residues of all sorts including bones, ash from domestic fires, clothing, vegetative matter in dwelling construction and also industries. They do not give estimates for excrement produced by livestock.

It should be noted that the anomalies produced by the above activities can be mimicked by natural geological anomalies in the surface horizon. The profile variation of phosphate and the form of the phosphate will however differ.

2.2.3 Retention of phosphate in soil

Here, the term phosphate refers to the phosphate ion $(\text{PO}_4)^{3-}$. The group of compounds associated with this ion, the orthophosphates, are the forms that phosphorus is almost exclusively found as within the soil environment (O'Neill, 1993). Natural soil phosphate is derived from the mineral apatite, $\text{Ca}_5(\text{PO}_4)_3\text{X}$, where X can be Cl^- , F^- , OH^- or $\frac{1}{2} \text{CO}_3^{2-}$. Rock phosphate contents range from $100 \mu\text{g g}^{-1}$ (0.01 %) in sandstones to $2000 \mu\text{g g}^{-1}$ (0.2 %) in phosphate rich limestones (Stevenson, 1986). The normal range for soil phosphate contents is $100\text{-}1000 \mu\text{g g}^{-1}$ (Bethell and Máté, 1989), but generally falls within the range of $500\text{-}800 \mu\text{g g}^{-1}$ (Stevenson, 1986). Values in excess of $2000 \mu\text{g g}^{-1}$ are frequently found in some archaeological situations (Sandor and Eash, 1995; Weston, 1995). In normal situations the highest total concentrations of soil phosphate exist in the upper A horizon where the residues of plant and animal material are greatest. It is lowest in the lower A horizon and upper B horizon due to plant uptake through their roots. Levels in the lower B horizon and C horizon are of the same order as the surface horizon.

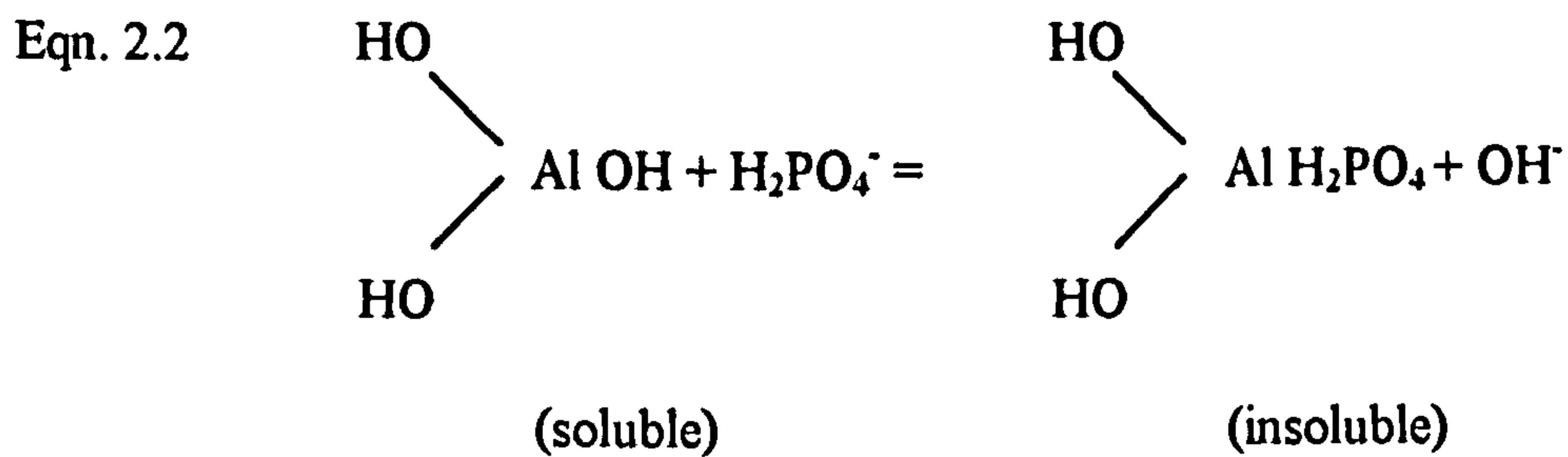
The soil solution contains on average phosphate concentration 0.05 mg l^{-1} and is in equilibrium with the soil phosphate content (Bethell and Máté, 1989). The rate and direction of phosphate movement is dependent on the cropping regime, pH, activities of micro-organisms, and the presence and concentrations of aluminium, iron and calcium ions (Bethell and Máté, 1989).

The sources of phosphate from human activities have been outlined above. The form of phosphate added to the soil is either inorganic or organic. Inorganic phosphate is

added in the form of bone, ash and industrial wastes such as construction materials and slags. Organic phosphate is added from plant and animal residues. Once added to the soil it may be broken down and released into the soil solution. Here the phosphate ion may occur as a discrete entity or bound to one, two or three hydrogen atoms (HPO_4^{2-} ; H_2PO_4^- or H_3PO_4). The discrete phosphate ion and phosphoric acid (H_3PO_4) are only found in extremely alkaline and acid conditions, respectively. The remaining two species are those found in the soil solution under normal soil conditions (pH range 5-8), H_2PO_4^- being the dominant species in acid environments and HPO_4^{2-} in alkaline environments (figure 2.1). Once in solution it may be;

- absorbed by plants,
- adsorbed onto the organic matter of soils,
- re-deposited as insoluble or slowly soluble mineral forms, such as calcium, iron and aluminium phosphates and occluded phosphates of hydrous oxides.

Phosphorus is essential to plants. It is required for photosynthesis, nitrogen fixation, crop maturation (flowering, fruiting and seed formation), root development and strength of straw in cereal crops (Brady, 1990). The actions of humans and their livestock in harvesting a crop results in the removal of phosphate from the soil. The amount taken up by a plant will depend on the availability of phosphate in the soil and the type of plant. Alfalfa, buckwheat, millet, lupins and sweet clover are efficient users of relatively insoluble forms of soil phosphate. Barley, cotton, corn, oats, potatoes and wheat are inefficient users (Stevenson, 1986). For example, a soil containing $500 \mu\text{g g}^{-1}$ phosphate has 1,120 kg phosphate per hectare to the plough depth. If this soil is continuously cropped for ten years with wheat, removing 10 kg annually, then 10 % of soil phosphate will be removed (Stevenson, 1986). The majority of this removal is supplied from phosphate held within organic matter. This is due to the practice of cultivation, which increases the oxidation of organic matter and enhances microbial activity.



In calcareous soils less soluble di-calcium phosphates ($\text{Ca}_2(\text{HPO}_4)_2$) and tri-calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$) are formed. If high calcium concentrations are maintained then the latter may convert to carbonate apatite (Bethell and Máté, 1989). Phosphate may also be adsorbed onto clay surfaces by anion exchange (equation 2.3).



It is because of the tenacious bonds that phosphate makes when adsorbed onto colloidal surfaces and the insoluble complexes it forms with divalent and trivalent cations that losses through subsurface and groundwater run-off are minimal (0.1-1.2 kg phosphate per hectare annually). The majority of soil phosphate losses are incurred by erosion (Stevenson, 1986). This is affected by slope, cropping practice, type of soil, and amount and intensity of rainfall.

2.2.4 Methodology of analysis

Whatever the method of soil phosphate determination, the extractant used is an acid or alkali which causes the alteration of phosphate compounds into soluble orthophosphate. The amount and type of soil phosphate extracted is a function of the strength of the acid or alkali used (Bethell and Máté, 1989). For example, the early

workers Arrhenius, Bagge and Christensen all used weak acid extractants which removed “plant available” soil phosphate into solution.

The first archaeological application of total soil phosphate analysis came from the work of Johnson and Nicol (1949). They extracted total soil phosphate using concentrated sulphuric and nitric acids. This work, compared with results for “plant available” soil phosphate, showed that the “plant available” amounted to only 2-11 % that of total soil phosphate and the spatial pattern produced by each technique was different. The results for total soil phosphate more closely correlated with the archaeological artefacts, in this case a cairn.

The determination of “plant available” and total soil phosphate have been the main methods of soil phosphate analysis used in archaeology. Despite its large potential, a third technique has been little used in archaeology due to its complex methodology and long processing time (Sánchez *et al.*, 1996). This technique is the fractionation and quantification of different soil phosphate species. The technique was developed by Chang and Jackson (1957) and has been modified by subsequent workers (Syers, 1972; Woods, 1977; Eidt, 1977, 1984a, 1984b). Eidt’s scheme for phosphate fractionation involved the separation of soil phosphate into three fractions. These are:

Fraction I: easily extractable,

Fraction II: tightly bound or occluded iron and aluminium phosphates,

Fraction III: apatite and other tightly bound calcium phosphates.

In theory, the pattern produced by phosphate fractionation should be different in areas put to different land uses, such as crop production and industrial areas or grazing and residential lands. This is borne out by research shown in table 2.1 (Eidt, 1984b). This table shows that mixed-vegetable producing land has the majority of soil phosphate in fraction I (80-90 % of total soil phosphate). Forest soils have soil phosphate in the first two fractions. It is only in residential areas that fraction III is significant and there is an

equal distribution across all three fractions. Therefore, it is possible that where the anomalies produced by conventional soil phosphate analysis are indistinguishable from each other in terms of determining land-use, then fractionation could be of use. Eide (1984b) also noted that the level of fraction II phosphate in modern residential areas was lower than abandoned residential areas (table 2.1). This is due to the creation of occluded iron and aluminium phosphates being time dependent. This idea has been followed up by Lillios (1992) to produce an estimate of the date of occupation. Here Lillios ranked the samples by their fraction II/ fraction I ratio, divided them into two groups (Bronze age and Medieval) by their associated artefacts and compared them to the total soil phosphate concentration (figure 2.3). Based on the fact that the total soil phosphate indicates intensity of land-use and the ratio of fractions gives an estimate of age, this figure illustrates the samples' history.

2.2.5 Statistical analysis of data

Some papers have used statistical approaches to improve the interpretation of soil phosphate data (Conway, 1983 and Cavanagh *et al.*, 1988). Conway employed a technique called trend surface analysis. This produced generalised maps of the phosphorus distribution for extractable ("plant available") and total phosphate. The technique allowed the separation of a general pattern of enhancement over the structures from residual enhancement values which related to small features such as hearths or pits.

Cavanagh *et al.* (1988) used change point analysis to delineate the boundaries of a site. The assumption made is that the data set is of two distinct populations, those that represent background (A) and those that represent background with the addition of a human derived phosphate anomaly (B). By this statistical approach they were able to locate the point at which B changed to A. However, the boundary does not necessarily

define the boundary of the site as it is the boundary of the area which had undergone the intensive application of animal and plant wastes which is defined, which probably relates to the infield cultivation area.

2.2.6 Phosphate analysis and complementary techniques

Eidt (1984b) stated that: "Soil phosphate fractionation should be carried out in conjunction with studies of organic matter, Eh and pH." This is as much a true statement whether it refers to "plant available" or total phosphate analysis. The additional information aids the understanding of the phosphate data and the archaeological interpretation. Organic matter enhancement could indicate where there had been significant additions of plant and animal residues. Organic matter in conjunction with results for Eh and pH give the soil conditions which influence the retention of phosphate.

Recent studies have used other analytical techniques in conjunction with soil phosphate analysis to improve the archaeological interpretation. The technique most commonly used is magnetic susceptibility (Weston, 1995). This technique measures the magnetic susceptibility (the ease with which a material can be magnetised) of a known mass or volume of a soil (Thompson and Oldfield, 1986). The presence of archaeological features, such as fires and rubbish pits is detectable by the enhancement of magnetic susceptibility they have caused.

2.3 Other Elemental Chemical Analyses of the Soil

2.3.1 Introduction

Elemental analysis has a number of applications in archaeology. These include artefact provenancing studies to identify the source of the artefacts' raw materials, nutritional and toxicological information from bone analysis, the detection of body silhouettes where bone has been dissolved, and identification of archaeological features. Despite beginning in the early nineteen fifties, the element analysis of archaeological soils to identify archaeological features is less developed than for the other three applications. It is only in the last two decades, with the improvements in availability and reliability of multi-element analytical instruments such as the inductively coupled plasma mass spectrometer (ICP-MS) and atomic emission spectrometer (ICP-AES), that elemental analysis has become a more practical and accessible tool for investigation. The following sections describe the development of elemental soil analysis in archaeology.

2.3.2 Development of Soil Elemental Analysis

In the early fifties, Sokoloff and Carter (1952) analysed soils from midden sites in Florida to assess the stratigraphic distribution of nickel, cobalt, copper, zinc, manganese, chromium, alumina and ferrous iron. Based on the assumption that the elements were enriched in human refuse and that these dissipated with time down to levels comparable to a control soil, the aim was to create floating chronologies of the middens by the degree to which the elements had been leached from the midden. Their results concluded that these elements were not easily removed from the midden, stating that "a period of 1000 to 2000 years is not enough to bring the distributions of trace elements in a midden to that in a

comparable undisturbed site (control soil)” (Sokoloff and Carter, 1952: 5). They also concluded that of the elements analysed, copper and zinc were particularly diagnostic of human refuse.

The early development of soil element analysis was hampered by “the great technical difficulty in performing the requisite analyses with a sufficiently large number of samples” (Cook and Heizer, 1965: 2). Also development was driven by the needs of agricultural science, hence analysis concentrated on the more easily detected major soil elements, such as calcium, carbon, nitrogen, phosphorus, magnesium, sodium and potassium. The principal study of this period was by Cook and Heizer (1965) who analysed a number of sites in California and Mexico for organic carbon, nitrogen and calcium in addition to phosphorus and pH. They noted that in addition to greater phosphorus levels, the concentrations of calcium and organic carbon were greater in anthropogenic soils.

Work on the major soil elements continued with Griffith’s (1980 and 1981) studies of the Benson Site, a former Huron Indian village of the seventeenth century, situated ninety kilometres north-east of Toronto, Canada. The first study (Griffith, 1980) observed the general enhancement of magnesium, organic phosphorus and inorganic phosphorus in soils of the village when compared to soils away from the village. The second study (Griffith, 1981) was the first to define use areas within a site based on the elemental signature. Analysing the exchangeable potassium, exchangeable magnesium, exchangeable calcium, organic phosphorus and inorganic phosphorus of soils sampled from a range of different site features, including a midden, pits, hearths, paths, longhouse interior and areas of village devoid of features, Griffith was able to discriminate which elements are characteristic of which feature. Griffith concluded that the midden feature was easiest to discriminate from other features as it had the highest values of magnesium, calcium, potassium, organic phosphorus and inorganic phosphorus. Midden values for calcium were three times higher than any other feature and both inorganic and organic phosphorus were

twice as high as in any other feature. Using discriminant analysis the lower magnesium values found in the soils of the paths could separate them from the soils of pits, posts and the longhouse interior, and the organic and inorganic phosphorus values of the paths, pits and longhouse were statistically distinct from each other.

Woods (1984) analysed iron, copper, zinc, nitrogen, potassium, magnesium, phosphorus, organic carbon, and pH to determine site boundaries, define stratigraphic units, delimit intrasite activity areas and features at Fort de Chartres I, an early eighteenth century AD French fort on the Mississippi in Illinois, USA. Results confirmed previous work that phosphorus, calcium and pH were effective cultural indicators, but the other elements were considered not diagnostic.

Recent research includes the study by Schuldenrein (1995) of two hunter-gatherer sites in North America. Schuldenrein analysed soil pH, phosphorus, potassium, calcium, magnesium and sodium from profiles on these sites and concluded that the presence of bone and the activity of butchering resulted in greater concentrations of phosphorus, calcium, magnesium and organic matter.

A study of importance to this thesis as it looked at a suite of elements, was conducted by Evershed *et al.* (1997) at the Butser Ancient Farm site. Soils from field VII at the site were analysed for the presence of 5β -stanols, magnetic susceptibility, and a range of elements analysed on an inductively coupled plasma atomic emission spectrometer (Al, Fe, Mg, Ca, Na, K, Ti, P recorded as weight percentage oxide equivalents, and Ba, Bi, Ce, Co, Cr, Cu, La, Li, Mn, Ni, Pb, Sb, Sc, Sr, V, Y, and Zn as parts per million). Field VII was divided up into four strips (figure 2.4), each strip measuring 7.5 m by 30 m. The strips were divided from each other by narrow access paths (Reynolds, 1990: 92). The central two strips were manured with a mixture of cattle dung and straw at a rate of 10 tons per acre per annum for a period of thirteen years (1976-1989). This left two outer strips which were un-manured. The strips were subject to an annual ard and hoe cultivation

of a variety of wheat crops, including emmer, spelt and a modern hybrid wheat (Reynolds, 1990: 92). In 1990 soil samples were taken, using a soil corer, at one metre intervals along a north-south transect across the field (figure 2.4). In addition three control samples were taken from an uncultivated part of the site. The results for 5β -stanol (figure 2.5) and magnetic susceptibility show greater values over the manured area of the site than the un-manured. The element analysis results were observed as showing no significant difference between the manured and un-manured areas of the field except for potassium (figure 2.6) and it was concluded that “at the level of application and soil type involved, inorganic elemental analysis does not show any clear evidence of addition of manure to the centre of the field” (Evershed *et al.*, 1997: 490). In the article only the results for potassium, aluminium, iron, calcium, phosphorus and manganese are shown (figure 2.6), but from these certain points may be made. There are three possible reasons for no discernible enhancement of most elements in the manured soil when compared to the un-manured soil: (1) insufficient period of application, (2) that the applied material is not sufficiently distinct in elemental composition from that of the soil, or (3) that there may be some soil mixing between the manured and non-manured plots. The first reason is related to the second reason as it assumes that the manure is only slightly different from the soil and through repeated application this will become detectable in analysis. The second possibility, that the composition of the manure is the same as that of the soil, is unlikely and the evidence supports some differences. Potassium has already been mentioned and phosphorus was described as showing a slight elevation in the manured zone. What was not mentioned in the article (Evershed *et al.*, 1997) was the decrease in calcium values (figure 2.6) over the manured area, suggesting that the application of manures can cause a dilution effect as well as an enhancement effect. The third reason is unlikely as the plots were divided by access paths which would have limited any soil mixing between the manured and non-manured plots. The lack of elements showing a distinct change over the manured area

probably reflects the absence of materials such as hearth ash, bone material and sherd fragments in the manure which would have been included in archaeological situations and would have produced greater differences between the manure and the soil (see chapter 12).

In the mid-eighties, Boeotian studies of the trace element soil contents on archaeological features and landscape began (Waters, 1987). This work concentrated on the elements lead, copper and zinc and is reviewed in chapter 3. The results show a clear relation to size of settlement, with higher values of these elements occurring over the settlement than the surrounding countryside. Studies at farmstead sites are less conclusive but suggest that higher values of lead are associated with the structures on the site, whilst higher values of copper and zinc are associated with the manured enclosure or infield around the structure.

Recent research has focused on multi-element studies. Ottoway and Matthews (1988), in addition to calcium and phosphorus, analysed samples from a tell in Gomolava, Yugoslavia for the biophile elements magnesium, strontium, zinc, copper, nickel, manganese, chromium, lead and boron. They concluded that the results for zinc, copper and nickel were highly correlated, with sharp peaks which could provide precise information about individual strata in the tell with greater experience of interpretation. It was suggested that manganese results could help to interpret phosphorus results further, as greater manganese values are an indicator of ruminant excreta, whereas human excreta tend to be lower.

Jenkins (1988) took another approach to trace element enhancements on archaeological sites in Wales. Looking at charcoal samples from archaeological sites he observed higher levels of silver, cobalt, chromium, nickel, lead and, in particular, tin in the archaeological samples when compared to control samples. This he concluded to be due to the ability of the charcoal to concentrate the elements through adsorption.

The first multi-element, ICP-AES analysis of archaeological soil samples was published by Linderholm and Lundberg (1994). The analysis provided results for iron, arsenic, copper, phosphorus, manganese, vanadium, cobalt, molybdenum, zinc, chromium, lead, and calcium. They observed that Cu, P, Mn, Zn and Ca had accumulated in feature and dwelling samples, and Fe, V, Co and Cr characterised control samples.

Middleton and Price (1996) also employed an ICP-AES to analyse for a suite of elements including Al, Ba, Ca, Fe, K, Mg, Mn, Na, P, Sr, Ti and Zn. The aim of their research was to distinguish variations in samples collected from two archaeological house floors (British Columbia, Canada and Oaxaca, Mexico). They concluded that floors and hearths could be separated from each other and from the natural prehistoric ground surface. They observed that aluminium and magnesium were accumulated in samples from food preparation areas and that potassium, magnesium and phosphorus were accumulated in samples from hearths.

2.4 Conclusion

Although in use since the early twentieth century, archaeological analysis of the soil's elemental composition has mainly been limited to phosphorus and other major ions such as calcium. Multi-element analysis, including the determination of trace elements, has only been in use over the last decade, as it required the availability of instruments capable of analysing a wide range of elements simultaneously and with precision.

Phosphorus analysis is the best established element in archaeological soil investigations, though its results have been variable. Different extraction methods have been developed to extract plant available and total phosphorus, and in the fractionation of phosphorus. The information gained through phosphorus analysis has limitations due to

problems of equifinality and is best used in combination with complementary techniques such as geophysical soil analysis.

The elements analysed in previous archaeological soil investigation have shown the following patterns:

- Phosphorus is accumulated in midden deposits (due to the presence of excreta, food wastes and bone), in grave deposits, stockyards and byres, food preparation areas and hearths.
- Calcium is accumulated in midden deposits and in food preparation areas due to bone.
- Magnesium is accumulated in midden deposits, food preparation areas and hearths.
- Copper is accumulated in midden deposits.
- Zinc is accumulated in midden deposits.
- Manganese could be used to interpret phosphorus results as higher values indicate ruminant excreta and lower values indicate human excreta.

Analysis of a thirteen year, annual cow and straw manure application to an experimental cereal cultivation area at Butser Ancient Farm has suggested that potassium is definitely enhanced in the manured soil, phosphorus slightly enhanced and calcium is diluted as the calcium content of the manure is lower than that of the soil.

CHAPTER 3

ELEMENT SOIL ANALYSIS IN BOEOTIA, GREECE

3.1 Introduction

Element soil analysis has been utilised as a technique of investigation on the Boeotia archaeological survey project since 1986. In 1988 the technique was also used on a similar archaeological project in Hvar, Yugoslavia and compared to the Boeotia data. The Hvar data are included in this chapter.

The technique was used at two levels: the regional and the site level. The regional level analysis had two aims, (1) establishing “background” values for the natural concentration of trace elements in the soil, which could then be compared to those on the sites to establish what chemical changes had occurred, and (2) to assess the impact on soils of human activities in the archaeological landscape. Regional level analysis was carried out on samples collected from areas where archaeological material was at low to medium densities. Site level analysis was carried out on two levels of occupation intensity: the city and the farmstead. The higher intensity of occupation for city sites when compared to farmstead sites should produce significantly larger changes in the soil trace element concentrations.

The element surveys carried out to date are shown below. Dates in brackets are dates of printed material. Dates without brackets are dates of sampling. Analyses produced by Waters (1987) are thought to contain a calculation error, which has proved untraceable and therefore makes it difficult to use this data set. Of the samples collected and analysed by Waters, the Thespieae transects and sites PP17 & PP27 have been re-sampled and

analysed. In these cases the data sets will be compared to assess whether the Waters data set can be used.

Regional level	1986	Thespieae transects 1, 2, 3 & 4 (Waters, 1987). Re-sampled in 1989 by Davies and Terzis (unpublished).
	1988	Hvar transects 1, 2 & 3 (Watson, 1989).
	1989	Area sampling of the Mavromati Plains and Mavromati West (Chapman, 1990).
Site Level	1986	Sites PP17, PP27 & VM4 (Waters, 1987). Sites PP17 & PP27 have been re-sampled and analysed. PP17 remains unpublished. The revised data for PP27 are in Chapman (1990)
	1987	Sites VM64, VM89, VM95 & TPW2 sampled by Davies and published in Gaffney (1990)
	1988	Site P4 in Hvar, Yugoslavia (Watson, 1989)
	1989	Sites PP27, TPW11 & Thespieae city (Chapman, 1990).
	1989	Sites PP17 and a single transect sample of Hyettos plain sampled by Terzis and Davies, analysed by Matthews (unpublished).

The results from Waters (1987) appear in publications alongside later information. The following list is where the accepted correct data are published: Regional surveys of Mavromati West and Mavromati Plains, and sites PP27, TPW11 and Thespieae city are in Chapman (1990). The revised Thespieae transects, revised PP17 and Hyettos city remain unpublished. The Hvar transects and site P4 are printed in Watson (1989). Sites VM64, VM89, VM95 & TPW2 are published in Gaffney (1990).

Results have also been published in Bintliff *et al.* (1990) and Bintliff (1992). Both contain data from Waters (1987) for the regional transects and for the sites, Thespieae city and PP17. The 1990 paper also contains reliable data for site VM64 and the 1992 paper contains reliable data from site VM64 and TPW2.

The computer generated contour plots presented in this chapter and in chapters 13-16 were produced using Uniras Unimap version 6.4. Using the fixed grid points the contour plots have been produced by first performing a bilinear interpolation and then computing gradients at the points.

3.2 Regional Level Sampling as a Means of Establishing a Base Level

One of the aims of the regional level sampling was to provide “background” values for the concentration of trace elements in the soil. These values could then be used to compare against values obtained for site based surveys.

Four regional level samples have been carried out to date. Three occur in Boeotia and one in Hvar. The three Boeotia samples are Mavromati West (Mavro.W.), Mavromati Plains (Plains) and the four landscape transects in the Thespieae region (Thes. Trans.) sampled by Davies and Terzis. The Mavromati West and Mavromati Plains samples are area sampling schemes in regions of low to medium archaeological material recovery. The lower levels of archaeological material recovered from these areas suggest that they have been little affected by past human activities and will yield useful “background” values. The regional sampling in Hvar, Yugoslavia consisted of three landscape transects. The transect samples should have larger ranges than the area samples due to collecting samples from more widely separated sample points and therefore sample conditions. The sample points on a transect survey may differ in their proximity to modern and archaeological

settlements, proximity to a pollution source (e.g. vehicle emissions from roads) and in the type of modern land-use (e.g. different crops will have different fertilisers, pesticides and herbicides). The result of these differing conditions will be to produce a larger range in values and a larger standard deviation than the area samples.

The resulting arithmetic means, ranges and standard deviation can be seen in table 3.1. The only comment that can be made for values of nickel, manganese and magnesium is that they are high in the Thespieae region of Boeotia where the transects were carried out. These high values probably indicate the presence of ultrabasic rocks which have high values of cobalt and chromium in addition to magnesium, manganese and nickel (Alloway, 1990).

The table also shows that values for lead, copper and zinc are fairly constant for these regional samples. Most constant are the values for lead and copper. The values for zinc are constant except for the Mavromati Plains sample area where it is much higher than the other sample areas. The zinc values are an interesting set of values to compare area regional surveys with transect surveys. Firstly, the assumption is made that the Mavromati West sample area is of low modern and archaeological human impact and that the zinc values obtained are indicative of the region. Then the Mavromati Plains data which have low amounts of archaeological evidence could be high in zinc values due to a modern impact. Chapman (1990) suggested that the higher zinc values could be due to the use of high zinc content phosphatic fertilisers on cereal crops. The zinc values for Mavromati Plains have a high arithmetic mean value (71.5 p.p.m.) and the standard deviation suggests that the majority of values in this sample area are around the mean. The problem this poses for establishing a regional “background” value is that samples can be collected from areas that are low in archaeological evidence and are thought to have minimal modern impact, but does in fact have modern impacts on it, which means the value obtained as a regional “background” will be higher than the real “background” value. The

soil is like a palimpsest; it is the overwritten record of all environmental factors and conditions (including human activities) which prevailed during its formation (Davies, 1980), which means that establishing “background” values is virtually impossible. The Thespieae transect samples (Thes. Trans.) which cross a diversity of soil conditions have the effect of averaging the zinc values. The transect samples have a wide range of values as in the Mavromati Plains sample but there are far fewer high values in the former. The resultant mean is much closer to that of the Mavromati West sample and the diverse nature of the zinc values is indicated by the high standard deviation. Area samples can give an accurate view of the “background” value of the region only if it is certain that there has been no major archaeological or modern intervening activity. Transect samples will average out the high values and thus provide a mean which is higher than the real “background”, but will be less prone to providing an erroneous value due to a missed observation.

The other feature in table 3.1 worthy of note is the lead values obtained for Thes. Trans. The very high standard deviation would suggest a wide variety of values around the mean. This is not so, the high standard deviation is due to the one result of 556 ppm. If this result was removed from the sample then the next highest value is 33.4 ppm. (displayed in brackets in table 3.1). The standard deviation would drop to only 5.3 and the mean would drop to 12.8 which is far lower than for the other samples.

The averages of the combined three regional surveys in Boeotia provides values for each element which can be compared to the values obtained for the sites. The averages are lead 27.5, copper 28.8, zinc 55.2, nickel 568, manganese 754 and magnesium 9370. If the lower lead average (12.8) is used for the Thespieae transects and the Mavromati plains zinc result ignored due to its probable modern origin, then the average for lead would be 24.6 and for zinc 47.0. The averages used to compare against the sites are lead 24.6, copper

28.8, zinc 47.0, nickel 568, manganese 754 and magnesium 9370. For site P4 the Hvar regional values of lead 29.3, copper 45.8 and zinc 44.7 are used.

3.3 Regional Transects and the Influences of Modern and Archaeological Human Activity

The second aim of regional transects is to assess the impact on the soil environment of human activity in the archaeological landscape. This second aim questions the validity of the first aim as it assumes that the whole soil landscape is an artefact of human activity and therefore, no true “background” value exists. What do exist are values relating to different levels of human activity. The Thespieae transects (transects 1-4) travel through areas of low to high human activity, as indicated by the sherd density (figure 3.1). When the Thespieae transects are compared against the surface sherd densities (figures 3.2 - 3.4) there appears to be little overall correlation between the elements and sherd density. In transect 1 (figure 3.2), all the elements except lead follow a similar pattern of concentration and do not correlate with sherd density. However, values for lead are elevated between 1800 m and 2200 m, where sherd densities are also high. Transect 2 (figure 3.3) crosses an area of low sherd densities and the elements all show a corresponding lack of variability supporting the view that human activity causes variability in the soil’s element composition. In transect 2, a rise in the value of all elements can be detected between 700 m and 1400 m which corresponds to the sample points nearest the modern village of Palaiopanagia and therefore reflects the habitation effect of modern villages. Transects 3 and 4 (figure 3.4) have been combined to produce a single transect. Values of all elements exhibit a similar pattern in concentration, the only deviation is for lead, which has elevated values between 600 and 800 m. This corresponds to an increase in sherd density at the 700 m mark.

Some of the Thespieae transect sample points can be compared with the earlier transects (figure 3.1) of Waters (1987). The results (figure 3.5a-e and figure 3.6a-e) show that only the lead values of Waters correspond to the lead values of Thespieae transect 1. The remaining results show little correlation and therefore do not allow the Waters data set to be used.

3.4 Sites

The site surveys were carried out at two levels. The major site level or high intensity/long period of use such as a city site and the minor site or low intensity/short period of use such as a farmstead.

3.4.1 Major sites

3.4.1.1 Thespieae City

The ancient city of Thespieae covers an area of up to one hundred and fifty hectares and has been occupied from the Neolithic until the Ottoman period (Bintliff, 1988). In the Neolithic period occupancy was restricted to the magoula or artificial elevation in the north of the survey area. Over the Bronze Age, early Iron Age and even into the Archaic period the settlement of the area expanded in a sporadic pattern suggestive of a group of villages and hamlets. The city's main period of occupation was from the Archaic to the Early Hellenistic. Its maximum extent was in the Classical period when the city covered some one hundred hectares and had an estimated population of 13,000 (Bintliff, 1996). During the Late Hellenistic period the city went into dramatic decline, reducing by at least one third in area.

Two trace element surveys have been carried out. Both surveys were conducted across the southern edge of the Late Roman defensive wall (figure 3.7), where there is a dramatic decline in sherd densities. The results of the Chapman survey will be discussed first and then corresponding sample points will be compared to values obtained by the Waters survey.

All elements are elevated well above the background values obtained by the regional samples and show a decline with distance away from the city centre (figure 3.8a-c). For all elements the wall acts as a barrier. Values outside the wall are less varied and lower than values inside the wall.

The comparison of values from the Chapman survey with those of the Waters survey (figure 3.9a-c) is only possible for four samples which is insufficient to draw any definite conclusions. Both surveys show that the values for lead and copper (figure 3.9a and 3.9b) are higher within the walls of the city than outside.

3.4.1.2 Hyettos Plain

The city of Hyettos had its origins in prehistory. The acropolis formed a small community throughout the Bronze Age. A dramatic expansion of this village community occurred in the late Geometric/ Archaic period. The settlement achieved city status by the sixth century B.C. and reached its apex in the Classical and early Hellenistic period. The occupied area comprises 28ha and represents an estimated 3500 towns people, representing 70 % of the total city-state population, the other 30 % lived in the countryside. The population was supported by the production of crops, the exploitation of the rich iron ore and an industrial quarter of the city, which produced rooftiles and pottery with a distinctive magnetite filler. The city continued to exist on a lively but reduced spatial scale through the Roman period until circa 600A.D (Bintliff, 1997a).

The geochemical survey of Hyettos Plain consisted of a 1230 m transect, starting from a position about 300 m east of the acropolis of Hyettos on the presumed edge of the occupied area (figure 3.10). The transect was sampled at 100 m intervals which meant that the first two samples were from the high sherd density of the city periphery and the next three samples fell within the Hyettos Plain sherd survey in the lower sherd density areas. None of the elements (figure 3.11) show the dramatic decline with distance from the city that the sherd densities exhibit. There are general declines in the concentrations of all elements with distance from the city. With the exception of lead, the elements exhibit fairly constant values over the plain near the city of Hyettos, and start to decline after the 800 m sample point. Lead shows a similar pattern but it starts to decline in concentration earlier, after the 500 m sample point. The higher values over the plain nearest the city reflect the more intensive use of this part of the plain by the city. Values for magnesium, manganese, nickel and zinc are above the average background values obtained from regional surveys. Values of copper and lead are equal to or less than their background values.

3.4.2 Minor sites

3.4.2.1 PP17

Discovered in the hilly hinterland of Thespieae during the 1984 field season, site PP17 was interpreted as a domestic farm. The diagnostic material collected from the site, dated the main phase of occupation from the Late Hellenistic period to the Early Roman period (table 3.2). High counts of unabridged pottery testify recent deep ploughing of the site. In addition to a ceramic density survey, the site has been surveyed (figure 3.12) for tile counts (Gaffney, 1990), resistivity (Gaffney, 1990), and two trace element soil analysis surveys (Waters, 1987 and Davies and Terzis, unpublished).

The twin-probe resistivity survey gives a good representation of the plan of a buried structure (A), possibly divided into two rooms, surrounded by an enclosing wall (B) (figure 3.3). The position of the buried structure coincides with the area of greatest tile concentrations and therefore supports the assumption that this is the main structure of this farm site. Two other high resistance features (C1 and C2) are observed slightly uphill of the buried structure and outside the enclosure wall. These two features correlate with the area of greatest sherd densities and are suggested as being middens, the product of domestic refuse dumping and other agricultural wastes (e.g. byre material).

The initial trace element soil survey of Waters (1987) is compared (table 3.3) to the 1989 trace element soil survey of Davies and Terzis (unpublished). The means of the two data sets differ widely and there is no discernible correlation between the two data sets which might have assisted in the recalculation of the Waters survey. Therefore only the results of Davies and Terzis' survey are described here. The samples collected by Davies and Terzis were analysed for lead, copper, zinc, nickel, magnesium and manganese (table 3.4). The ranges of lead, copper, zinc and magnesium exhibit values which exceed

background values, although only lead and magnesium have mean values that exceed background. The surface distribution of each of these elements can be seen in figures 3.14a to 3.14f. Using overlay 1, the following observations can be made:

- The values of copper, zinc, nickel, magnesium and manganese are elevated over the area inside the enclosure wall and outside the structure. This feature is best defined by the results for zinc, which shows larger values in the enclosure to those of the surrounding samples.
- The suggested midden feature C₁ also has elevated values for copper, zinc, nickel, magnesium and manganese. This suggests that this midden feature is the product of periodic cleaning of the enclosure.
- The results for lead show a strong positively skewed distribution which reflects the very great values exhibited by four samples. Only one of these samples correlates with an archaeological feature, the midden feature C₂. Over the rest of the site lead values are low and are below background.
- None of the elements show an enhancement over the house structure.

3.4.2.2 PP27

Discovered in 1983, this small farmhouse site is situated in the hilly hinterland to the north of Thespieae. It has a dated range from the Early Roman period to the Late Roman period (table 3.5). The site has been subject to a surface soil sherd, surface soil tile, soil resistivity and trace element soil survey (figure 3.15).

The original soil resistance data of Gaffney (1990) have been reprocessed using Insite 1.0 (figure 13.16a and b). The western extension of this survey, shown in figure 3.15 is not available for reprocessing. The soil resistance survey revealed four high resistance features. Features A, B and C correspond to the position of the highest surface tile concentration (figure 3.17) and are interpreted as part of a structure. It is proposed that feature D is a boundary wall (Gaffney, 1990). The survey of surface sherd densities (figure 3.18) shows that the highest sherd densities are to the west of the structure and along the northern edge of the surface sherd survey grid.

Soil samples were analysed for their lead, copper and zinc concentrations. All three elements contain values in their ranges that exceed the “background” values (table 3.6). However, only lead has an arithmetic mean that exceeds “background”. All three elements show a similar peak in soil concentration which approximates to the position of the proposed structure (figures 13.19a - c). Lead (figure 3.19a) is generally elevated over the whole of the survey grid and shows little relation to other evidence. Values of copper and zinc (figures 13.9b and c) when the anomaly of the structure is removed, are lower in value over the central area than on the periphery of the survey grid. The boundary between higher and lower values of copper and zinc relates well to the resistance features suggesting a walled area outside which manuring and dumping of refuse occurred.

3.4.2.3 TPW2

Discovered in 1985, TPW2 is a large site of 3.4 hectares, situated on the plain to the west of Thespieae. Diagnostic material from the site dates the site as Late Roman (table 3.7). This site has been surveyed for the surface soil tile, magnetic viscosity, magnetic susceptibility and trace element survey (Gaffney, 1990).

The surface distribution of tile (figure 3.20a) shows two areas of high density, one to the north of the survey grid and one to the south-west. These two areas, whose samples also exhibit the largest magnetic viscosity (figure 3.20c) values found in the survey grid, relate to probable structures on the site. The magnetic susceptibility of samples (figure 3.20b) shows their greatest values in the north-west corner of the survey grid suggesting the accumulation of organic matter in this area, which could be confirmed if sherd distribution in this area was investigated.

The soils of the survey grid were analysed for lead and copper (figures 3.21a and b). Values of both these elements exceed “background” values. The greatest values of lead in the survey grid correspond to the areas of greatest tile density and therefore to the structure of TPW2. Copper is greatest over the south-west corner of the survey grid and corresponds to the area of greatest magnetic viscosity.

3.4.2.4 TPW11

This small site, situated on the north bank of the Askris River in the Thespieae Plains West area, was discovered in 1985. The diagnostic material collected from the site suggest a very limited chronological span being the location used in the Roman and Late Roman periods (table 3.8). In addition to the surface sherd density survey (figure 3.22), the site has been surveyed for surface soil magnetic susceptibility, magnetic viscosity and tile density by Gaffney (1990). Chapman (1990) surveyed an additional area for the surface soil concentrations of lead, copper and zinc and tile densities.

The surface sherd density survey (figure 3.23) shows the area of greatest densities to the west of the area of rubble. The surveys of Gaffney (1990) overlay the 20 m by 20m area of greatest sherd densities. The surveys show (figure 3.24) that magnetic susceptibility values vary little across the area, the largest values reside in a band from the south-east side to north-west corner. Magnetic viscosity and tile densities are greatest over the south-west corner of the survey grid. The tile suggests the position of the main structure on the site. Chapman's tile survey (figure 3.25) confirms that this area has the greatest tile densities.

None of the three elements (lead, copper and zinc) have mean values above "background" (table 3.9). However, they all contain values within their ranges that exceed "background". These greater than "background" values are present over the area of highest tile densities and sherd densities (overlay 3) for all three elements (figure 3.26a - c), suggesting elevation in these elements due to the use of the structure. The elements copper and zinc also show higher than "background" values in the north of the survey grid. The lack of other information means that it is impossible to ascribe these to any archaeological activity.

3.4.2.5 VM64

Discovered in 1984, this small site situated in the Valley of the Muses has a dated occupation from the Roman to Late Roman period (table 3.10). The site has been surveyed for surface soil tile density, magnetic susceptibility, magnetic viscosity, and soil copper concentration and lead concentration (Gaffney, 1990). The main area of the survey was a forty metre by thirty metre square with an additional eight, fifty metre transects extending out from the main area to the north, east, south and west (figure 3.27). All methods provide information for the main survey area. Magnetic susceptibility, magnetic viscosity, lead and copper values are provided for the transects.

The tile densities in the grid survey (figure 3.28a) are greatest over the central southern edge. The same area of the survey grid contains the highest values of magnetic viscosity (figure 3.28c) and magnetic susceptibility (3.28b). Magnetic susceptibility values also exhibit their highest values over the south-east corner of the survey grid.

Values of lead do not exceed “background”. Values of copper only exceed the “background” above the highest concentration contour (30 ppm). The highest copper values (figure 3.29a) exist in the central and eastern parts of the survey grid. The majority of the highest values are therefore associated with the soils outside the structure. The highest lead values (figure 3.29b) are in a band running from the central southern edge to just short of the north-western corner. Therefore some of the highest lead values are associated with the structure, but others are also associated with the soils outside the structure.

The values of magnetic viscosity and susceptibility (figure 3.30) show varying results. The magnetic viscosity values for transect 1 A, 1 B, and 3 B, and the magnetic susceptibility values for transect 2 A, 2 B, 3 B and 4 B show a decline in values with distance away from the main survey grid. However, magnetic viscosity values for transect

2 A, 2 B, 3 A and 4 A, and magnetic susceptibility values for transect 1 A, 1 B, 3 A and 4 A show an increase in value with distance from the main survey grid and may reflect an manured infield area around the main grid. A similarly unclear set of results is displayed for the lead and copper soil values (figures 3.31a and b, 3.32a and b). For all transects, both elements show no decline in soil concentration with distance from the main survey grid. The only positive feature of these transect surveys is that values of both elements tend to display less variation over the site than over the surrounding suggesting that human activities on a domestic site cause a lower variability in soil concentration by smoothing out the peaks and troughs in the natural signal.

3.4.2.6 VM89

Discovered in 1984, VM89 is a large site (2ha) situated in the Valley of the Muses. Diagnostic sherds collected from the site suggest it to be a Classical, Roman and Late Roman site (table 3.11). Gaffney (1990) lists the site as being surveyed for its ceramic count, tile count, twin-probe resistivity, and soil magnetic susceptibility, magnetic viscosity, copper and lead values. Gaffney's research was conducted on two small areas of this site and only area 2 provided lead and copper values, to which values for magnetic susceptibility, magnetic viscosity and tile counts can be compared.

The greatest tile counts are detected in the south-west portion of the survey (figure 3.33c). The tile peak is not mimicked by either of the results for soil magnetic susceptibility (figure 3.33a) or magnetic viscosity (figure 3.33b). Values of magnetic susceptibility are greatest in the west and in the east of the survey grid and values of magnetic viscosity are greatest over the central portion of the survey grid. Neither the lead or copper values (figure 3.34a and b) exceed "background". The greatest copper values are in the north-west and south-east corners of the survey grid, areas of higher magnetic susceptibility. The greatest lead values correspond to the highest magnetic viscosity values over the centre of the survey grid. Neither of the elements are associated with the tile suggested structure.

3.4.2.7 VM95

Discovered in 1984, this small site situated in the Valley of the Muses, with a scatter of approximately 2000 square metres is dated to the 4th-3rd century B.C. (table 3.12). The site has been surveyed by Gaffney (1990) for tile counts, and soil magnetic susceptibility, magnetic viscosity, lead and copper values. The information provided by Gaffney does not include any map location, but the surveys all use the same survey grid and can be compared against each other (figures 3.35a - e).

Tile counts suggest a structure in the left of the survey grid (figure 3.35c). Magnetic susceptibility values are greatest in the bottom right corner (figure 3.35a) and magnetic viscosity values are greatest in the top right corner (figure 3.35b). Values of both lead and copper are below “background”. Both elements have their highest values associated with the area of highest magnetic viscosity values in the top right of the survey grid.

3.4.2.8 P4

This site is on the island of Hvar in Yugoslavia. It is a small Hellenistic site covering some 2000 m². In addition to the survey of surface sherd densities (figure 3.36) carried out by (Bintliff, 1988), the site has been surveyed by Watson (1989) for the magnetic susceptibility, and concentrations of lead, copper and zinc of its soils. The greatest sherd densities form a band stretching from the south to the north in the centre of the soil survey grid. The highest values of magnetic susceptibility (figure 3.37) are to the east of and associated with the area of high sherd densities.

The mean values of lead, copper and zinc do not exceed “background” (table 3.13). The ranges of all three elements do contain values which exceed “background”. The area of highest magnetic susceptibility values (overlay 4) is associated with the higher lead values (25 - 40 ppm). The highest lead values (> 40 ppm) are not associated with any of the available evidence. The highest values of copper (> 40 ppm) are associated with the western area of the highest sherd densities. The central portion of the grid, where both the higher sherd and magnetic susceptibility values are, exhibit the higher values of copper (> 25 ppm). The highest values of zinc (> 50 ppm) are not associated with any other available evidence. Higher values of zinc (40 - 50 ppm) are associated with the highest magnetic susceptibility values.

3.5 Conclusions

Regional sample surveys can provide regional averages for elements. Whether these averages can be used as “background” values will depend on the care taken in selecting the site and careful observation of any external influences, such as modern human pollution. The nature of some of the regional results, especially zinc call into question the use of regional samples to provide “background” values. If one considers the whole landscape to be an artefact of human activity then no “background” value is obtainable, only differing levels of activity. Even if there are areas devoid of archaeological and modern activities it is not likely that these soils had similar properties to those of archaeological activity otherwise they too would have been subject to exploitation.

The use of these regional “background” values is further questioned by the values obtained on single farmsites. The average values on these sites are, with only a few exceptions, below the regional average “background” values. The pattern of the results on these sites is often locally interpretable despite being below these regional values. The result often relate to archaeological features. Lead has consistently been highest over the areas of the highest tile counts. These areas of highest tile counts are suggested to be an indicator of the structure. If so, then lead is highest over the structure. Copper sometimes shows the same pattern as lead, but is more often low over the structure and highest around the structure. Zinc results are not clear, though at PP17 higher values do appear to be associated with the enclosure immediately around the structure.

The size and intensity of the site is proportional to the values of lead, copper and zinc found on a site. Thespieae city clearly shows the intensity of activity at city sites. Values are well above the regional “background” and show a marked decrease over the wall of the city which is mimicked in the sherd data. Inside the walls the values increase towards the centre of the city.

The previous work does not provide conclusive theories, but does show broad trends which are worthy of further investigation. The aim of this thesis must be to investigate further;

- a) Scale of occupation and enhancement.
- b) Duration of occupation and enhancement.
- c) How human occupation causes enhancement.
- d) Time since abandonment and the degree of amelioration.
- e) The establishment of background values based on pedological and geological conditions.

CHAPTER 4

RETENTION OF TRACE ELEMENTS IN SOILS

4.1 Introduction

The elemental signature detectable by trace element analysis on archaeological sites and the archaeological landscape in the present day is dependent on two factors; the original input of trace elements to the soil and the retention of those elements in the soil environment. The ideal element for an archaeological indicator would remain in the position of original deposition indefinitely. This chapter will discuss the means of retention for trace elements in the soil environment, the influences of soil properties on the retention, and the tenacity of the individual elements in the soil environment. This will provide information for a predictive model of the trace element signature in the soil from an archaeological activity (chapter 7).

4.2 Soil Properties and Trace Element Retention

Trace metals are retained within the soil system as bound constituents of (i) inorganic and (ii) organic soil colloids. The key features for the retention of trace elements in the soil environment (Alloway, 1990) are:

- the presence of soil colloids, both inorganic (clay) and organic colloids,
- the hydrogen potential (pH),

- and the reduction-oxidation potential (Eh).

4.2.1 Soil Colloids

Soil colloids are important to the chemical behaviour of the soil. They provide the sites to which trace metals bond. Their importance is due to their large specific surface area, as one gram of clay has at least one thousand times the surface area of one gram of sand (Brady, 1990).

Colloids can be formed in two ways. Firstly, rock fragments and other inorganic inputs to the soil are physically and chemically weathered to form the inorganic soil colloids. They may also be formed by the existence, degradation and decomposition of plant and animal material (e.g. carbohydrates, proteins, nucleic acids) in the soil. This is known as the organic soil colloid fraction (Tan, 1993).

4.2.1.1 Inorganic Soil Colloids

These are the clays. The term clay and colloid are used synonymously in soil science. True soil colloids only account for the very fine clay fraction ($<0.002\text{mm}$) and smaller (Tan, 1993). Clays can be divided on the basis of their structure. These are:

- Crystalline,
- Poorly crystalline or structurally disordered,
- Amorphous to X-ray diffraction.

Crystalline clays are characterised by their leaf or layer-like structure. These are termed the phyllo-silicates (phyllon=leaf, Greek). Their main components are the sheets of

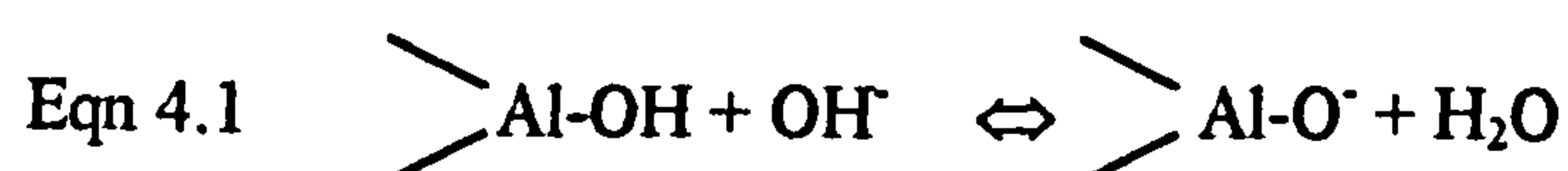
silica tetrahedra and alumina-magnesia octahedra which are bound together into layers by the sharing of oxygen atoms. The arrangement and number of sheets varies between clay types and is responsible for a major part of their physical and chemical characteristics.

Amorphous clays have no recognisable shape or geometric internal arrangement of atoms under X-ray diffraction analysis. They may occur as discrete, independent minerals or as coatings around crystalline clay particles and other inorganic soil constituents (Tan, 1993). They are primarily hydrated oxides of iron and aluminium, such as goethite (α -FeOOH), the most common hydrous iron oxide.

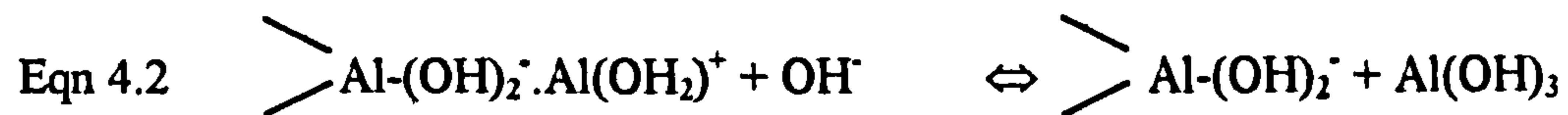
Ions in the soil solution are electro-statically adsorbed onto clay particle (micelle or micro-cell) surfaces by the creation of a charge on the clay. There are two types of electro-static charge that can be created: constant and variable.

Constant charge occurs by the isomorphous substitution of silicon or aluminium and magnesium from their tetrahedral and octahedral sites respectively. An element may be substituted by another of similar ionic radius. Both an electro-positive and electro-negative charge may be created and, therefore the clay can adsorb both cations and anions. An example of a electro-negative charge would be the replacement of a silica ion (Si^{4+}) by an aluminium ion (Al^{3+}) in the tetrahedral sheet. That of an electro-positive charge would be the replacement of a magnesium ion (Mg^{2+}) by an aluminium ion in the octahedral sheet.

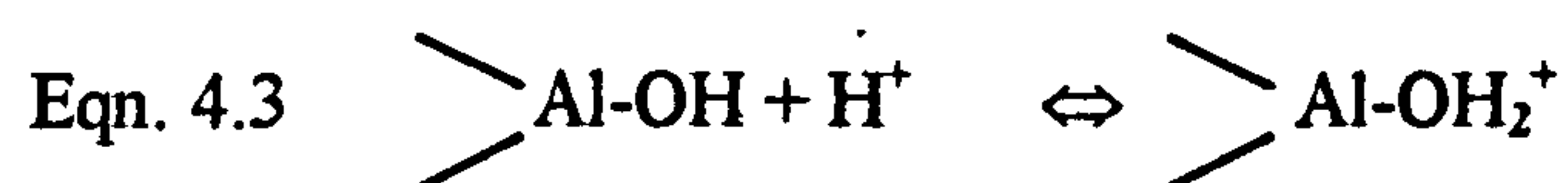
Variable charge (pH dependent charge) occurs as a result of dissociation or protonation of the hydroxyl groups present in the octahedral sheet of clays. In alkaline environments the high hydroxyl ion content of the soil solution promotes the dissociation of hydroxyl groups in the alumina-magnesia octahedral sheets (eqn. 4.1). This produces an electro-negative charge on the clay which promotes cation adsorption.



At low pH, aluminium hydroxy ions ($\text{Al}(\text{OH}_2)^+$) can block cation exchange sites, thus negating any charge. As pH rises hydroxy ions react with the attached aluminium hydroxy ion and forms soluble aluminium hydroxide ($\text{Al}(\text{OH})_3$), which is brought into solution, thus freeing the cation exchange site of the clay micelle (eqn. 4.2).



An electro-positive charge can also be created by protonation (eqn. 4.3). In very acidic conditions the uncharged aluminium hydroxyl (AlOH) accepts a hydrogen ion (H^+).



The degree and type of electrostatic charge varies between clay minerals. Kaolinite has very little permanent charge as very little isomorphous substitution can occur. Its charge is mostly pH-dependent through the dissociation of hydroxyl groups from the octahedral sheet.

Montmorillonite clay has mostly constant charges. There is very little pH dependent charge due to the octahedral sheet being surrounded by tetrahedral sheets and, thus being less prone to dissociation of its hydroxyl groups.

4.2.1.2 Organic Soil Colloids

The organic portion of the soil is composed of living or dead plant and animal material. Numerous products exist but only a few are present in detectable amounts (Tan, 1993). These are:

- Carbohydrates,
- Amino acids and proteins,
- Lipids,
- Nucleic acids,
- Lignin,
- Humus.

Out of these, humus is the most important to the chemical nature of the soil. It is considered an end product of organic decomposition. It is defined by Brady (1990; p.289) as *"a complex and rather resistant mixture of dark brown amorphous and colloidal organic substances that results from microbial decomposition and synthesis and has chemical and physical properties of great significance to soils and plants"*. It is due to its resistant nature and the constant supply of new humus that it tends to be high in surface soils. It accounts for between 60 and 80% of soil organic matter (Brady, 1990).

The adsorptive nature of organic material is due mainly to the presence of carboxyl and phenolic-OH groups and, to a lesser extent, such processes as complex formation and chelation.

The electro-static charge that occurs as a result of the dissociation of carboxyl and phenolic-OH groups is similar to that of silicate clays in that it is pH dependent. The charge increases with pH. Below pH 3 the electro-static charge is small, if not zero. At pH 3 the carboxyl groups start to dissociate. At pH 9 the phenolic-OH groups start to dissociate (Tan, 1993).

Complex formation and chelation are two terms that are often used synonymously and they are similar. Both these compounds are formed by Lewis acid-base reactions between a metal ion and ligands. The metal ion (complex ion) acts as a Lewis acid (it accepts a pair of electrons), and the ligand as a base (it donates a pair of electrons).

However, there is a distinction between the two. A complex is a compound in which the metal ion bonds with a number of ligands defined by the co-ordination number of the metal ion. A chelated ion is a metal ion which is bound to a single ligand by two or more sigma bonds (Kotz and Purcell, 1987). The most common ligands in the soil are humic and fulvic acid (Brady, 1990). It is the nature of the ligand that defines the mobility of the chelated or complexed metal ion, for example fulvic acids are soluble and therefore the metal ion bound with them is far more mobile than one which is bound to a humic acid (Tan, 1993).

4.2.2 The hydrogen potential (pH)

The hydrogen potential (pH) of a soil applies to the H^+ ion concentration in the solution present in soil pores, which is in dynamic equilibrium with the predominantly negatively charged surfaces of the soil particles. H^+ ions are strongly attracted to the surface negative charges of soil particles and have the power to replace most other cations. In general, cations are most mobile under acid conditions due to the excess of H^+ ions present in the soil solution (Alloway, 1990, 8-9).

Soils generally have a pH within 4 - 8.5, owing to the buffering effect of hydroxyaluminium ions in acid conditions and calcium carbonate in alkaline conditions. The maximum range of pH conditions found in soils is 2 - 10.5 (Alloway, 1990, 9). Soils of arid and semi-arid climatic regions lack the leaching of temperate and humid climatic regions and tend to have a soil pH in the range of 7 - 9 (Brady, 1990, 242).

4.2.3 The reduction-oxidation potential (Eh)

The reduction-oxidation (redox) potential (Eh) of a soil is the negative common log of the aqueous free electron activity where the redox reaction is in equilibrium. The level of

the redox potential can alter the chemical form of an element in two ways: direct or indirect. Direct alteration causes the oxidation state of the element to change. Indirect alteration causes the change in oxidation state of another element with which the element can bond (Tan, 1993).

The colour of the soil can indicate whether the redox potential of the soil environment is oxidising or reducing. Oxidising soil environments (high Eh) are red, yellow or reddish-brown in colour. A blue or grey soil colour indicates a reducing (low Eh) soil environment (Brady, 1990). The redox potential of the soil environment is important to the retention of elements in the soil, as oxidising environments promote the retention of elements through the oxidation of elements into less soluble forms (Alloway, 1990).

4.3 Element retention in soil

The evidence for the tenacity of individual element retention in the soil environment comes from a number of sources: Eh-pH diagrams combined with chemical data books, laboratory based soil leaching experiments and the observation of soil profiles on sites of historic contamination.

The soils of the Boeotia region are oxidising and alkaline (pH 6 - 8). Based on this, the Eh-pH diagrams (Brookins, 1988) would suggest that the elements reside in the forms stated in table 4.1. The solubilities of these forms can be found in chemical data books (e.g. Weast, 1987) and are listed in table 4.1. These data would suggest that the most insoluble elements and therefore the most likely elements to be retained in their position of deposition in Boeotian soils are aluminium, cerium, scandium, cobalt, chromium, copper, nickel and vanadium. Other elements of low solubility are iron, lead, zinc and barium. In comparison with the other elements in the table, phosphorus is soluble.

Laboratory experiments involve the leaching of columns of soil with extracts such as EDTA which replicate the equivalent of years of precipitation. Korte *et al.* (1976) studied the mobility of eleven elements in ten soils. Six of these elements: chromium, copper, nickel, lead, vanadium and zinc were analysed as part of this thesis. Copper and lead were the most immobile elements, exhibiting low mobility in all but sandy soils. Nickel and zinc exhibited low mobility in four of the soils, all were clay soils. Vanadium and chromium are anions and only exhibit low mobility in clay soils. The observation that copper, lead and zinc are of low mobility was confirmed by Miller *et al.* (1983), who in a similar study to Korte *et al.* (1976) subjected sandy soils to the equivalent of ten years rainfall and found that all these elements remained in the upper 5 cm of the soil.

The observations in profiles of sites of historic contamination further supports the evidence for the immobility of certain elements. A study of the downward migration of the elements copper, lead and zinc, nine years after the soils had been contaminated with sewage sludge containing industrial effluent, showed no movement down the profile (Williams *et al.*, 1987).

Kabata - Pendias and Pendias (1992) list the elements Vanadium and zinc as highly mobile in neutral or alkaline soils. The elements barium, cobalt, copper, manganese, nickel and lead are listed as being of low mobility in the same soils, and aluminium and iron as of very low mobility. The elements cobalt, copper and nickel are listed as both low and very low in mobility. Under lysimetric conditions zinc has a half-life residence time in the soil of 70 - 510 years, copper 310-1500 years and lead 740 - 5900 years (Kabata-Pendias and Pendias, 1992).

4.4 Conclusion

The retention of elements within the soil environment is dependent on the chemistry of the element and the nature of the soil. An alkaline, oxidised soil with a high clay content is more likely to retain elements than an acidic, reducing, sandy soil. The elements vary in their mobility in the soil from more mobile phosphorus, vanadium and zinc to immobile aluminium, cerium, scandium, cobalt, chromium, copper, nickel.

For the purpose of placing this information in a model the following groupings and half-life soil residence times are assumed.

- High mobility elements including magnesium, calcium, phosphorus, lanthanum, strontium, vanadium, zinc, are ascribed the half-life of 500 years.
- The low mobility elements manganese, lead, barium are ascribed a half-life of 1000 years.
- The very low mobility elements aluminium, iron, cerium, scandium, cobalt, chromium, copper, nickel are ascribed a half-life of 1500 years.

The elements potassium and yttrium are placed in the high mobility group as insufficient data was available on yttrium. Potassium, being a major element of importance to plant growth, is assumed to be of relatively high mobility within the soil environment in terms of removal in plant material.

CHAPTER 5

FIELD SURVEY AND GREEK ARCHAEOLOGY

5.1 Introduction

Until recently, the efforts of archaeological study in Greece have concentrated on the artefact rich urban palatial and temple sites (Gaffney, 1990). Over the last quarter of a century, an increasing effort has been directed towards the study of the archaeology of the landscape through field survey. Such surveys, involving the meticulous counting of surface ceramic concentrations and study of artefact assemblages, have highlighted changing patterns of human settlement and activity. It is the purpose of this chapter to give an overview of the survey practice, problems, interpretation and results.

5.2 The Origin of Artefacts in the Landscape

The discipline of field survey archaeology relies on there being discernible patterns in the density of artefacts on the surface of the soil. In Greece, surveys have found that the artefacts left by our predecessors form a continuous carpet of material across those areas of the landscape amenable to human settlement and exploitation (Bintliff and Snodgrass, 1988). The presence of settlement and activity foci are defined as discrete concentrations of artefacts at a higher density than the continuous carpet, “background” of artefacts or by the presence of distinctive types of artefacts (e.g. a surface scatter containing masonry, floor and roof tile would indicate a structure). The presence of high concentrations of

artefacts over sites is easy to understand. When a site becomes deserted the structure will decay, producing a spatially discrete concentration of building materials such as roof tiles, floor tiles, masonry and fragments of agricultural processing features such as press beds. Sherd concentrations over the site will be high, as continual occupation will have resulted in the breakage and disposal of pottery. The broken fragments of pottery may have been used in the construction of walls, levelling and filling of floors or discarded onto the domestic rubbish heap.

The origin of off-site scatters (the carpet of material) is less obvious. Models have been proposed and discussed (Bintliff and Snodgrass, 1988; Hayes, 1991; Alcock *et al.*, 1994; Snodgrass, 1994) for the origin of off-site scatters. These models include accidental loss, less intensively used activity areas, natural transportation and post-depositional disturbance, and collection of refuse for use as a manure. The first two models, though contributing to the carpet of material, are not the primary origin. Accidental loss, such as the pot falling from the back of a donkey (Bintliff and Snodgrass, 1988), could not account for the sheer quantity of off-site artefacts. The second model, less intensively used activity areas, should still be definable as a site, producing lower density discrete concentrations than the more intensively used sites and still distinct from the carpet of material. A clue to the origin of off-site scatters is given by survey results (figure 5.1). These show that sherd concentrations decrease with distance from the site. This pattern could occur from the final two models. The first, post-deposition disturbance by natural agents such as wind and rain and by human activities, especially ploughing, would disperse artefacts from the site in a pattern, which would strongly reflect the local topography and physical features of the landscape (e.g. walls, streambeds). Figures 5.2a and 5.2b illustrate the effect of post-deposition disturbance on the expression of surface soil sherd densities. Each diagram shows a site positioned on a slope. Figure 5.2a shows the sort of pattern that would arise if topography and erosion were the only two influences on sherd movement. Sherds from the

site are transported down the slope by natural and human erosion influences, the resulting pattern is a rapid decline in sherd density with distance upslope from the site and an extension of sherd densities down slope from the site. Figure 5.2b illustrates the pattern if an obstacle existed on the slope which impeded the movement of the sherds. The sherd density map would show the same rapid drop in density upslope and the same downslope movement of sherds to the position of the obstacle. The obstacle prevents further transport of sherds down the slope and therefore produces an abrupt drop in sherd densities. The obstacle also causes the accumulation of sherds on the upslope side and this may produce a “ghost” site if the soil is also being deflated. However, the distribution of sherd densities shows a concentric pattern around sites with equal decline in sherd densities upslope as downslope. This indicates that post-deposition disturbance is not the primary agent in the production of a continuum of material across the landscape. The pattern illustrated by survey results is most likely to be the result of the final model, manuring, with the others factors adding to and altering the pattern formed.

The systematic collection of human wastes, animal wastes and rubbish in cities for use as a manure on the surrounding fields is well documented in history. The practice was observed around Chinese cities, where the fields around the city formed concentric rings of green, becoming less verdant with distance away as the amount of manure decreased (Chisholm, 1979). This concentric pattern can be observed in survey results (figs. 5.1 and 5.3). The intensity of manuring and therefore sherd concentrations is greatest around cities, but is visible around individual farmsteads. The area extent of sherds is related to settlement size (table 5.1).

The pattern of sherd distributions suggest manuring which in turn suggests intensive farming of the land in the immediate proximity of sites. The manuring helped maintain the fertility and condition of the soil.

Once incorporated as part of the soil the artefacts are subject to attrition and displacement through the action of cultivation, geomorphic processes and bioturbation. Attrition is responsible for destruction of artefacts over time, but more importantly it is responsible for removal of dateable features from artefacts (Gaffney and Tingle, 1985). In part the amount of attrition is dependent on the nature of the artefact, harder materials last longer and protruding parts are more susceptible to being broken off. For ceramics the firing temperature is important, as the lower the firing temperature the more susceptible the ceramic is to damage (Skibo *et al.*, 1989).

The action of cultivation causes abrasion and impact damage to artefacts. The abrasion of artefacts is greatest in wet sediments (Skibo and Schiffer, 1987). At Camel Down (Reynolds, 1990a, 159-164) an area of farmland came under modern, intensive cultivation, with a September ploughing which turned over the soil to a depth of 200 mm, exposing the sherds to frost action and general weathering. In spring the weathered sherds were subject to the impact of a cultivation regime which included the use of a multi-tined chisel plough acting to a depth of 150 mm, a spike harrow and a heavy roller. The area was field walked in 1968, 1978 and 1988. The results show a decline in the mean weight and mean area of the sherds (table 5.2), demonstrating the potential for loss of archaeological information through intensive cultivation. The geomorphic processes, such as freeze and thaw, wetting and drying, which are important in reducing the ability of artefacts to resist damage from cultivation affect only those artefacts that reside in the top fifty centimetres of the soil (Kirkby and Kirkby, 1976).

Displacement of artefacts is important to the interpretation of surface scatters. Spreading out from the point of original deposition and subsequent re-concentration in new locations (e.g. in a hollow) can lead to misinterpretation of the surface scatters. Experiments at Butser ancient farm project have investigated sherd movement. They have shown over an eight year period (1981-1989) of spring and autumn cross-ploughing with a

winged ard, that at the end of any cultivation cycle $16 \% \pm 5 \%$ of the sherds held in the plough-soil are present on the surface (Reynolds, 1990b). Also, out of thirty six sherds placed at regular intervals throughout the field only two sherds exited from the thirty by thirty metre cultivation plot.

5.3 Survey Methodology and Site Location

The aim of field survey is to create the best reconstruction of the past landscape through the evidence provided by surface artefacts. For this to be possible it is important that the survey methodology detect a representative sample of all types of settlement and activity foci throughout its region. Only by the intensive field walking of contiguous blocks of landscape large enough to contain all types of site can this be achieved (Bintliff, 1995).

A survey of the island of Melos divided the area into strips one kilometre wide (Renfrew and Wagstaff, 1982). One in five of these strips was surveyed (20 % transect survey). This method would only work for sites that are uniformly spread across the landscape. If at any time the settlement pattern became nucleated then this methodology would stand a 80 % chance of missing them. This would lead to an inaccurate conclusion which suggested a decline in population. The error associated with 20 % transect survey method was tested in the east Hampshire survey, on the settlement pattern of the modern landscape (Shadla-Hall and Shennan, 1978). The test showed that such a survey would give a representative sample of the farms which are dispersed across the survey area, but it would miss the main town of the area.

A one hundred per cent survey would detect all levels of site. The survey around the ancient city of Hyettos, Boeotia highlighted the advantage of this type of intensive survey. The city of Hyettos ceased being occupied in the sixth or seventh century A.D. and

was only reoccupied in the high medieval period. In the countryside surrounding the site of Hyettos city, the occupation of this region continues. Within a strip five hundred metres west to east, a chain of five discrete settlements each relating to a different phase, indicate a continuous occupation of the region from the seventh/eighth century A.D. to the late nineteenth century. It is possible that a 20 % transect survey would have completely missed these sites, leading to a deserted landscape interpretation (Bintliff, 1995).

100 % survey does not detect every archaeological site in the survey area. The invisibility of archaeological sites causes a loss of information (site loss). If site loss is great and the surveyor remains ignorant of it, the interpretations based on the collected data could be seriously distorted from the true pattern of archaeological sites. It is therefore necessary to be aware of the causes of site loss and to account for their potential in the collected survey data. The following factors cause site loss;

- Archaeological visibility of culture,
- Size of site,
- Geomorphologic processes and sea level change,
- Cultivation practice,
- Conditions of survey.

The first two factors are the archaeological site loss factors, those that are present at the time the deposit was laid down. The degree to which a culture leaves artefacts which are discernible to the archaeologist is termed the “archaeological visibility” (Barker, 1995). In the Biferno Valley survey, Barker (1995) compares the visibilities of the classical and the medieval periods. During the classical period there was an abundant rural population in a dispersed settlement pattern. Structures contained brick and tile, and there was extensive use of pottery. The classical period has a high archaeological visibility. In contrast, during

the medieval period the rural population was far less than that of the classical period and the pattern of settlement was nucleated. The nucleated sites are often located on hill-tops which are now tree-covered, making survey difficult. Combined with the fact that structures were composed of wood, and pottery was poorly made and less likely to be preserved, means that archaeological visibility of this period is poor.

Sites of archaeological activity exist on all scales from the industrial city down to the temporary camp of a hunting party. It is the latter scale which is subject to site loss. Sites producing surface scatters of archaeological material less than 20-30 m across could be missed by an intensive survey with a commonly used 15 m separation between fieldwalkers. This grouping includes rural cemeteries, rural shrines, farmsheds, and small farmsteads whose scatters have been reduced in size and partly buried by cultivation and obscured by vegetation (Bintliff, 1995).

Geomorphological processes and sea level changes reduce the surface area available for the detection of sites. The potential invisibility of a site due to these two processes increases with the age of a site. For the area covered by the Southern Argolid survey (Jameson *et al.*, 1994) 56 % of the Upper Palaeolithic land surface is now either submerged (48 %) or buried (8 %), whilst for the Classical period only 11 % is now submerged (6 %) or buried (5 %). Fluvial processes in the valley bottoms producing alluvium, and hill-slope processes towards the edges of the valley producing colluvium, cover parts of the landscape making them invisible. Sea-level changes, resulting in the flooding of low-lying areas, also remove some of the archaeological evidence. In the Southern Argolid survey (Jameson *et al.*, 1994), sea level inundation has submerged a large portion of the landscape.

The difficulty of carrying out systematic survey in woodland has already been alluded to. The vegetation cover of the area, here referred to as the cultivation practice, affects the amount of bare soil visible and therefore the surveyor's ability to record sherds

in the surface soil. It is necessary to correct for the influence of vegetation cover on observed surface soil sherd concentrations. The Boeotia survey (Bintliff, 1992a) gives a visibility count to each unit of the survey area. The count is from nought to ten. Nought represents a unit where the soil is totally covered by the vegetation and a count of ten represents bare soil. Values in between represent tenths of the soil visible; e.g. a count of 3 represents $\frac{3}{10}$ of the soil area in the survey unit visible. These counts can then be used to correct the recorded concentration of sherds for surface visibility, as shown in the example from Hvar, Yugoslavia (figure 5.4).

The final factor, the conditions of survey, includes such influences as the time of day, weather, commitment of surveyors and recent cultivation of land. The first three influences overlap. A survey at the beginning of the day is likely to be more reliable than a survey at the end of the day. Likewise, if the weather is not amenable to survey (i.e. too hot or raining) then the survey is likely to be less reliable than a survey carried out in perfect weather conditions. The time of day affects the angle of light on the land, which will pick out different sherds at different times of the day. Rain may rinse the soil off some sherds and make them more visible to the surveyor. Recent cultivation of the land will bring fresh sherds to the surface which will be more recognisable to the surveyor than weathered sherds. The nature of survey conditions affects the reliability of survey, a factor that can be recognised and acknowledged in results, but not easily corrected for.

The problems of site visibility and the skill, experience and commitment of each surveyor affect the reliability of the survey results. Some of these factors (e.g. surveyor, cultivation practice, conditions of survey) vary from one survey season to the next. This produces the question "how reproducible are the results of survey?". The answer is that the pattern produced by surface finds is reproducible, but the concentration may vary. Variations in concentration results in the "fade and return" of individual sites and the re-interpretation of a group of sites into a large single site complex or vice versa. Site C36 in

the Biferno Valley survey (Barker, 1995) was surveyed in 1974 and interpreted as a group of individual sites (figure 5.5). A repeat survey in 1978 produced a similar pattern, but some of the peripheral sites had faded and the central group of sites were re-interpreted as a single large complex (figure 5.5).

5.4 Site dating and interpretation of function

A survey produces a collection of site localities, which then needs sorting into time periods and activities, if a reconstruction of the archaeological landscape is to be achieved. The date of a site is deduced from such diagnostic sherds as can be found on the site. The degree to which diagnostic sherds can date a site is dependent on the type of sherd. The best diagnostic sherds are those that can be confined to a specific century or period, these are termed period-specific or definite sherds (Cherry *et al.*, 1991). Cherry proposes three other groups of diagnostic sherd, which in descending period specificity are: possible definite, overlap, possible overlap. Possible definite sherds are those sherds which may indicate a specific period and definitely no other. Overlap sherds are those which could be from two or more periods. Possible overlap sherds are ones which may indicate two or more periods and are definitely not from any other time period. The number of diagnostic sherds is small and the number of definite diagnostic sherds is a smaller proportion of this. For example, out of 1300 diagnostic, on-site sherds for the Archaic to Roman period in the Northern Keos survey (Cherry *et al.*, 1991) only 35 % (455 sherds) can be dated to a single period, 10 % (130 sherds) to a single century and 75 % (1075 sherds) to only two periods. These 1300 sherds come from 58 sites. This means that on average the site is determined using 22-23 sherds, the definite dating of a site to a single period is on six to

seven sherds. Such a small number of sherds could be biased to a single period by definite sherds.

With the date of each site established, one can produce maps of site distribution through the landscape for each period. What do these distribution patterns mean? In periods of highly dispersed site patterns, are people living in more areas of the landscape or are these dispersed sites only stores and stock-folds? To create more meaning from the survey data the function of each site must be established. The function of a site is defined from several sources of evidence: (1) the size of the site; (2) the nature of any architectural remains and topographical features; (3) the assemblage of artefacts from the site. Table 5.3 illustrates how each of the above sources of evidence leads to a definition of the site activity. For example, a farmstead would produce a scatter often smaller than two hectares containing evidence of a structure, and an assemblage which would contain objects such as lamps, storage vessels, cooking vessels, fine wares, millstones, loom weights and oil press beds. Sites of this nature are apparent in survey results, but like the occupancy of a site the continuity of function throughout the active life of the site cannot be presumed. One site probably went through a number of functions.

5.5 The Pattern of Settlement in Greece

The previous sections of this chapter have discussed the methods and problems of survey archaeology and the interpretations made from the data. In this last section, the general trends of site distribution and function will be highlighted and discussed. The information collated here comes from the Boeotia (Bintliff, 1985; Bintliff, 1991), the Southern Argolid (Jameson *et al.*, 1994), Northern Keos (Cherry *et al.*, 1991) and Gubbio (Stoddart and Whitehead, 1992) surveys.

The surveys produce some very similar trends. The main trends are listed below:

- A rise in the total number of sites found in each survey starting in the Archaic period and peaking in the Classical period. The rise in the total number of sites is due to a more dispersed pattern of settlement with a large increase in the number of individual farmsteads. Also in this period towns reach their peak. The total number of sites declines during the Hellenistic period.
- The total number of sites drops rapidly during the late Hellenistic period/Early Roman period and reaches a low in the Early Roman period. In Boeotia the decline in rural sites is dramatic. Four out of every five outlying sites becomes deserted during the period between 300-100 B.C (Bintliff, 1991). Towns contract in size and some are destroyed by invading Roman armies e.g. Haliartos in the Boeotia survey (Bintliff, 1991).
- During the Middle Roman and Late Roman periods the number of sites increases again, reaching a peak in the Late Roman period. The rise in this period is due in part to the establishment of individual farmsteads as in the Classical/Hellenistic period, but primarily to the establishment of larger habitations such as villa complexes and villages. Many of the new sites are in fact re-occupation of deserted Classical sites. In Boeotia it is estimated that two-thirds of all Classical sites are re-occupied in the Late Roman period, though not all recover their Classical size (Bintliff, 1991).
- Subsequent to the Late Roman period there is a decline in the number of sites and a trend towards nucleation in the settlement pattern. Village sites tend to be located either in hill-top positions, probably for defence, or in low-lying areas close to good agricultural areas (Bintliff, 1985).

The changing patterns of settlement have in a number of texts been viewed as either nucleation or dispersion (Jameson *et al.*, 1994). The two need not be mutually

exclusive. In the Archaic-Classical period there is a dramatic increase in the number of sites, due to an increased dispersion of settlement throughout the landscape, but there is also an expansion of towns and villages. The increase in nucleated sites and the increase in dispersed sites is, undoubtedly, due to an expansion in the size of population. The number and size of sites can indicate whether the population is growing or being reduced, but it cannot easily be used to provide an actual figure for population size (Bintliff, 1997a). The survey results can also be used to establish how population affects the use of the landscape. The Archaic-Classical period produces a large number of rural sites which have agricultural processing equipment, suggesting more widespread intensive farming of the landscape in this period and a pattern of land-holding which may be different from that in recent Greek history (see Chapter 6). The widespread intensive farming of this period is also indicated by the dominance of this period's sherds in the surface artefact scatters of the landscape (figure 5.6). Even in the Roman period, when many of the Classical sites were re-occupied the ceramic counts for landscape survey transects does not compare in number to the Archaic-Classical.

5.6 Conclusion

Survey is best carried out on contiguous blocks of land at one hundred percent coverage by intensive methods. This is more likely to produce a representative sample of all sites in the survey area. Survey archaeology can never locate every site in its study area due to factors which cause site loss, but understanding these factors can allow the surveyor to attempt to compensate for the loss in the interpretation. Sites can be dated to a period or range of periods and assigned an activity based on the assemblage collected and the size of the site. The period and function of the site should be given with the caveat that the site

may have gone in and out of use during that period and may have changed function several times.

Results from surveys across Greece show some very similar patterns. These indicate periods of population expansion during the Archaic-Classical period and in the Late Roman period, which led to an increase in the number of sites in both periods, expansion of nucleated sites in the former period, and a more widespread pattern of settlement in both periods. The more widespread pattern of settlement combined with the quantity of agricultural processing artefacts found at rural sites suggests a more intensive use of the landscape, which is also reflected in the dominance of off-site scatters for the Classical period. Settlement in this Classical period is most likely to produce changes in soil chemistry due to its intensive nature and therefore the following chapters will be devoted to the archaeology of one of the periods of high population, the Classical period.

CHAPTER 6

CLASSICAL GREEK AGRICULTURE

6. 1 Introduction

What did the Classical agricultural landscape look like? The purpose of asking this question is to illustrate what activities were evident in the classical landscape based on the available evidence. Once the probable activities have been identified then the activities can be placed in a model and the probable changes in the elemental composition of the soil can be calculated. These theoretical alterations to the elemental composition of the soil can then be used to interpret observed soil elemental data from archaeological investigations. The Classical period has been chosen as it is one of the two periods (the other being the Late Roman period) that there is evidence of settlement in dispersed farmsteads. The Classical period was chosen in preference to the Late Roman because the ubiquitous spread of ceramic material across the greater parts of the landscape is almost all Classical (figure 6.1)

To provide an answer for the initial question it can be broken down into smaller questions. Where did the farming community live and what structures existed? How was land divided? What were the principal crops and cultivation strategies? What livestock husbandry was practiced? The individual questions can be brought together to create an image of the landscape.

We have four main sources of information; contemporary literature, archaeological discovery, surviving implements and practice, and representation in art. On the subject of Greek agriculture there is very limited information from these sources (White, 1988),

though recent surveys have improved our knowledge of settlement and use of the countryside. Varro gives an impressive list of fifty contemporary writers on the subject of Greek agriculture or topics relating to Greek agriculture (White, 1970). Very few of these works remain, among those extant are works by Democritus, Theophrastus, Xenophon, Aristotle (White, 1970).

6.2 Where Did the Farming Community Live?

There is little information on the occupation of the landscape and it is still a subject of much debate. What is known comes from documents, archaeological excavation and from the recent landscape surveys, such as in Boeotia. Documents and archaeological excavation tend to concentrate on the lands of the wealthy and not the more numerous peasant farmers. Eighty percent of the population of the polis of Athens were peasant farmers (Lohmann, 1992). Foxhall (1992) gives a lower figure of 68 %, farming 55 % of the available cultivable land in classical Attica, in units of less than ten hectares. The remaining cultivable land was owned by the wealthy elite, about 10 % of the population. In Boeotia, it is argued that during the Classical period 70 % of the population lived in urban sites and commuted out into the fields and the remaining 30 % lived in the countryside (Bintliff, 1997a). We may suggest that in Boeotia numerous households existed in the countryside carrying out subsistence agriculture on smallholdings. This image of dense rural occupation in Classical Greece is supported by the archaeological surface survey evidence (Bintliff, 1988).

Each area (deme) would have its political centre. This was usually manifest as a nucleated settlement of village or town scale. An excavated example of a village at Kalabokas in Attica shows them to be made up of loosely connected buildings, with broad

streets and extensive, enclosed but unbuilt areas thought to be gardens (Lohmann, 1992). At this particular example, a tower was the central feature. These towers, more common in the rural farmsteads of Attica, were stronghold, storage and living areas (Lohmann, 1992). Agricultural towers are almost absent from the Boeotian landscape (Bintliff, pers.comm.)

The classical landscape outside the nucleated settlement contained numerous farmsteads. The structure of these farmsteads can be observed from examples that have survived in remote parts of Greece and Greek colonies. The most well cited rural sites are the country houses at Vari and Dema (Jones *et al.*, 1973). The connection of these to agriculture is uncertain, but the evidence of their isolated position, presence of storage vessels and beehives are strongly suggestive of agriculture. These structures are commonly rectangular. They vary in size from the larger sites, such as the country house near the Cave of Pan at Vari (Jones *et al.*, 1973), which is 20 m by 15 m (figure 6.1), to the smaller, simpler structures such as the small country house near Vari (Isager and Skydsgaard, 1992), which is 15 m by 10 m (figure 6.2). Other examples include a country house from the Attica survey (Lohmann, 1993), which is 20 m by 15 m (figure 6.3) and from the Boeotia survey, the resistivity derived plans of two small country houses, PP17 (figure 6.4) and VM70 (figure 6.5). PP17 is 10 m by 15 m with an exterior courtyard. VM70 is a square house 15 m by 15 m.

A common feature of these structures is the courtyard, which is apparent in figures 6.1 - 6.3. PP17 does not have a courtyard, but does appear to have an attached yard. VM70 may have a courtyard but this is not discernible in the resistivity plot. Around this courtyard are the different rooms and areas for habitation, storage, food processing and koprones (manure pits). Ault's (1994) investigation of houses in the small polis of Halieis showed individual press room and kopron area (figure 6.6). Other features outside the house include animal pens and threshing floors (figure 6.7).

In addition to the living areas, animal pens, and food processing and storage areas there was probably an area devoted to the production of labour intensive crops or “garden” crops such as peas, beans and other vegetables. The existence of gardens in the Classical Greek world is known, though the evidence is scarce, and has been collated in Osborne (1992). Gardens (*képos* is conventionally translated as garden) are mentioned in a number of legal documents. Osborne (1992) quotes six cases where the garden was used as a security on a loan. The association of house and garden is given definition in the return of exiles from Delphi to Tegea. Each exile was to be given a house and garden, and the garden was not to be more than 30 m from the house. The area outside the house and defined by the ditches and terraces at VM70 (figure 6.5) may represent the garden area. The intensive nature of management of the garden is inferred in the use of the garden with its elaborate irrigation channels as an analogy for the flow of blood in the body by the philosophers Plato and Aristotle (Osborne, 1992).

6.3 The Pattern of Land-Holding

The pattern of land-holding is unknown for the Classical Greek period. Some workers have suggested a fragmented land-holding pattern akin to that in existence today (Gallant, 1991; Foxhall, 1986). Others have suggested that the fields were more focused around a farm centre in the Classical period (Whitelaw, 1991; Bintliff, pers.comm., 1995).

In the fragmented land-holding system each household owns a number of small land plots scattered across their region. There are two mechanisms that encourage the development of a fragmented land-holding pattern; partible inheritance and risk management. Partible inheritance (equal portions to all sons or heirs) has been the main type of inheritance, at least, since the time of Hesiod and leads to the fragmentation of

land-holdings (Foxhall, 1986). The second mechanism of risk management dictates that the fragmented land-holding pattern is beneficial as it allows the exploitation of different micro-environments. Thus, crops can be grown on the most suitable land and the risk of all fields being damaged from natural disaster, such as fire or hailstorms is minimized (Foxhall, 1986).

If the mechanisms of fragmentation continued unchecked it would result in unworkably small and separated fields. Mechanisms such as the amalgamation of farm units through marriage dowries or the inheritance that passes land onto only one offspring counteract the fragmentation of holdings. Plato describes partible inheritance making farms too small to be manageable and to counteract this problem only one son should inherit the farm, the other sons marrying into land (Sallares, 1991).

Damaskenides (1965), in a country-wide survey of Greece found that the average number of plots per household varied between 7.5 and 12.5 and that they ranged in size from 0.48 to 0.78 hectares. One could assume a similar pattern for antiquity. These plots were divided into smaller units for cultivation, the *schoinoi* (100' x 120'), the *plethron* (100'x 100'), the *pelethrai* (10' x 100') and the *kapholaia* (10' x 10'), the latter two being applied to the planting of vines and the cultivation of vegetables (Cooper, 1993).

6.4 Crops and Cultivation Strategies

The crops of the Classical household were varied, including cereals, legumes, vegetables, herbs, fruits and nuts (Gallant, 1991). The subsistence farm concentrated on the diversification of crops to minimize risk, rather than the three cash crops cereal, olive and the grape, though these still played an important role (Gallant, 1991).

Cereals were undoubtedly important to the subsistence household. Foods manufactured from them, supplied perhaps 70 percent of an individual's calorific intake (Brothwell, 1988). The normal theory of cereal cultivation in the Classical period was that the cereals were cultivated in rotation with fallow, thus, allowing the soil to "rest" between crops. This system, known as the "thrice ploughed" or, in Greek, "tripolos" field, is derived from writers of the period, such as Hesiod's *Works and Days* (Hesiod lived at Askra in the Valley of the Muses). The fallow field was ploughed in spring before the weeds had seeded, which served two purposes. It reduced the presence of weeds in the growing crop of the following year and the ploughed in weeds acted as a green manure. The second period of ploughing was in the summer. This was carried out in order to retain moisture in the soil. The final ploughing was in autumn prior to sowing. After the crop had matured and been harvested, the stubble may have been burnt to reduce the presence of weeds (White, 1970), though the only evidence is in the texts of Roman writers (Virgil, *Georgics*, I, 84). Sarpaki (1992) has suggested an alternative method of cereal cultivation, with legumes being sown in alternate years instead of leaving the land fallow. Harvested in spring, this crop of legumes would supply fodder for livestock and possibly for human consumption. It would, more importantly, fix nitrogen in the soil, improving the fertility of the soil for the following year's crop of cereals. The evidence for this is again limited to Roman writers, Virgil states "sow your golden corn on land where grew legumes" (*Georgics*, I, 73). The climate of Greece would only have permitted species resistant to drought to be grown in rotation cropping (Sarpaki, 1992).

The need to rest a soil and the fragmentation of land has already been mentioned. Both practices aim to ensure a constant supply of food. Other cultivation techniques were also employed to minimize risk of crop failure and maximizing survival. These include inter-cropping and manuring. Inter-cropping provided a greater yield per hectare and greater assurance of some return through the production of a crop at different periods of

year on a single plot of land. If fire or weather resulted in one crop being ruined, there would be the second crop. It was practiced in three forms; mixed cultivation, row inter-cropping and relay cropping. Mixed cultivation involves two or more crops grown on the same piece of land with no specific arrangement as in garden agriculture. Another example could be growing vines up olive trees. Rows of vines or olives inter-planted with cereals or legumes was a common example of row inter-cropping. Relay cropping involved successive cropping on a single piece of land, a cereal crop followed by lentils, cow peas, millet, or vetch (Gallant, 1991).

Manuring both by the direct application of materials such as animal dung and ash or by composting prior to application was another method of maintaining soil fertility and crop productivity. The writers of antiquity recognized the value of manure. Theophrastus listed the manures in the order of their strength: human, swine, goat, sheep, ox, and pack animals (*Historia Plantarum*, 2.7.4). Similar rankings are given by the Roman agronomists (Varro, I. 38 and Cato, II.15). In the ranking given by Columella (II.14.1-4) the highest position is given to bird manure, which combines the liquid and solid contents in their excreta, then human, cattle, sheep, goat, draught animals and swine. The manure may then have been composted prior to application. The need to compost is mentioned by Theophrastus (*Historia Plantarum*, 2.7.4) who states that human excrement is a more pungent and powerful fertilizer than animal dung, requiring dilution, composting or time to rot before it can be applied to most crops. Roman agronomists advise about the location, construction and number (two: one for fresh and one for rotted manure) of the composting site. Columella (II.14.6-8) advised that it should be sited in hollowed-out, shelving ground which is packed hard to prevent moisture loss and an ample supply of water should be maintained to ensure decomposition of weed seeds. Columella also lists the types of material, which became incorporated in the compost as leaves, ash, filth, bramble waste,

sewage, straw and dirt. This alludes to the varied material which became incorporated in the compost.

Oliviculture and viticulture are integral parts of the Classical landscape. The improved olive (*olive europaea*) was firmly established in Greece by the time of the palace cultures of the Bronze Age (Isager and Skydsgaard, 1992). Its uses are varied, in addition to olive oil the by-products of its production are used as a fuel, animal feed, fertilizer, insecticide, mothproofer, wood-preserver and lubricant (Mattingly, 1996). The wood of the olive was used as kindling (Theophrastus, V.8.39). Both Xenophon and Theophrastus discuss the preparation of olive cuttings, which once inserted in the ground are covered with clay and a potsherd (cf. Burford, 1993). Pruning of the olives was important to promote of fruiting. Theophrastus recommended that they should be manured and watered, Columella recommended goat dung (XI.2.87). The processing of olives for oils involved a two stage process: the removal of the kernel in a *trapetum*, an oil-mill (figure 6.8) and the removal of the water content in a press such as the simple lever press (figure 6.9). The vine may have been grown up the olive (White, 1970) or kept separate from the olive (Burford, 1993). Wherever it grew, it needed much cultivation, including control of weeds, draining the ground when it was too wet, applying dust about the roots, digging about the roots to air them and pruning. Pruning was carried out in the winter months (White, 1970). Three diggings were made (White, 1970), the first in late autumn and early winter involved digging around the roots to enable air to penetrate, some surface roots were removed and manure was applied. The second digging was in May just before flowering and was accompanied by the training of the vine shoots. The final digging was in the summer and involved the pulverization of clods to create dust, which covered the grape and aided the maturation of the fruit. The harvested grape was processed firstly by treading in a vat to gently release the juices. The trodden grapes were transferred to a simple lever press

(figure 6.9) where the remaining juice was extracted. This juice was placed in storage containers and allowed to ferment (White, 1984).

In Greece, vegetables, would have cultivated in a garden close to the house due to their high labour and water requirement, along with herbs. There are references to onions, chervil, succory, lettuce, garlic, leek, asparagus, artichoke and bean (Brothwell, 1988 and Columella X.100). Osborne (1992) lists garden crops as including cabbage, radish, turnip, beet, lettuce, rocket, mustard, coriander, dill, cress, leeks, celery, long onion, orache, cucumber gourd, basil, marjoram, garlic, rue and fennel. Although Columella gives a description of the garden in antiquity, it should be remembered that Columella was a first century AD native of southern Spain and therefore temporally and geographically distant to the period we are writing about. However, it does not seem unreasonable to suppose that garden agriculture occurred in Greece. Columella (XI.III.3-16) describes the garden as being close to the villa, if the nature of the ground allows, with a water supply from a stream or well. The garden was more likely to be surrounded by a quickset hedge than a wall, due to the lower cost and greater lifespan of the hedge (Columella, XI.III.3) or a ditch as suggested by the resistivity survey of VM70 (figure 6.5). These barriers would have prevented damage of crops by browsing animals. The garden is not unknown in the archaeological record and the Greek evidence has already been discussed (section 6.2). Other examples include the Roman garden at the House of the Ship Europa at Pompeii (Jashemski, 1979), which contained two vegetable beds in its walled garden, vines and an intricate irrigation system which included a cistern collecting water from the roof of the house. The vines were inter-cropped with horse and broad beans.

6.5 Animals and Animal Husbandry

Horses, donkeys, mules, oxen, sheep, goats, pigs and poultry are all known to have been present on farmsteads in antiquity. The frequency of occurrence and the number on individual farmsteads varied. The horse was a luxury, a status symbol. As such, it was only used as a mount or racehorse. Thus it rarely occurred on the subsistence farmstead (Isager and Skydsgaard, 1992).

Donkeys, mules or oxen carried out draught work (Isager and Skydsgaard, 1992). Despite Aristotle's description of the ox as "the poor man's slave" (Pol. 1252b12), their presence on the farmstead is uncertain. The amount of land required to produce fodder for the draught animal would have been beyond the means of most small landowners (Alcock *et al.*, 1994). A household would require approximately five hectares for the use of oxen to be feasible (Hodkinson, 1988; 39). Those with smaller holdings may have shared another's ox or done without and cultivated by hand (Hodkinson, 1988; 39), a situation described by Hesiod as the man with no ox who has to ask another and might well be refused (*Works and Days*, 451).

Other animals, such as pigs, poultry, sheep and goats were the sources of animal food and other products for the household. Pigs were kept in a sty, close to the home (Alcock *et al.*, 1994). Likewise, poultry were kept nearby. A few goats and sheep were also kept near to the home as "house" animals, providing the household with milk, meat and wool (Isager and Skydsgaard, 1992).

The bulk of the evidence for the keeping of larger numbers of livestock, describe flocks of sheep or goats, ovicaprines (Hodkinson, 1988; 55). This evidence usually relates to the flocks of the wealthy, though the preference for ovicaprines over cattle may have been more important for the subsistence farmer. This is because ovicaprines, despite being more prone to drought and disease than cattle, have a faster rate of regeneration and

growth after decimation (Hodkinson, 1988; 60). How were these flocks managed? Two models exist. The older model proposes a two-stage rotation of cereal and bare fallow, which reduces lowland summer grazing and creates a need for moving livestock onto mountain pasture grazing in the summer months. This model, drawn from recent traditional farming practices, is associated with nucleated settlement in which households own a collection of dispersed and fragmented plots. These dispersed plots make it impracticable for the farmer to graze their livestock on their own plots and encourages the pooling of a number of households' livestock into a communal herd which necessitates the exploitation of more distant seasonal grazing land (Hodkinson, 1988; 39). The second model is associated with a dispersed pattern of settlement, which is a characteristic of the Classical period. In this model the closer proximity of plots allows the more labour-intensive rotation of cereals and legumes. This method of cultivation increases lowland summer grazing, permitting the maintenance of small herds on the plots and diminishing the need for summer grazing on the uplands. The maintenance of livestock on the cultivated fields has the advantage of the livestock consuming weeds and adding manure (Hodkinson, 1988; 39).

6.6 Conclusion

The discussion of individual aspects of agriculture enables the general reconstruction of the rural, Classical landscape. A picture emerges of a nucleated political centre surrounded by a farmed landscape in which small, individual farmsteads were common. Each farmstead had as its centre the farm building. The size of the building varied, but examples have been shown to be between 15 m by 10 m and 20 m by 15 m. A common feature of these buildings was a courtyard, around which there were rooms for a

variety of activities, such as habitation, storage, food processing and waste disposal. The presence of amphorae, trapetum, presses and koprones can help indicate which rooms served which purpose. The land near the main building would have been reserved for the “garden” crops, such as vegetables and herbs which have a greater labour and water requirement than other crops. There is some evidence that vines may also have been grown in the garden. The nature of the dispersed settlement would suggest that there would have been a concentration of fields around the farm and garden. These fields would have been given over to cereal production either in rotation with fallow or legumes. If in rotation with legumes the flocks of sheep and goats would have been able to feed on these and weeds as fodder crops. If in rotation with fallow the flocks of sheep and goat would have to be transferred to mountain pasture in the summer months. Pigs, poultry, a number of “house” sheep and goats and the draught animal were all kept in the vicinity of the farm.

CHAPTER 7

MODELLING CHANGES IN SOIL ELEMENTAL COMPOSITION DUE TO HUMAN ACTIVITY

7.1 Introduction

The aim of this chapter is to present a simple model of the changes in the soil's element composition created through human activity. Keeping the model simple means it will not be exhaustive, but it will highlight possible patterns useful to the analysis of soils on archaeological sites and will provide a base for more complex models to be formed upon in the future.

The study can be broken in to three sections;

- The baseline,
- the inputs and outputs through human activity,
- the stability of the change.

7.2 The Baseline

The baseline represents the element composition of the soil prior to the inputs from human activities. The only previous attempt at modelling the element changes in the soil due to human settlement has been by Cook and Heizer (1965). However, their model considered the inputs from human activities building up on a blank baseline, a soil with no element content. As well as being impossible, this approach omits the important influence

of the soil's elemental composition prior to the activity on the detectable concentrations after the activity. Consider two soils, one has an average composition of 50mg lead kg^{-1} and the other 500mg lead kg^{-1} . If an human activity adds one kilogram of material, containing 150mg lead kg^{-1} , for every kilogram of soil, and it is then well homogenised, then the effect on the first soil is to increase the concentration of lead to 100mg lead kg^{-1} . The effect on the second soil is one of dilution, decreasing the concentration to 325mg lead kg^{-1} . Therefore, depending on the nature of the soil, the same human activity can have an enhancing effect or a dilution effect.

The elemental composition of the soil is primarily derived from the geology. It is then modified by pedogenic processes. In the Mediterranean where semi-arid conditions exist there is little differentiation in the soil profile and the elemental character of the soil is similar to that of the geology from which it is derived. Therefore for simplicity, the composition of two rock types occurring in the Boeotia survey area will be used to represent the elemental composition of the soil (the baseline) prior to human activity. The two rock types chosen, the ultrabasic and calcareous rocks, are markedly different in their elemental composition and reflect the range of values found in the control areas (chapter 13). The ultrabasic rock is characterised by high values of iron, cobalt, chromium, nickel, manganese, lead and zinc. The calcareous rocks by high values of calcium, cerium, lanthanum and strontium, and by low values of many of the other trace elements.

7.3 The Inputs and Outputs of Archaeological Human Activities

The inputs to the soil from human activities are many in number and diverse in their element composition. The materials added from human activity may have included excreta, pottery, ashes from domestic fires, house sweepings, bones, food wastes, animal

excreta, and animal byre materials. Tables 7.2 and 7.3 show the element composition of five of these materials based on a literature survey and sample analysis, compared against the two substrates chosen as a baseline.

On the soil derived from the limestone parent material (table 7.2) the elements potassium, copper, manganese, lead, zinc and barium are increased by the addition of each material. The elements calcium and lanthanum are diluted in the soil by the addition of these materials. Of the five materials, the hearth waste causes the greatest number of element increases, with 17 of the 21 elements being of higher concentration in the hearth waste than in the limestone. The addition of hearth waste material would also result in the greatest change per unit weight added, for the most elements out of the five materials (11 elements). Most notable of the changes that would result from the addition of hearth waste are potassium, strontium, copper, manganese, zinc and barium.

On a soil derived from the ultrabasic (table 7.3) the elements calcium, sodium, potassium, cerium, strontium, copper and barium would be increased by the addition of each material. The elements iron and nickel would be diluted by the addition of each of the materials.

The material values in tables 7.2 and 7.3 assume an average value (manure, pottery, hearth waste) or a normal range (bone and vegetable waste) for each material type. Each material type will vary depending on their type and origin. Manure values vary depending on the animal (table 7.4) and with the composition of the animals food source. The faecal material produced by poultry contains a greater proportion of liquid than the other animals shown in table 7.4 and tends to have higher concentrations of major elements than the other types.

The same variation is true of the other materials. The composition of bones will depend on environmental exposure. Human bones during the Classical period may have contained more lead than present day bones due to the greater use of lead in plumbing,

containers and as an additive in wine. Human bones of the Roman period, which had similar exposure to lead, have been found to contain more lead than present day bones (> 40-50 ppm), with 5 % exceeding 500 ppm (Waldron, 1982). Bone content of humans also varies with diet, a higher shellfish diet increases the strontium content of bones relative to meat diet (Runia, 1987).

The composition of pottery varies with the materials used to produce it. In the Hyettos region of Boeotia, magnetite is used as a filler in the pottery, this will increase the iron content. The composition of the vegetable waste will vary according to the portion of the vegetable discarded. The distribution of elements within the plant material is dependent on the ability of the element to be translocated once absorbed by the plant roots. Manganese and zinc are readily translocated to the plant shoots, nickel, cobalt and copper are intermediate and chromium and lead are retained in the root (Alloway, 1990). The root portion is therefore the most likely to be elevated in metal ions. Table 7.5 shows some major element concentrations in food materials in comparison to the rock types and illustrates that the content of most food materials is below the rock content, which would therefore cause a dilution effect. The exceptions to this are potassium which is higher in all food materials than the rocks, and the same is true of sodium in breadwheat and phosphorus in breadwheat and broadbean.

The materials also vary in their quantity of production. Different animals produce differing amounts of manure per annum (table 7.6) and therefore, although some materials such as hearth waste are elevated in most elements when compared to the two rock types, the quantity of production lessens their influence on soil changes. The amount of pottery generated is based on evidence from Greek koprones found in Halieis (Ault, 1994). A five cubic metre kopron contained 1200 sherds and 900 tile fragments at the time of abandonment. On the assumption that the tile is from roof collapse after abandonment (Snodgrass, 1994), this leaves a sherd density in the kopron of 240 sherds per cubic metre.

Snodgrass (1994) used this figure to calculate an original density of sherds in the kopron. He argued that the manure would be assiduously collected but not the sherds, that a hypothetical 10 % of the sherds would remain in the pit at each of the hypothetical 100 times the kopron was cleaned out giving an original density of 24 sherds per cubic metre. I believe that no such preferential removal of manure would have occurred when cleaning out the kopron. I believe this for two reasons: (1) it would have reduced the volume of the kopron at each cleaning and (2) sherds were valued in agriculture being used to protect roots from the sun. I therefore assume that the density of the sherds in the pit was that found by Ault (1994), at 240 sherds per cubic metre. I will assume an average sherd weight of 2.4 g (Rick, 1976), which gives 576 g (0.58 kg) per cubic metre.

The outputs from the system include the decay of organic matter, soil erosion, leaching and removal in the form of crops. The manuring of the soil will increase the organic matter content of the soil. After abandonment this organic matter content will decline. Loss on ignition analysis of samples from the VM70 farmstead suggest a natural organic matter content of 3 % and a present, manured soil content of 7 %. The median organic matter content of composts is 32 % (Olness *et al.*, 1998). These figures will be used to calculate the loss of soil mass due to organic matter decay.

The effect of soil erosion is difficult to calculate and for the purposes of the model it is assumed that the site is on level ground with insignificant erosion. Erosion will depend on a number of factors including slope angle, vegetation cover and climate (especially precipitation and wind strength).

Leaching through the soil profile will affect the more soluble. The rate of leaching will depend on the climate and the characteristics of the soil environment. For the purposes of this simple model the effects of leaching are covered by a half-life dependent on the solubility of an element in a calcareous environment (section 7.4).

The effect of cropping on the element composition of the soil will depend on the type of crop being grown. Some elements such as lead are not readily translocated in plants (Fergusson, 1990) and therefore if the crop is a leaf crop then they will in the root system and be re-incorporated into the soil on the death of the plant. However, if the crop is a root crop then it will be removed. For the purposes of this model it is assumed that no cropping has gone on at the site subsequent to its abandonment.

7.4 Stability of Change

The stability of the changes will determine whether the changes caused by the inputs from human activities are detectable in the present day. It is affected by numerous factors such as climate, erosion, nature of the soil prior to archaeological modification and human activities subsequent to the human activity of interest. For the purposes of generating a model the three groupings from chapter four are used. These are:

- High mobility elements include magnesium, calcium, sodium, potassium, phosphorus, lanthanum, strontium, yttrium, vanadium, zinc are ascribed the half-life of 500 years.
- The low mobility elements manganese, lead, barium are ascribed a half-life of 1000 years.
- The very low mobility elements aluminium, iron, cerium, scandium, cobalt, chromium, copper, nickel are ascribed a half-life of 1500 years.

7.5 Model

A simple model is presented here showing the general changes to the composition of the soil caused by the application of manure to the area around a single farm settlement occupied for 200 years. Only the inputs from outside the infield will be considered in the model as those within the infield are cycled within a closed system (figure 7.1). The inputs are manure from animals grazed outside the infield, pottery, hearth waste and metals. The model of the household used is the “hypothetical household B” (table 7.7) from Alcock *et al.* (1994) which was used in the calculation of sherd density in the applied manure (Snodgrass, 1994). The rate of manure application is assumed to be a light dressing of 40 cubic metres per hectare, which if the manure is rotted means that 0.25 hectares can receive a heavy dressing of manure (Alcock *et al.*, 1994). It is assumed that the same area is manured over the entire period of occupation. The resultant change is then compared for the stability of the change, at 500, 1000, 1500 and 3000 year periods.

The soil to which the manure is added is assumed to be the average arable mineral surface soil (3 - 5 % organic matter) with a density of 2.65 Mg / m³ (Brady, 1990). The depth of soil to which the added manure is effective is assumed to be a cultivation depth of 25 cm. This gives a soil volume of 0.25 m³ and a soil mass of 662.5 kg for every square metre of the surface. To each square metre of soil is added 716 kg of manure, 9 kg of hearth waste and 0.5 kg of pottery, which gives a total weight of soil per square metre of 1388 kg. This figure is double that of the original soil mass. However, the organic matter will have decayed during use and after abandonment. The original soil contained 3 % organic matter. The soil, if no decay of organic matter during use, was 17.9 % organic matter at the time of abandonment. Observations at a farmstead site (VM70) show a present day content of 7 %. To reach this 611 kg of the manure added will have decayed leaving a soil mass of 777 kg.

Tables 7.8 and 7.9 show the changes in element composition of the soil by the addition of the material and the stability of the change with time. On a limestone soil the elements sodium, potassium, phosphorus, strontium, copper, manganese, nickel, zinc, and barium are significantly increased by the addition of the wastes. The elements calcium and lanthanum are significantly decreased by the addition of the wastes. The stability of calcium, sodium, phosphorus, lanthanum, zinc is low and by 3000 years after the addition of the materials no difference is detectable. Therefore Hellenistic-Classical farms are unlikely to produce detectable features using these elements, whereas medieval sites may. From this model the elements potassium, copper, manganese, nickel and barium are most useful for sites on limestone parent materials, being stable over the 3000 year period after abandonment and being significantly altered by the application of manure.

On a soil over ultrabasic material the elements calcium, sodium, potassium, phosphorus, strontium, copper, manganese, zinc and barium are increased in concentration through the addition of material. The elements iron, cobalt and chromium are decreased. The elements calcium, sodium, phosphorus, strontium and zinc are not stable and by 3000 years after the addition the effect is no longer traceable. The elements iron, potassium, cobalt, chromium, copper, manganese, nickel, and barium are useful diagnostic elements on ultrabasic derived soils 3000 years after use.

7.6 Conclusion

The wastes are varied in composition and production, hearth waste is greatest in effect per kilogram added to the soil but is low in quantity of production. Manure is the greatest component of waste added to the soil but is much lower in effect when compared to the hearth waste. The model could be improved by using values for manure and hearth

waste from samples collected in Boeotia, which reflect the influence of local geology on their composition.

The most useful elements in diagnosis on both soil types for sites occupied 3000 years ago are predicted to be potassium, copper, manganese, nickel and barium. For more sites with a shorter period since abandonment, other elements such as calcium, sodium, phosphorus, strontium and zinc are useful indicators. On both ultrabasic and limestone underlain soils the elements sodium, potassium, phosphorus, strontium, copper, manganese, zinc and barium are increased in concentration by the addition of material. On limestone soils calcium, cerium and lanthanum are decreased in concentration by the addition of material. On ultrabasic soils iron, cobalt, chromium and nickel are decreased in concentration by the addition of material.

Lead, which was identified in previous studies as an element enhanced on archaeological sites is notable in the model in showing very little change in concentration through the addition of materials. This probably reflects the absence from the model of the contribution from metals used on the site.

CHAPTER 8

SAMPLING

8.1 Introduction

This chapter will describe the general sampling methodology and the choice of archaeological sites for sampling. The specific sampling strategy for each site will be described in the results section. Sites, dates of sampling, sampling strategy and types of sample collected are shown in table 8.1.

8.2 Archaeological Site Selection

The Boeotian archaeological sites sampled were chosen to reflect the different scales of occupation, length of occupation and period of occupation found in the archaeological record of the Boeotian landscape. The sites chosen can be divided into three categories: cities, villages and rural sites. The city site chosen was Hyettos. This site existed from the Bronze Age to the Late Roman period, reaching its maximum extent (28 ha) and population (~3500 people) in the Classical and early Hellenistic period. The site had a varied economy which included farming, extraction of the local iron ore, and roof-tile and pottery manufacture.

The village sites chosen were Askra, VM4 and Rhadon. Askra, a village of an estimated 1300 people at its maximum in the Classical period, existed for 5000 years from the Early Bronze Age to the 13th century AD. The neighbouring village of VM4 is a

continuation of the village of Askra. VM4 reached a population size comparable with Askra, of 1100 people in the 16th century AD, and although it was occupied from the Late Bronze Age (c.1600 BC) its most intensive use was over a period of 450 years from the 13th century AD to the mid 17th century AD. Rhadon is a much smaller site, reaching a recorded maximum of 260 people in 1642. The site's main period of village occupancy is similar to VM4, 500 years from late 14th century to late 19th century AD.

The rural sites chosen were VM70, VM87 and CN11. These like the village sites vary in their scale and period. VM70 is a small Classical (3rd and 4th centuries BC) farmstead. VM87 is unusually small for the Valley of the Muses and dates to the Classical and Hellenistic periods. Unlike the other sites chosen, it has no ceramic halo. CN11, unlike the first three sites which are in the Valley of the Muses, is in the hinterland of Hyettos city. The site is a small farmstead of the Archaic period to Hellenistic period.

8.3 Soil sampling

8.3.1 Surface soil sampling

The pattern of sampling was usually of regular spacing in either a grid format or along a transect. This regular pattern of sampling means that relocation of sample points is possible.

Surface samples were collected using a stainless steel trowel which sampled to approximate depth of five centimetres. The preferred method of using a screw auger or hand corer could not be implemented owing to the dry and impenetrable nature of the soil.

At each sample point five trowel samples were collected in a circular formation (figure 8.1), one from the centre point and one each from the principal bearings (i.e. N,E,S,

and W) of a circle one metre in radius from the centre point, thus giving a composite sample which will represent the average of the area enclosed by the circle (Tan, 1996). These five samples were bulked together in a polythene sample bag to give a representative sample of the area around each sample point.

8.3.2 Soil Profile Sampling

Due to the soil conditions the preferred method of soil coring could not be employed. Instead the soil profile samples were collected by the excavation of a soil pit. The soil pits were dug to a depth of 50-60 cm or to the soil-rock interface. The pits were square or rectangular in plan with the approximate dimensions of 60 cm by 60 cm. Samples were collected using a knife and trowel from the first 5cm depth of the soil profile and then from the 10-15 cm, 20-25 cm, 30-35 cm, 40-45 cm and 50-55 cm depths. At each depth all four faces of the pit were sampled and bulked together in polythene sample bags.

8.4 Rock and human occupation debris sampling

Samples of the rock types characteristic of the area, and human occupation debris samples were collected by field collection involving hand-picking and removal by hammer. Samples were then placed in polythene sample bags and labelled with their name and location.

8.5 Storage

The samples were air-dried in Greece before resealing and transporting back to the United Kingdom for analysis. In the UK the samples were stored in their polythene sample bags in a cool and dark environment.

CHAPTER 9

ELEMENT ANALYSIS

9.1 Introduction

Element analysis was carried out using the NERC Inductively coupled plasma atomic emission spectrometer (ICP-AES) based at Royal Holloway and Bedford New College. The instrument is a combined simultaneous-sequential 49 channel ICP optical spectrometer. It is capable of analysing a range of elements and provides results for major and minor elements in the soil, in addition to trace elements. The elements Al, Fe, Mg, Ca, Na, K, Ti and P are determined as their weight percentage oxide equivalents; Al_2O_3 , Fe_2O_3 , MgO , CaO , Na_2O , K_2O , TiO_2 , P_2O_5 . The elements As, Ba, Bi, Cd, Ce, Co, Cr, Cu, La, Li, Mn, Mo, Ni, Pb, Sb, Sc, Sr, V, Y, and Zn are recorded as parts per million (ppm) of the sample.

Two types of extraction procedure were employed in the elemental analysis of samples; pseudo-total extraction and a Tessier-style sequential extraction. The pseudo-total analysis was used on all soil and rock samples, a 33 % concentrated nitric acid oxidising agent being used to bring elements into solution. The Tessier-style sequential extraction was used on selected samples. Each sample is sequentially extracted with a different reagent designed to extract the elements bound in a specific portion of the soil.

9.2 The ICP-AES

The ICP, operating at atmospheric pressure, was originally used as a technique for growing crystals at very high temperature (Walsh and Howie, 1986). The application of the technique for elemental analysis was demonstrated by the work of Greenfield *et al.* (1964) in the United Kingdom and Wendt & Fassel (1965) in the U.S.A.

The sample is introduced into the instrument as a solution. The solution is converted to an aerosol by an argon gas cross-flow pneumatic nebulizer (figure 9.1). The solution is introduced to the nebulizer at right angles to a tube carrying argon gas. The effect is to nebulize 1-2% of the sample solution producing an analyte aerosol which proceeds into the ICP. The remaining solution exits the nebulizer by means of a drain.

From the nebulizer the analyte aerosol enters the ICP torch (figure 9.1). The torch consists of three concentric fused silica tubes each carrying a flow of argon gas. The innermost tube carries the analyte aerosol from the nebulizer and is known as the “injector” or “carrier” gas tube. The tube immediately outside the “injector” gas tube contains the “auxiliary” gas flow. Both the “auxiliary” and “injector” gas flow straight up the torch. The outermost tube carries the argon gas which produces the plasma. The argon gas enters at right angles to the main tube and flows tangentially upwards cutting through the magnetic lines of force generated by r.f. coil at the top of the torch. The gas is “seeded” with a Tesla spark to make it charged. As the charged gas cuts through the magnetic lines of force it produces ohmic heating and creates a plasma with a temperature range of between 6000K and 10,000K.

The plasma forms a doughnut shaped flame around the centre of the torch. The “auxiliary” gas and “injection” gas pass through the central hole of the flame. The heat from the plasma inductively transfers through the “auxiliary” gas to the “injection” gas

exciting the elements present. The elements then release the gained energy by the emission of photons which can be measured by the spectrometer.

The ICP has a number of characteristics which make it a superior technique to other methods of elemental analysis. The most important characteristic is the geometry of the excitation source, the plasma. Unlike other techniques which have a “hot-spot” in the excitation source with rapidly declining temperatures either side, the ICP has a broad temperature profile for the analytical part of the plasma. This feature increases the residence time of the analyte in the plasma and thus ensures excitation. It also means that there is a general absence of self-absorption and self-reversal effects and therefore the relationship between concentration in analyte and measured intensity remains linear over four to five orders of magnitude (Walsh and Howie, 1986). The other two characteristics which make this technique superior to others are the ICP’s high temperature (between 6000K and 10000K) which ensures more complete ionisation and the inert argon gas environment which ensures minimal background interference (Walsh and Howie, 1986).

9.3 General Sample Preparation

The following stages in the preparation of a sample are common to both the pseudo-total and the sequential extraction procedures.

- Each sample was air dried.
- Each sample was weighed in a pan to the nearest one-hundredth of a gram (± 0.01 g).

- The samples were then gently disaggregated in a glass pestle and mortar. Care was taken not to exert excessive pressure which would result in the destruction of rock fragments present in the soil sample.
- The disaggregated sample was then placed in a sieve tower consisting of a coarse sieve (2 mm) above a fine sieve (211 μm). The coarse sieve removed the stones and plant debris present in the soil sample.
- The sieve tower was then shaken vigorously to ensure passage of soil particles into the correct particle size section of the sieve.
- Each sieved fraction was weighed and placed in a polythene sample bag for storage.
- The sieves and pestle and mortar were all cleaned thoroughly after processing each sample to avoid contamination.

9.4 Pseudo-total Analysis

9.4.1 Introduction

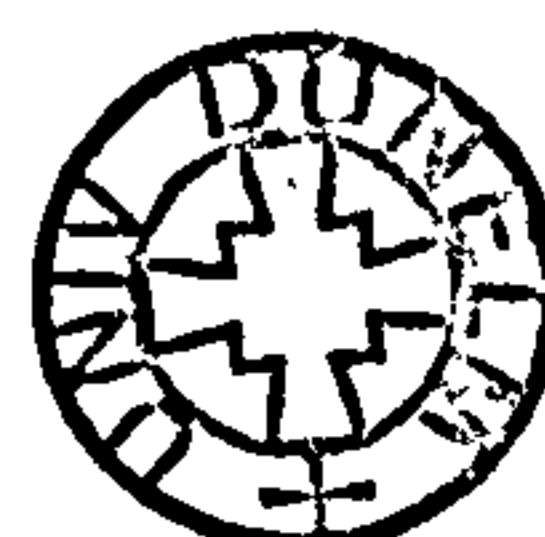
Pseudo-total analysis was carried out on all samples using 33% concentrated nitric acid (HNO_3) as an oxidising agent. Concentrated nitric acid is a strong oxidising agent which brings most elements into solution. In addition a number of samples were also digested in aqua regia for comparison with the nitric acid digestion. Aqua regia, a mixture

of three parts concentrated hydrochloric acid (HCl) to one part concentrated nitric acid, is thought to be a better oxidising agent, especially for the precious metals.

Preparation of samples collected in the summer of 1994 was performed at the Royal Holloway and Bedford New College, Egham, Surrey in the winter of 1994/5. Preparation of samples collected in the summer of 1995 was performed at Durham University in winter 1995/6. Since the 1994/5 and 1995/6 sample preparations were carried out in different laboratories there are slight differences in the apparatus. Where the 1995/6 preparation differs from the 1994/5 preparation, it has been noted in bracketed italics.

9.4.2 Sample Preparation

- 1.2500 g (\pm 0.0005 g) of each (<211 μ m) sample was accurately weighed into a 50 ml glass beaker (25 ml test tube). Every twentieth sample was repeated to test accuracy of the sample preparation. Every fortieth beaker contained no soil sample ("blank") to test for impurities in the nitric acid and distilled water, and any matrix interference effects.
- 10 ml of 33 % concentrated Aristar nitric acid was added to each beaker. Samples were then placed on a hot plate at 80°C for one hour. They were then removed and allowed to cool.
- Soil samples were then washed into 25 ml volumetric flasks and made up to the mark using double distilled water, shaken and allowed to settle.
- The samples were then decanted into polythene centrifuge tubes and stored in a cool, dark environment prior to analysis.



9.4.3 Sample Analysis

- The ICP-AES was calibrated using two laboratory standards; Blankag and KC11.
- A stock solution containing 20 ppm of Ce, La, Y, Bi, Co, Cr, Cu, Mo, Pb, Zn, Cd was analysed as a instrument drift monitor. This sample was analysed after every ten samples to monitor instrument drift. If drift exceeded 10 % then the instrument was re-calibrated.
- Each sample was given a unique identifier and analysed.
- Every twentieth sample solution was analysed twice to monitor for instrumental error.

9.4.4 Data Quality

“All analytical results are wrong, it is just a question of by how much” (Ramsey et al., 1987). This statement is fundamental, as the quality of the data depends on the amount of error that exists in an analytical result. Errors are cumulative and occur from the initial sampling to the final analytical result. Sample preparation involves stages of weighing and measuring volumes, all of which will incur some error in the final data-set. To analyse for error due to sample preparation every twentieth sample was prepared twice. In the analysis stage errors can occur from interferences. Interferences can result from the digesting solution of nitric acid and from the double distilled water (matrix interference) and from the presence of large quantities of major cations (major ion interference). The matrix interference was overcome by analysing a blank solution containing only the nitric acid

solution and double distilled water every fortieth sample. The effect of major ion interference was important due to the high calcium carbonate content of samples. The influence of this type of interference was assessed by taking a blank, adding a known concentration of lead (which suffers a calcium interference for which there is a computer correction before presentation of result), and increasing the calcium content in stages, but no effect could be detected.

An additional error may occur which is attributable to the instrument. To monitor instrumental reproducibility every twentieth sample was analysed twice.

The following assessments of the quality of the data set were made;

- Detection limits,
- Analytical reproducibility,
- Instrumental reproducibility,
- Internal standard,
- Reference material standards,
- Variability due to sieving,
- Comparison with previously observed soil values.

9.4.4.1 Detection Limits

The detection limit of an element is defined here as the mean concentration in the reagent blanks plus three standard deviations. The assumption is made that errors in the analysis of the blank are normally distributed about the mean and therefore 99.9 % of the results will be less than a value of three standard deviations above the mean. The results for detection limits are shown in tables 9.1 and 9.2 for the years 1994 and 1995 respectively. Major soil constituents are expressed as a percentage to two decimal places and minor soil constituents as parts per million to one decimal place.

The results for 1994 (table 9.1) show that the mean soil contents for bismuth, silver and cadmium are below detection limits and thus they will not be interpreted in the results. It also shows that the mean blank content for arsenic, silver and lithium are negative values and are therefore not reliable.

The results for 1995 (table 9.2) show that only the mean soil content of bismuth is below its detection limit and thus it will not be interpreted in the results. Lithium again exhibits negative values for its mean blank concentration and will not be interpreted in the results.

The values displayed as zero for mean blank concentration and detection limit are not real zero values. They are a production of the method of instrument display of results which displays major elements as a percentage to two decimal places and minor elements to the nearest part per million. For major elements a mean blank concentration displayed as zero means that the mean blank concentration is below 0.005 % and for minor elements displaying zero the mean blank concentration is below 0.5 ppm. As no known values exist for these elements in the blank, the detection limit is uncertain, however the maximum possible standard deviation for the major elements is 0.005 % and for the minor elements is 0.5 ppm. Therefore, for a detection limit given as zero the maximum value for the detection limit of a major element is 0.02 % and of a minor element is 2 ppm.

9.4.4.2 Analytical Reproducibility

The analytical reproducibility is defined as the maximum variation exhibited by approx. 95 % (two standard deviation) of the sample population, assuming errors exhibit a normal distribution, about a true sample concentration. Every twentieth sample had a duplicate sample prepared and analysed in immediate succession. The mean concentration

of these two samples was taken as the true concentration. The analytical reproducibility represents the cumulative error of sample preparation and analysis.

The results for both 1994 (table 9.1) and 1995 (table 9.2) show that the only element to have a soil content range within the error of reproducibility is titanium and it will therefore not be used in the interpretation. In 1994 the elements iron, titanium, lithium, scandium, chromium, lead, antimony, vanadium, cadmium and arsenic have poor reproducibility (greater than 20 %) . In 1995 the elements titanium, lithium, yttrium, bismuth, lead, antimony and cadmium have poor reproducibility.

In the interpretation of results the analytical reproducibility will be used on each site to assess whether the range of soil values for that site could fall within the error of analytical reproducibility. Analytical reproducibility will be referred to in the results as the reproducibility error.

9.4.4.3 Instrumental Reproducibility

During the analysis of 1995 samples, in addition to a duplicate extraction sample being run for every twentieth sample, every twentieth sample solution was also re-analysed immediately to assess the reproducibility error attributable to the ICP-AES. The true concentration of the sample was taken as the average of the two results and the instrumental reproducibility error as the percentage of the true concentration that the difference between the true concentration and one of the results accounts for. The results (table 9.3) show that the errors attributable to instrumental reproducibility are very small except for arsenic which has an error of almost 10 %.

9.4.4.4 Internal Standards

The results of the 1994 and 1995 analyses are not comparable without the use of internal standards. Five samples were analysed in both the 1994 and 1995 analysis runs to compare the results given. The results (table 9.4) show that in general the values given for most elements are lower in 1995 when compared to the 1994 samples. The exceptions to this are arsenic, molybdenum and cadmium which have larger values in 1995 than 1994. The results show that most of the elements display a good correlation between the two years. The exceptions to this are aluminium, iron, magnesium, phosphorus, cerium, copper, antimony, vanadium, cadmium and titanium (below detection limits). The poor correlation for iron, antimony, vanadium, cadmium and arsenic can in part be explained by their poor reproducibility. The other cause for the poor correlation is the lack of samples used, as a single sample in the five samples with a non-correlating result could alter the correlation coefficient of the set of samples.

The use of internal standards shows that the majority of elements show good correlation between the two years. A greater number of samples used as internal standards would improve the usefulness of this method and give a better reflection of correlation.

9.4.4.5 Reference Materials

In the 1995 analyses two certified reference materials were analysed to assess the efficiency of the extraction procedure and to verify any potential errors in the data set. The two reference materials used were SO-3 and MRG-1. SO-3 is a calcareous soil chosen because calcareous soils are a common soil type of Boeotia. MRG-1 is a gabbro rock chosen because it exhibited the high nickel and chromium values of some of the 1994 soil samples.

The results are displayed in table 9.5. They show that the elements arsenic, cadmium, antimony, molybdenum and bismuth are producing unreliable results and thus they will not be interpreted in the results. The results also place a question mark over the results for lanthanum and lead. The high lanthanum extraction for SO-3 may be due to a interference effect. The lead values for both reference materials are uncertain and therefore not much can be drawn from these results except that the inability to detect any lead in SO-3 is an unlikely situation and is likely to be the result of a major ion interference (probably from calcium).

9.4.4.6 Variability due to sieving

One sample was divided into four sub-samples prior to sieving to assess the possible variability in result caused by contamination from the sieves. The results are displayed in table 9.6 and show no evidence for variable results from this method of preparation.

9.4.4.7 Comparison with Previously Observed Soil Values

Comparison of the 1994 samples and 1995 samples to previously observed soil values will highlight abnormally high or low values in the two data sets (table 9.7). The results show that most elements in the samples have ranges within those of previous observations. Of those exceptions, some can be accounted for by variations in the geology (e.g. laterite and igneous deposits produce large values for nickel, magnesium, and cobalt) and some can be accounted for by the archaeological activity (e.g. large phosphorus values). The comparisons for antimony and arsenic confirm their unreliability.

9.4.5 Summary

The data quality methods used have eliminated the following elements from the discussion in the results chapter: Ti, Li, Bi, Ag, Mo, Sb and As. The values in the results chapters are expressed as weight percentage oxide equivalents (%) for Al, Fe, Mg, Ca, Na, K and P, and parts per million (ppm) for the elements Ce, La, Sc, Sr, Y, Co, Cr, Cu, Mn, Ni, Pb, V, Zn and Ba.

9.5 Sequential Extraction of Selected Soil Samples

9.5.1 Introduction

A sequential extraction of selected soil samples was performed to establish within which portions of the soil elements are bound. The aim was to establish whether any particular portion of the soil was responsible for the retention of elements in areas suspected of human alteration through archaeological activities. The extraction scheme used (figure 9.2) was a modified version of an extraction scheme developed for calcareous soils of Greece by Breward *et al.* (1996). The modification to Breward's scheme is in the first stage extraction of exchangeable cations, where 1M magnesium chloride solution was used rather than 1M ammonium acetate. This change was made as ammonium acetate attacks carbonates and over-represents this fraction (Breward *et al.*, 1996) .

The extraction procedure used the following reagent purities to prepare the extraction solutions: magnesium chloride hexahydrate BDH Analar, sodium acetate trihydrate BDH Analar, Ammonium solution BDH Analar, Hydrochloric acid BDH Aristar, hydrogen peroxide Fisons SLR grade, hydroxylamine hydrochloride Aldrich 99 %

ACS reagent, oxalic acid dihydrate Aldrich 99 % ACS reagent, ammonium oxalate monohydrate Aldrich 99.9% ACS reagent and nitric acid BDH Aristar.

The extracts were analysed on the ICP-AES instrument used in the pseudo-total analysis. Two samples had five replicates to assess reproducibility of the analytical result.

9.5.2 Methodology

- 1 g of sample was weighed into a 50ml polythene centrifuge tube.
- 20ml of reagent was added and the tube sealed.
- The sample was either heated, agitated or left to stand for a period of time. The method was dependent on the reagent used (see figure 9.2).
- The sample was then centrifuged at 3000 revolutions per minute for five minutes.
- The liquid (liquid A) was decanted into another polythene centrifuge tube.
- 10 ml of distilled water was added to the solid residue. The sample was agitated and then centrifuged at 3000 revolutions per minute for five minutes. The resulting liquid was added to the liquid A.
- The process was then repeated with the next extraction reagent (see figure 9.2)

9.5.3 Sample Analysis

Sample analysis was as for the pseudo-total analysis and results are presented as weight percentage oxide equivalent for the major elements Al, Fe, Mg, Ca, K, Na, P and as ppm for the remaining elements.

9.5.4 Data Quality

Data quality for the sequential extraction procedure consisted of an assessment of matrix effects, detection limits and reproducibility error. The detection limits used were those from the 1995 analysis run of pseudo-total samples and the elements Ti, Li, Bi, Ag, Sb, Mo and As which proved unreliable in that run are also discarded in the sequential extraction results.

Mg and Na were excluded from the results on the basis that both are present in extractants and may leave a residue in the samples to be extracted at a latter stage. Mg is added in stage 1 as magnesium chloride and Na is added as sodium acetate in stage 2.

The matrix effect was assessed by the use of a single blank sample in each extraction (table 9.8). The results show that for most extractions the element values are mostly below detection. Comparison with the results (tables 9.9 to 9.15) show that the matrix effect is only important in extraction 4 (table 9.12) where it accounts for the lower values in the ranges of sodium and phosphorus, and extraction 6 (table 9.14) where it accounts for the lowest vanadium values.

The reproducibility error was assessed by the use of five replicates for each of two samples. The resulting reproducibility error is the standard deviation divided by the mean expressed as a percentage. Reproducibility error, detection limits and element mean and ranges for samples are expressed for each extraction (tables 9.9 to 9.15).

The element discrimination criteria for their use in the discussion (final three columns of tables 9.9 to 9.15 are as follows;

- Some of the values within the range should exceed the detection limit.
- Some of the values within the range should be outside that which could be accounted for by the reproducibility around the mean.
- Elements are subjectively excluded if they exhibit an insufficient range of values.

These criteria exclude the element Y from further discussion. All other elements are usable for discussion in at least one extract. The elements Ni and Mn are the only elements which are of use in all seven extracts.

9.5.5 Summary

The sequential extraction of samples produce results for a number of elements which fall below the detection limit and therefore cannot be discussed in the results chapters (table 9.16). Those elements which do prove useful in archaeological investigations could be analysed in the future using a single element analysis Tessier extraction with lower detection limits than are achieved here.

The elements that will be discussed in the results chapters are Al, Fe, Ca, K, P, Ce, La, Sc, Sr, Co, Cr, Cu, Mn, Ni, Pb, V, Zn and Ba.

CHAPTER 10

RESISTIVITY SURVEY

10.1 Introduction

The usefulness of geophysical investigation in conjunction with soil chemical analysis was stressed in chapter 2. Resistivity, a field based method was employed in this thesis.

Wenner (1916) was the first to publish the technique of resistivity, applying it to the discipline of geology. The first archaeological application was made in 1946 by Atkinson, to the investigation of crop marks near the Big Rings Neolithic “henge” monument at Dorchester (Clark, 1990, p.11). Since this time many types of resistivity instrument have been developed. The method chosen for this study is the twin-probe array (figure 10.1).

Resistivity is defined as the resistance per unit length of a specific material. In the case of its archaeological application this material is soil. Soil is a heterogeneous material composed of minerals, organic matter, water and air. Soil particles are insulators. The controlling influence on the resistivity of the soil is the amount and distribution of moisture (Clark, 1990, p.27). Moisture contains dissolved carbon dioxide and carbonic acid which by reaction with the soil form conducting electrolytes which carry the electricity (Clark 1990, p.27). Therefore, features which reduce soil moisture, such as stone building foundations and areas which have been compacted (such as living areas and areas which have had structures on them), will produce high resistance anomalies. Features such as

ditches and refuse pits that enhance soil moisture retention will produce low resistance anomalies.

10.2 Methodology

- A grid of 20 m by 20 m squares was laid over the part of the site to be surveyed.
- The fixed probes (figure 10.1) were inserted at a position which was at least 15 m from where the remote probe (figure 10.1) readings were being taken. The position of the fixed probes was also designed to minimise the number of times they had to be moved.
- The remote probe measurements were then taken at one metre intervals on transects one metre apart in a zigzag pattern (figure 10.2).
- Results were interpreted using the Insite 1.0 computer software program.

CHAPTER 11

COMPLEMENTARY SOIL ANALYSES

11.1 Introduction

A single analytical technique can be used in isolation, but results can often be ambiguous, as a number of sources can cause the same result. For example, a geological signal may mimic the anomaly produced by manuring and cultivation in phosphate analysis. Using two analytical techniques together or a group of techniques can clarify the results and improve the interpretation. In our example above the soils which had the same phosphate result, will differ in their organic matter content, their particle sizes and their magnetic susceptibilities. The manured soil will have a greater organic matter content, greater magnetic susceptibility and probably have more clay sized particles than the soil with a phosphate content derived from the geology. The use of more than one technique in archaeological investigations of the soil is becoming more common (examples include Dockerill and Simpson, 1994; Weston, 1995; Weston, 1996; Eidt 1984b). This chapter details the complementary techniques used in the course of this research.

11.2 Soil colour

11.2.1 Introduction

Soil colour is an indicator of the soil particles present and the events that have developed the soil (Quine, 1986). All additions to the soil will alter its colour. Terracotta pottery will increase the red colour of the soil, ash will make the soil more grey and organic matter will make the soil darker. Lime plaster placed down as a floor at the Templo Mayor, Mexico made the soil much lighter than those surrounding it (Barba *et al.*, 1996).

The soil colour analysis of samples employed the use of Munsell soil colour charts. These score the colour of the soil according to its colour, chroma and hue. Figure 11.1 shows the notation for a dull yellow orange soil. The yellow-red scale goes from 1 to 10, a score of 1 indicates a yellow soil, while a score of 10 indicates a red soil.

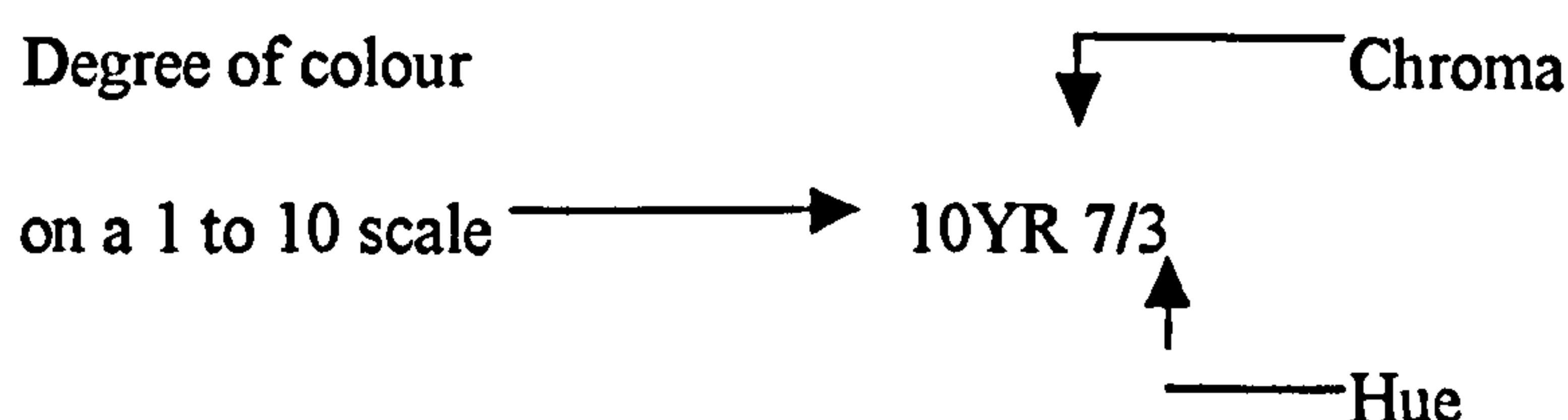


Figure 11.1 Munsell soil colour notation for a dull yellow orange soil (YR is the yellow - red Munsell colour scale).

11.2.2 Method

- An air-dried sample was placed under illumination from a north facing window.

- Munsell soil colour charts were then compared with the sample until a match was found.

11.3 Particle size analysis

11.3.1 Introduction

Particle size analysis may distinguish the archaeological activity that has been imposed on a soil. The activity of burning may cause the fragmentation or fusion of soil particles (Quine, 1986), whilst cultivation tends to encourage the formation of finer soil particles (Clark, 1990; p.103).

Particle size analysis also gives information on the ability of a soil to retain trace elements. The clay sized fraction is most important in the retention of elements (see section 4.2.1). Therefore, the greater the proportion of the soil that the clay sized fraction accounts for, the greater the soil's ability to retain elements.

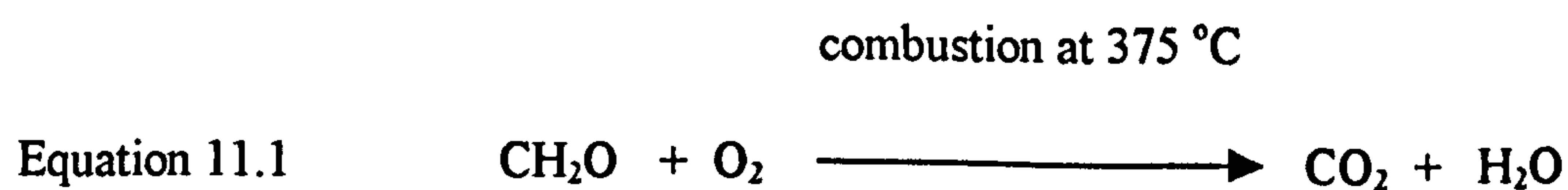
The method used for particle size analysis was a dry sieving separation, performed as part of the general sample preparation for trace element analysis (section 9.3). In this, two portions of the soil were weighed: the coarse and medium sand fraction (2 mm to 212 μm) and the fine sand and smaller fraction (less than 212 μm) according to the British Standards Institution scale (table 11.1). The results are presented as the percentage of the total weight of these two fractions which is accounted for by the fine sand and smaller fraction.

11.4 Organic matter content

11.4.1 Introduction

Soil organic matter is the organic fraction derived from living organisms. It includes the living organisms, partly decomposed and decomposed plant and animal residue (Tan, 1996). On archaeological sites organic matter content of the soil is increased in areas that have been used as latrines, byres, middens and on yard surfaces. In addition the organic matter added increases the ability of the soil to retain elements through the provision of adsorption sites.

The loss on ignition (LOI) method was used in this study. LOI is an estimate of soil organic matter content by the measurement of weight loss of a sample from its oven dried state and a specific temperature of combustion. The majority of organic matter is burnt off at 325 °C (Rowell, 1994). In the burning process carbohydrate is oxidised producing carbon dioxide and water vapour (equation 11.1).



The temperature of combustion used in this study was 375 °C. This temperature ensured combustion of organic matter, whilst minimising losses from calcium carbonate decomposition and loss of structural water in clays and sesquioxides. Calcium carbonate decomposes by evolution of carbon dioxide at 770 °C (Rowell, 1994). Weight losses due to the loss of “structural” water in clays and sesquioxides occurs between the temperatures of

105 °C and 500 °C (Rowell, 1994), though the greatest weight loss occurs between 450 °C and 600 °C (Ball, 1964).

11.4.2 Method

- A five centimetre crucible was weighed (+/- 0.001g).
- 10 g (+/- 0.001 g) of air-dried sample was weighed into the crucible.
- The sample was oven-dried at 105°C overnight (eight hours), allowed to cool in a desiccator and re-weighed.
- The sample was placed in a furnace at 375°C to oxidise for eight hours.
- The sample was removed, allowed to cool in a desiccator and re-weighed.
- The sample was re-inserted into the furnace for a further four hours at 375°C.
- The sample was removed, allowed to cool in a desiccator and re-weighed. If there was further weight loss then the previous stage was repeated until no further weight loss occurred.

CHAPTER 12

RESULTS FOR ENVIRONMENTAL SAMPLES

12.1 Introduction

The environmental samples analysed in this chapter fall into three categories: (1) geological samples, (2) archaeological artefacts and sediments of archaeological significance, and (3) samples of sediment to assess modern interference in the element signal from the soil. The purpose of collecting and analysing environmental samples was to improve the interpretation of the results from sampling surveys of archaeological sites and landscapes.

12.2 Geological samples

All geological samples were collected from Boeotia, Greece over the two field seasons of 1994 and 1995, and analysed with the 1995 soil samples. They were chosen to reflect the geology of fragments found in the soils of archaeological sites and landscapes of Boeotia. The samples chosen were: a soft limestone, a red shale, an ultrabasic rock from the edge of Hyettos city and three igneous samples from the farmstead at VM70. The purpose of collecting geological samples was to highlight which elements are characteristic of which rocks and therefore elucidate where changes in geology occur in the archaeological soil sampling programme.

The results of the analyses are shown in table 12.1, where they are compared to the mean soil contents of 1995 soil samples. They show the following characteristics:

- The limestone is characterised by high calcium, cerium, lanthanum and strontium values and low values of many of the other trace elements, notably chromium, manganese, nickel, lead, zinc and barium.
- The Hyettos ultrabasic is characterised by high iron, magnesium, cobalt, chromium, manganese and nickel values and low values of calcium, cerium, lanthanum, strontium, copper and barium.
- The igneous rocks are all characterised by high aluminium, sodium and lead values. Igneous rocks A and B exhibit high potassium and cobalt values. In addition igneous rock A has high nickel and vanadium values and igneous rock B has high strontium values.
- The red shale is only characterised by high cobalt values.

12.3 Archaeological samples

The archaeological samples include archaeological artefacts and samples from modern simulation of archaeological activities and deposits. The archaeological artefacts were all collected from Boeotia, Greece in the 1995 field season and were analysed as part of the 1995 samples. The simulation samples came from Castell Henllys Iron Age reconstruction settlement, Wales and from the rare breeds farm of Louisa Gidney in Tow Law, County Durham, England.

12.3.1 Boeotian artefacts

The Boeotian archaeological artefacts include a pottery sample from VM70, and a sample of iron slag and lime slag from possible iron working at VM4. The results are shown in table 12.2 compared with 1995 soil samples and the following conclusions can be drawn:

- The pottery sample has a high cobalt value and low iron, magnesium, calcium and phosphorus values
- The iron slag has a very high iron value and high sodium, potassium, phosphorus, strontium, and barium values. It has low nickel and zinc values.
- The lime slag has high aluminium, sodium and strontium values. Low values are displayed for iron, magnesium, scandium, yttrium, chromium, copper and nickel values.

12.3.2 Castell Henllys samples

Castell Henllys is situated near Cardigan in Wales. It is a reconstruction of an Iron Age settlement. The samples collected from this site investigate the influence of a domestic fire in a round house on indoor surface soil concentrations, surface soil concentrations outside, the influence of a charcoal clamp, and a pottery clamp.

The Earthwatch hut is a reconstruction of an Iron Age round house. It contains a fire, fuelled with wood and charcoal, which has been kept going continuously since May 1992 and sporadically since 1989. Samples were collected from the fire, indoor soil surface, indoor soil subsurface and outdoor surface soil (figure 12.1). The effect of a fire, the accumulation of its ash, in comparison to the subsoil beneath the fire shows that all

elements except lead and iron are elevated in the fire (figure 12.2). The elevation of values is most significant (greater than doubled in concentration) for the elements magnesium, calcium, potassium, sodium, phosphorus, manganese, lanthanum, barium and strontium. The comparison of indoor surface soil concentrations, where the spreading of ash and deposition of smoke particles will contribute to soil development, with outdoor soil concentrations, shows an elevation in all elements except lead (figure 12.3). The greatest enhancements occur for the elements strontium, barium and manganese. Comparison of values for indoor surface and indoor sub-surface soil samples (table 12.3) show fewer elements elevated than the comparison of indoor and outdoor surface samples. This may be due to downward migration of elements in the soil, evening out values in the surface and sub-surface samples. Only the elements manganese and barium show significantly larger values in the surface soil when compared to sub-surface samples.

Samples collected from the site of a recently used charcoal clamp at Castell Henllys (table 12.4) show increased concentrations for most elements when compared to samples from around the clamp. The most notable increases are in aluminium, iron, calcium, sodium, potassium, phosphorus, strontium, manganese, zinc and barium. A similar investigation on the site of a recently used pottery kiln (table 12.4) does not show a similar increase in values and values appear to be similar and in many cases lower to those of the samples from around the kiln.

12.3.3 Tow Law samples

Samples from the rare breeds farm at Tow Law include fresh cow midden material, fresh hen midden material and burnt hen midden material (table 12.5). The fresh cow and hen midden samples have values of sodium, potassium, phosphorus, strontium, copper, nickel, zinc and barium which could cause enhancement in the soil signal if applied

to the soil. Values of the two fresh samples are very similar except for lead and zinc which are greater in the hen midden. The comparison of the fresh hen midden to the burnt hen midden shows the effect of burning on the element concentrations (table 12.5). Values of magnesium, calcium, sodium, potassium, strontium, manganese, zinc and barium show a dramatic increase and most other elements show a more modest increase. The two exceptions to this increase are lead and nickel which are lower in the burnt midden. The results for lead and zinc may be caused by a major ion interference such as the increased calcium content of the sample.

As noted in the modelling chapter, the element composition of animal manure will depend on the diet of the animal and as the animals are herbivorous this will reflect the nature of the soils and geology of the area where the plants grow.

12.4 Modern Interference

The assessment of modern interference was of the influence of vehicle emissions on soil concentrations with distance from a road. The road chosen, near Rhadon in Boeotia, was the busiest road close to a sampling site in this study. Even though this is the busiest road, no more than a dozen vehicles past the point of the assessment in every hour. The soils were sampled at ten metre intervals on two fifty metre transects running away from the road. The results (figures 12.4a to 12.4u) do not show any significant influence on the element composition of the soil through vehicle emissions. The elements phosphorus, cerium, lanthanum and strontium appear to decline with distance from the road, however values at the 10 m sample point are similar to those at the 40 m and 50 m sample points and the appearance of decline is due to a peak at the 20 m sample point. This is thought not to be due to automotive emissions from vehicles using leaded petrol as the expected

indicator, lead, shows no similarity. It is also thought that this is not due to emissions from agricultural vehicles using diesel fuel, which form the majority of vehicles using the road.

12.5 Summary

The results of this chapter help define which elements reflect geology, archaeology or modern activity. The clearest geological associations are for the limestone and ultrabasic rocks. Limestone is reflected in soil element data by the characteristic association of larger calcium, cerium, lanthanum and strontium values and low values of many other elements. The ultrabasic rock is reflected in soil element data by the characteristic association of larger magnesium, cobalt, chromium, manganese and nickel values.

Pottery did not show any significantly large values except for cobalt. Activities such as iron-working would leave residues of iron and lime slag both of which produced large strontium and sodium values. The iron slag also produced a large iron, potassium, phosphorus and barium value. The lime slag also had a large aluminium value.

The influence of a domestic fire on the element composition of the soil is to raise almost all surface soil element concentrations, except lead, for indoor samples, when compared to outdoor samples. The most consistently enhanced elements for the three studies at the Earthwatch hut were manganese and barium. The influence of a charcoal clamp is similar to the domestic fire, showing an increase in most elements. The pottery kiln does not show any such increase.

The addition of midden materials to the soil could alter the element composition of the soil. The samples from Tow Law suggest sodium, potassium, phosphorus, strontium, copper, nickel, zinc and barium could be increased in the soil by the addition of midden material. Burning increases the concentration of elements in the hen midden material.

Based on the evidence of the two fifty metre transects away from a road, the influence of modern vehicle emission appears to be minimal due to low volume of vehicle traffic on the roads of Boeotia.

CHAPTER 13

CONTROL AREAS

13.1 Introduction

The use of control area surveys had the aim of confirming the observations of the previous Boeotian soil geochemical studies. In these it was observed that the establishment of a background value, to which human altered soils could be compared, was very difficult to achieve, due to the diverse influences on a soil's development. For this study two areas of low to moderate archaeological ceramic density evidence in the Valley of the Muses were chosen. The samples were collected in the 1994 field season.

The ideal archaeological activity indicator element should be constant and low in concentration over the areas of low archaeological ceramic density evidence, based on the assumption that the ceramic represents the only activity on the soil. It should be of a single population and exhibit no skewness (normal distribution) in areas of no archaeological activity.

This chapter will also introduce the statistical assumptions used in the results chapters. The first of these assumptions is that a population of less than a few thousand samples that has values outside of four standard deviations about the mean ($4 \times \text{S.D.}$) contains possible anomalous "high" or "low" values, as 99.99 % of a normally distributed population should reside within $4 \times \text{S.D.}$ A population sample with values outside of six standard deviations of the mean ($6 \times \text{S.D.}$) contains definite "anomalous" values (Davies, 1980). The second assumption is that if per cent cumulative frequencies are plotted against element concentration on probability plotting paper then a normal distribution would

appear as a straight line, a skewed distribution as a simple curved line and a distribution that contains two populations or more as a complex curved line (Davies, 1980).

13.2 Control Area One

Control area one is situated on a gentle north facing slope in the Valley of the Muses. The area is developed on Quaternary alluvium, which is underlain by flysch deposits and limestone rocks. It is in a zone of low to moderate sherd and tile densities (0.001-0.004 sherds and tiles per square metre) located in the area between site VM61 and VM64 (figure 13.1). The basic particle size (figure 13.2 and table 13.1) analyses performed on the samples suggest a greater proportion of fine soil particles in the central and eastern parts of the control area.

Initial analysis of the element data (table 13.2) shows that the elements iron, phosphorus, scandium and vanadium exhibit ranges which are within reproducibility error and will not be discussed further. Sodium is also eliminated from the following discussion as it has an insufficient range.

Of the remaining elements magnesium, calcium, lanthanum, strontium, yttrium, copper, manganese, lead, zinc and barium have values that are outside 4 x S.D and probably contain anomalous values (table 13.3). Of these only values for magnesium and copper are outside 6 x S.D. The correlation coefficients (table 13.4) suggest that some of the elements can be placed into three groups:

- a *calcium* group containing calcium, magnesium, lanthanum, and strontium,
- a *lead* group containing lead, zinc, barium and manganese,
- and a *nickel* group containing nickel, cobalt and chromium.

The contour plots for the *calcium* group suggest the presence of calcareous rocks under the soil in the north-western corner of the control area and in the area to the east of centre on the southern edge of the control area (figures 13.3c, e, k and m). The cumulative frequency plots support the theory that this is due to a change in geology through the presence of minor inflexions in the line, suggesting two or more populations (figures 13.3d, f, l and n). The summary table (table 13.5) of cumulative frequency defined populations shows that the calcareous rocks are indicated by the calcium population with the largest values (5-9 % CaO) and the largest value lanthanum population (21-27 ppm La). The values for magnesium and strontium belong to single populations, with their largest values correlating with the largest valued calcium and lanthanum populations.

The *calcium* group is negatively correlated with the *lead* group. Values for the lead group are greatest in the east and south of the control area (figures 13.3α, γ and ε). The cumulative frequency plots (figures 13.3β, δ and ζ) show that the results for lead, zinc and barium come from two populations. For lead the two populations have a concentration range of 10-25 ppm Pb and 25-45 ppm Pb, for zinc the ranges are 38-55 ppm and 55-70 ppm, and for barium the ranges are 15-30 ppm and 30-50 ppm (table 13.5). In the case of each of these elements the population range with the lowest values relates to the areas of suggested calcareous rocks. The higher range with its bias to the eastern side could relate to archaeological activity associated with site VM64 or could relate to the presence of rocks richer in these elements. The suggestion that it could be due to a rock type with higher values is shown by the fact that some of the higher values for the *lead* group relate well with the *nickel* group (figures 13.4q, s and y) which exhibit their greatest values along the southern edge. However, the absence of large nickel values in the east of the control area would suggest that it is not the presence of rocks but the effect of archaeological activity.

The association of and values observed for the *nickel group* suggest the presence of ultrabasic rocks or weathered ultrabasics (e.g. laterites). The pattern of the nickel group is mimicked by aluminium, potassium, manganese (figures 13.4a, g and w) and the lower soil content of fine particles (figure 13.2) which suggest that the larger values of these elements are associated with the ultrabasic rocks.

If the high values of the lead group to the southern edge of the control area are eliminated on the grounds that they are due to the presence of ultrabasic rocks this leaves the large values to the east which may relate to archaeological activity associated with site VM64. In addition the elements cerium, yttrium and copper have their largest values to the east of the control area, show a distinct population relating to this eastern area (table 13.5) and are therefore suggested to be indicating archaeological activity.

13.3 Control Area Two

Control area two is situated on the north-eastern slope of Strongyli Hill in the Valley of the Muses, sixty metres north-east of the 1994 surface soil survey grid of VM70. It is situated on soils overlying flysch deposits, which are in turn underlain by limestones. The area is located (figure 13.4) in a zone of low sherd and tile density (0.0005 - 0.001 sherds and tiles per square metre). The basic particle size analysis (figure 13.5) shows a larger fine particle soil content in the south and north of the control area. The mean, minimum, maximum and standard deviation values are similar to control area 1, though the results are far more positively skewed in the control area 2 data set.

Initial analysis of the element data (table 13.7) shows that the elements iron, sodium, phosphorus, scandium, chromium and vanadium have ranges within reproducibility error and will not be discussed further. The statistical data (table 13.8) shows that all the elements except copper have values outside 4 x S.D. The elements magnesium, cerium, lanthanum and strontium are positively skewed, have values outside of 6 x S.D. and probably reflect the presence of calcareous rocks. The correlation coefficients between elements (table 13.9) cannot be grouped as easily as in control area 1, though the following observations can be made:

- *Calcium* is strongly correlated with lanthanum and negatively correlated with manganese and lead.
- The *lead* group contains lead, manganese, zinc and barium.
- The *nickel* group contains nickel and cobalt.

Calcium is high in the south-east, east central and north-west of the control area (figure 13.6e), a pattern which is mimicked by lanthanum (figure 13.6k). Both these elements have a distinct population relating to this area (table 13.10), calcium values are between 9 and 12 %, and lanthanum values between 20 and 30 ppm La. The strontium

results which should be largest over the calcareous rocks are not (figure 13.6m). The results for strontium bear a similarity to the results for cerium.

The results for aluminium, potassium, manganese, nickel, lead, zinc and barium (figures 13.6a, g, u, w, y, α and γ) all exhibit their greatest values in a band running from the north-eastern corner of the control area to the central western edge of the control area and all, except for zinc, exhibit at least a two populations in the plots of cumulative frequency (table 13.10). The association of all these elements makes it impossible to draw any detailed conclusions for their origin, though the concentrations of nickel, manganese and cobalt would suggest ultrabasic rocks.

The elements that had large values occupying the eastern part of control area one are in a similar range over the calcareous rocks in control area two. Lead again has a distinct population of 20-35 ppm, as does copper (27-37 ppm), barium (20-30 ppm) and manganese (500-775 ppm). Zinc is of one skewed population with the lower values over the calcareous rocks.

13.4 Conclusions

The results for control area one are easier to interpret than the results for control area two due to the ability to group more elements in the data from control area one. The results illustrate that it is very difficult to find a background value for each element, as even when archaeological activity on an area may be minimal, then the effects of geology can be important. The results suggest that the presence of calcareous rocks can be detected by the association of calcium, lanthanum and strontium. The presence of ultrabasic rocks can be detected by the association of nickel, chromium and cobalt with the probable association of larger aluminium, manganese and potassium values. On the other elements lead, zinc, barium, copper, manganese, cerium and yttrium possess the potential of being good archaeological activity indicators.

The use of cumulative frequency plots to define populations within the data for each element proved to be very useful. This technique has highlighted the following features:

- A calcareous geology is indicated by values of calcium (CaO) exceeding 5 % and lanthanum values between 20 and 30 ppm La.
- The presence of ultrabasic rocks is indicated by nickel values in excess of 900 ppm Ni, values of cobalt between 70 and 80 ppm Co and values of Chromium between 350 and 500 ppm Cr.
- Potential archaeological indicators have populations which are low over calcareous rocks in both control areas. Values on the calcareous rocks are 15-30 ppm Barium, 10-25 ppm Lead, 27-37 ppm Copper, 38-55 ppm Zinc and 500-600 ppm Manganese. In the control areas these elements display their highest values in samples which also have high nickel, cobalt and chromium values. This would suggest that the presence of ultrabasic rocks leads to higher values of these elements.

CHAPTER 14

HYETTOS: A CITY SITE

14.1 Introduction

The intensive survey of surface sherd densities at Hyettos began in 1989. The aim was (Hyettos being in the north of Boeotia) to provide a control over the results achieved from the 50 square kilometres of rural and urban survey in south-west Boeotia (Bintliff, 1995). The first stage involved the commencement of an intensive, 100 % field survey of some 2.74 km² of countryside to the north and north-east of the city of Hyettos. The results presented in this chapter relate to the second stage of the Hyettos survey, the intensive survey of the city (figure 14.1). The survey of the city began in 1990 with a pilot survey of the acropolis and the entire city area was surveyed by the 1992 field season. The survey units were 10 m by 10 m for the first forty units surveyed over the acropolis, but this was since found to be too time consuming due to the small size, subsequent units were 20 m by 20 m. At the end of the survey 664 of these units, plus five double units and a single block comprising the equivalent of 15 units, had been surveyed. In addition to the counting of ceramic in the units, diagnostic sherds were collected to assess the historical development of the city.

As noted in chapter 3 the historical development of the city is as follows. The origins of Hyettos city lie in prehistory. The acropolis (figure 14.1) formed a small community throughout the Bronze Age. A dramatic expansion of this village community occurred in the late Geometric / Archaic period. The settlement achieved city status by the sixth century BC and reached its apex in the Classical and early Hellenistic period when

the occupied area comprised 28ha, representing an estimated population of 3500, which represents 70 % of the total city-state (the remaining 30 % being rural dwellers). The population was supported by the production of crops, the exploitation of the local rich iron ore and an industrial quarter of the city, which produced roof-tiles and pottery. During the Late Hellenistic era the city went into a period of demographic decline, in which the occupied area contracted to between a third to a half of its Classical extent. The city remained in this contracted state until the sixth century AD. After the Roman period the city only shows evidence of sporadic use, probably one or two medieval farms. Nucleated settlement of the Hyettos region continues by a move to site CN3, 500m north of the acropolis, in the Early Medieval period.

14.2 The Trace Element Survey

Trace element surveys were carried out in both field seasons, 1994 and 1995. The 1994 survey consisted of three transects starting in the south of the Classical city centre, where the densest sherd concentrations are to be found, and progressing westwards, where there is a dramatic decline in sherd concentrations (figure 14.2). The aim of this survey was to assess the trends in trace element concentrations from a high intensity use, high sherd density city site to a low sherd density landscape.

The second survey of 1995 repeated the aim of the 1994 survey, but added an extra aim, the assessment of surface variability in trace element concentrations. This survey consisted of four, twenty by twenty metre grids (figure 14.1). This allowed the variability of surface soil trace element concentrations in each area to be assessed. In addition two soil pits were dug, one in grid one and the other in grid four. The aim of this

was to assess soil development and to analyse the trace element concentrations through the profile.

In 1996 three samples from grid one and three samples from grid four of the 1995 surface soil survey were subjected to a sequential extraction. The aim was to assess whether any specific portion of the soil was retaining the elements added by the use of the city.

Both surveys were conducted in the flat plateau area to the south of the acropolis, which is underlain by Mesozoic (Triassic and Jurassic) deposits of a marine transgression and regression (thin limestones, shales and clays) intruded by ultrabasic rocks containing peridotite, dunite and olivinite. The boundary between the Cretaceous limestones of the acropolis and the Mesozoic deposits of the plain is marked by conglomerates of the Upper Cretaceous marine transgression and chrome-nickeliferous lateritic iron-ore.

14.3 The 1994 Surface Soil Survey

The 1994 surface soil survey consisted of three transects, two of 380 metres in length and one of 180 metres in length (figure 14.1). These transects were separated from each other by 20 metre intervals and samples were collected at 20 metre intervals. The transects ran from the city core, where sherd densities exceeded 16.67 sherds per square metre, out into the surrounding landscape where sherd densities fell below 1.67 sherds per square metre. Particle size analysis (figure 14.3 and table 14.1) of soil samples shows little difference between the soil in the city and the soil outside the city in terms of the percentage particle size below 212 μm . The city core samples of the 40 m transect exhibit percentages in excess of 10 %, which as these samples are the closest to the city centre would suggest that city samples will have a higher percentage of less than 212 μm particles

than the surroundings samples. The band of higher percentages at 300 m from city core are attributed to an area of macchia, which as it is uncultivated will allow a surface soil of wind blown fine particles to develop.

Initial analysis of the results (table 14.2) highlighted that the elements iron, sodium, scandium, chromium and vanadium had ranges which were within reproducibility error and will not be interpreted further.

The statistics (table 14.3) show that the results for calcium are very low when compared with the control areas in the Valley of the Muses where values reached 11 %. The low values suggest there is an absence of calcareous rocks in this area.

The results for magnesium (some of which exceed the instrument's maximum detection), nickel and cobalt are high and suggest the presence of ultrabasic rocks in the area (see chapter 12). Nickel is negatively correlated (table 14.4) with most elements except manganese and cobalt. With cobalt it has a positive correlation and with manganese no correlation. The distribution of nickel and cobalt surface soil concentration (figures 14.4q and 14.4w) shows both increasing in value away from the city. This confirms the known presence of ultrabasic rocks beneath the soil at the end of the transect. The plotting of cumulative frequencies against surface soil concentration allows populations to be found within the sample (table 14.5). These show that nickel has three populations, the greater value population resides over the ultrabasic rocks and the lower over the city, with the middle population forming a transition between the city and the ultrabasic rocks. Cobalt has three populations, with the highest value population over the ultrabasic rocks, the lowest value population over the city periphery and the middle value population over the city, suggesting that cobalt values had been enhanced over the city by the archaeological activities as well as being elevated by the presence of the ultrabasic rocks at the end of the transects. Manganese is similar to cobalt in that the city area and the presence ultrabasic rocks towards the end of the transects show high values and would suggest that both the

presence of a ultrabasic rocks and activities in the city's use are causes of higher manganese values in the soil.

All the other elements show higher values over the city and show a decline with distance away from the city core. Most of these elements show a strong positive correlation with each other (table 14.4). There exists a very strong to strong correlation between zinc, copper, lead, barium, yttrium, cerium, potassium and lanthanum, strontium, and weaker positive correlation with aluminium, calcium and phosphorus. Strontium shows a stronger correlation to calcium than any other element and is tentatively placed with this element. All are suggested to be elevated due the activity of the inhabitants of Hyettos city.

The elements aluminium, cerium, lanthanum, lead, zinc and barium display a mid-value population between the high value population over the city and the low value population over the ultrabasic rocks. This population is associated with the city periphery where sherd densities show a dramatic decrease and may represent a zone which had some city influence but to a lesser extent than the city itself.

14.4 The 1995 Surface Soil Survey

The 1995 surface soil survey consisted of four, twenty by twenty metre, grid samples. From each grid sixteen samples were collected giving a five metre separation. The grids are numbered one to four. Grid one is in the city centre and has a sherd density of eleven sherds per square metre. Grid two is also in the city centre and has a higher sherd density of seventeen sherds per square metre. Grid three is on the city edge and has a sherd density of three sherds per square metre. Grid four is outside the city and has a sherd density of one sherd per square metre. Particle size analysis (figure 14.5) shows a greater percentage of the particle size below 212 μm in the city (grid 2) and in grid 4 and the

lowest percentages in samples from grid 3. Grid 4 was in an area of macchia and thus this is believed to be an accumulation of wind-blown particles. If the results of grid 4 are omitted then the city has a greater percentage of particles below 212 μm than the surrounding area, which leads to the conclusion that human activity in the city leads to the development of finer particle soils.

Initial analysis of the results (table 14.6) shows that all the elements have ranges outside that which could be attributed to reproducibility error.

Values for calcium reach higher values than in the 1994 survey (table 14.7). Calcium is strongly correlated (table 14.8) with strontium, lanthanum and phosphorus. The highest values for each of these elements occurs over the city grid 2. Values of calcium are lower than those attributable to calcareous rocks and it is probable that the elevated levels are due to the human activity on the city site.

Nickel values are again negatively correlated (table 14.8) to most elements. The exceptions are iron, scandium, cobalt, chromium and manganese. The values of each of these elements is greatest in grid four (figures 14.6) and suggest the presence of ultrabasic rocks beneath the soil. Values of magnesium also show the same trend but are not included in the correlation coefficients as values exceed the instrument's maximum detection. All these elements have a low value population over the city and a high population over the ultrabasic rocks (grid 4). For nickel there is a middle value population which forms a transition between the ultrabasic rocks of grid 4 and the city. Manganese also has three populations and like the 1994 survey shows values over the city as the middle value population suggesting that both the ultrabasic rocks and human activity are causes of increased soil manganese values.

The elements zinc, barium, lead, copper, phosphorus, potassium, aluminium, cerium, yttrium have a strong positive correlation with each other. These elements are also positively correlated with the calcium group of elements (calcium, lanthanum, and

strontium) reflecting the common trend of highest values over the city and the lowest values in grid 4, over the ultrabasic rocks. Phosphorus is associated with both groups but is more highly correlated with the zinc group of elements. Both these groups, with the exception of yttrium and cerium, have values which correspond with sherd density supporting the theory that these elements are increased in value by human activity. The values of elements cerium, yttrium and vanadium are greatest over grid one suggesting a different cause for the enhancement of these elements or a different human activity in this area.

14.5 The Soil Pit Survey

Two soil pits were excavated at Hyettos city. One in grid 1 and the other in grid 4. The grid 1 soil pit was excavated to a depth of 45 cm without reaching the underlying geology and contained archaeological material throughout the profile. The grid 4 soil pit was excavated to a depth of 25 cm, the ultrabasic rocks being encountered at 15 cm depth as a highly weathered gravel.

The results show that the elements that have their greatest values over the city, also show a relatively constant value throughout the profile of the grid 1 soil pit and are higher in value than the grid 4 soil pit. This, therefore emphasises the archaeological importance of the grid 1 soil pit. Lead, zinc, barium, copper and aluminium (figure 14.10p, q, r, m and a) have their greatest concentration in the grid 1 soil pit at the 10-15 cm depth and decrease with depth in the grid 4 soil pit. The elements associated with the ultrabasic rocks, nickel, manganese, cobalt, and chromium show the same profile in grid 1 soil pit as do the lead group with the greatest value at 10-15cm depth, but have greater values in the grid 4 soil pit. Nickel is constant through the grid 4 profile reflecting the underlying

geology. Manganese, cobalt and chromium are highest in the top 15 cm of the grid 4 soil pit and decrease in the 20-25 cm depth sample.

Calcium, strontium, lanthanum, cerium and yttrium (figure 14.10c, i, h, g and j) show a depth decline in grid 4 soil pit and are lower in concentration in this profile than the grid 1 soil pit. The values of this group are highest in the 30-35 cm depth sample of grid 1 soil pit and the calcium, lanthanum and strontium values may reflect the presence of calcareous rocks at depth.

Sodium, potassium and phosphorus are greater in value in the grid 1 pit than the grid 4 pit. The values in the grid 1 pit are greatest in the surface 0-5 cm depth sample. Potassium and phosphorus are also elevated in the 30-35 cm depth sample.

14.6 Sequential Extraction of Hyettos Samples

The results from the 1994 and 1995 surface soil survey and soil pit survey have shown that some elements are greater in value in soils over the city than outside the city, some are greater over the ultrabasic rocks in grid 4 and one element, manganese is elevated over both. The aim of a sequential extraction of samples is to assess whether any particular portion of the soil is responsible for the greater values found over the city site. Three samples were analysed from each of grid 1 and grid 4. The average value of the three samples for a grid is considered the representative value of that grid.

The results displayed are those that give values that are in detectable amounts (table 14.10 and 14.11). The results show that of the elements which had been greatest in value over the city (Al, Ca, K, P, Ce, La, Sr, Cu, Pb, V, Zn, and Ba) all have greater values in the grid 1 samples than in the grid 4 samples in all extracts that are in detectable

proportions. The only exceptions being aluminium (extract 4), lead (extract 6) which show no change and cerium (extract 6) which shows higher values in grid 4 than grid 1.

Of the elements greatest in value over the ultrabasic rocks (Fe, Sc, Mn, Ni and Co), iron and scandium show no difference between the grids for extract 7. Iron, cobalt and nickel display higher values in grid 4 samples than grid 1 samples in all extracts with values above detection limits. Manganese which is elevated in value over both city and the ultrabasic rocks, is higher in grid 1 samples over the city for extracts 1, 2 and 7 and values of extracts 5 and 6, which are higher over the ultrabasic rocks, thus reflecting the different sources for the elevation of manganese values.

Values of calcium in extracts 1, 2 and 7 all show higher values in the city soil when compared to the soils of grid 4. This would be expected for the increased presence of carbonates in the soil (perhaps as the result of limestone used as building material or the presence of calcareous rocks).

14.7 Summary

The elements aluminium, calcium, sodium, potassium, phosphorus, cerium, lanthanum, strontium, yttrium, copper, lead, zinc, vanadium and barium are greater in value over the city than outside the city. The soil values for the elements nickel, chromium, cobalt, iron, scandium are greatest outside the city and relate to the presence of laterite rocks. Results for manganese are greatest over both city and laterite reflecting that both the geology and human activity are responsible for its increase in the soil environment.

The elements greatest in value over the city can be subdivided into two groups: a lead group and a calcium group. The lead group contains lead, zinc, barium, copper, aluminium, potassium, sodium and phosphorus. These are greatest in concentration in the

top two samples of the grid 1 soil pit, which suggests that these greater concentrations are the product of human activities. The values of lead, zinc and copper from the Hyettos City survey can be compared to the values of Chapman's Thespiae city survey. Values of lead and copper in soils from Thespiae City have ranges with higher values than those at Hyettos (Lead at Thespiae 60-112 ppm and at Hyettos 50-60 (1994) and 60-75 (1995). Copper at Thespiae 24-68 ppm and at Hyettos 30-45 (both years)) reflecting the greater size of the occupation at Thespiae. Zinc values are lower at Thespiae than Hyettos (Thespiae 34-82ppm and at Hyettos 85-95 (1994) and 60-85 (1995)). The calcium group containing calcium, strontium, lanthanum, cerium and yttrium is highest in the bottom sample of the grid 1 soil pit and may reflect the influence of underlying rocks. Higher calcium, strontium, lanthanum and cerium values would indicate calcareous rocks.

The nickel group of elements which reflect the ultrabasic rocks may also be elevated over the city. Manganese and cobalt both have their highest value population over the ultrabasic rocks, but they also have a middle population which is associated with the city samples. The high values associated with the ultrabasic rocks may be masking the city effect.

The sequential extraction shows that the exchangeable, carbonate bound and nitric acid extractable portions of the soil are responsible for the retention of those elements elevated in the city soils. Secondary iron (extract 6) and manganese (extract 5) oxides are responsible for the retention of the nickel group above the ultrabasic rocks. The sequential extraction of manganese clarifies its two modes of enhancement, in the city soils exchangeable, carbonate bound and nitric acid extractable portions are greater than in the soils over ultrabasic rocks, whilst the soils over ultrabasic rocks are greater in the secondary iron and manganese oxide portions of the soil. The results for the sequential extraction also clarify the calcium enhancement which is elevated in city soils in the easily

extractable exchangeable and carbonate bound portions, but also in the nitric acid extractable portion which may reflect more crystalline forms of calcium.

CHAPTER 15

VILLAGE SITES

15.1 Introduction

The three village sites chosen are of different time periods, population intensity and length of occupation. The general information for each of these sites is displayed below in table 15.1.

Site	Main period of occupation	Maximum population
Askra	Early Bronze Age, then Geometric - 13 th century AD	c.1300
VM4	Middle - Late Bronze Age, Classical, then 13 th century AD - mid 17 th century AD	c.1100
Rhadon	late 14 th century AD - late 19 th century AD	c.260

Table 15.1 General information for the three village sites.

15.2 Askra

15.2.1 History of Askra

The history of this site is taken from Bintliff and Snodgrass (1988), Bintliff (1996) and Bintliff (pers. comm.). This ancient site has its earliest phase of occupation in the Early Bronze Age, when settlement was comparable in scale to the Classical period. The site appears to go out of use until the Early Iron Age when the population re-occupy the north-west extremity of the site (figure 15.1). This is the period in which Hesiod lives in Askra and writes his poem *Works and Days*. During the following Archaic and Classical periods the village of Askra expanded, reaching its maximum size of 11 ha and a suggested population of c.1300 in the 4th century BC. During the Archaic period, it may have had a stone defence wall, traces of which are thought to have been found.

After this maximum, came a period of decline. This may have led to a period of abandonment, which is suggested by the dearth of material from earlier Roman Imperial times and from the comments of the 2nd century AD travel-writer, Pausanias who states that, in his day at Askra, there was “a tower and nothing else to remember it by”. During the decline, in the Hellenistic period, the main nucleus of the settlement began to shift to the south of the site. This new centre was the focus for the revival of Askra during the 4th to 6th AD centuries, when Askra recovers its full Classical extent of occupation. The focal point for this period of occupation and later periods was the area around the now ruined church of Episkopi, in the south of the site (figure 15.1).

As a result of the 6th century AD Black Death and the politico-military breakdown in the provinces of the 7th century AD the Greek population of Askra declined and the name Askra disappeared. However, the site continued as a small hamlet or village through the influx of Slav settlers, reflected in the new medieval name of the settlement, Zaratoba.

The settlement continues until the 13th century AD when the population are relocated to the Frankish settlement of VM4 on a hillside half a kilometre to the east.

15.2.2 Soil survey of Askra

The soil survey of Askra was conducted in both the 1994 and 1995 field seasons. In the 1994 field season a five hundred and fifty metre transect was sampled at ten metre intervals. The transect started in the core of Askra, near the ruined church of Episkopi, where the densest sherd concentrations had been found (figure 15.1) and progressed northwards out of Askra.

The 1995 soil survey of Askra consisted of two sampling methodologies. Firstly, four 5 m interval grids of twenty five metres by twenty five metres were sampled (figure 15.1). The grids were numbered one to four, one being the area of densest sherds near the Episkopi church and four being outside the village with grids two and three representing intermediaries. The grids each had twenty five samples collected from the intersections of the grid. The grids were spaced out along the line of the 1994 transect at 150 metre intervals. The second methodology used in 1995 was the excavation of two soil pits. Soil pit one was excavated in the rough pasture field just to the north of the field of the grid one samples, but is referred to as the grid one soil pit. The reason for excavating just to the north was to avoid and assess the possible copper contamination from the cultivation of vines in grid one samples, as blue deposits on the vine leaves suggested the use of blue vitriol, which is 25 % copper, as a fungicide. The second soil pit was excavated in grid four.

The soils sampled are developed over undivided flysch deposits and Upper Cretaceous limestones.

15.2.3 Results of 1994 Surface Soil Sampling

The surface soil sampling of the 1994 field season consisted of the 550 m sampled at 10 m intervals starting at the core of Askra, near the Episkopi church and progressing northwards.

The percentage of fine particulates (% less than 212 μm) in samples (figure 15.2) shows values differing greatly between adjacent sample points. The values are restricted to between 5 and 20 %, except for samples between 270 m and 370 m where values are more than 20 %.

All elements except sodium are used in this discussion. Sodium is excluded as it exhibits insufficient range (table 15.2). With the exception of potassium all remaining elements exhibit values outside 4 S.D. of the mean (table 15.3) and therefore exhibit values which are possibly anomalous. Iron, calcium, cerium, scandium, yttrium, vanadium and barium exhibit anomalous values (values outside 6 S.D. of the mean).

Correlation coefficients (table 15.4) allow the grouping of the elements into (1) a lead group including aluminium, magnesium, potassium, phosphorus, strontium, nickel, lead and zinc. (2) A calcium group containing calcium, lanthanum and strontium. (3) A barium group including manganese and barium. The association of strontium with both the lead and the calcium group reflects the fact that positive soil anomalies of this element can be caused by both geology and human activity.

The plots of the elements (figures 15.3a-p) show three patterns. The elements aluminium, magnesium, calcium, strontium, manganese and barium exhibit lower values in samples between 270 m and 370 m than samples from the remainder of the transect. These samples are also those which have a higher percentage of fine particles.

The elements potassium, phosphorus, nickel, lead and zinc (the lead group) exhibit higher values in samples over the first 200 m of the transect than the remainder. These elements represent those enhanced by human activities.

The final pattern exhibited is one of more constant values in samples between 30 m and 100 m. This can be attributed to the additions of human activities smoothing out variability in element concentrations in the soil. The elements that exhibit this are lanthanum (19 ppm), cobalt (17-18 ppm), manganese (850-900 ppm), lead (42-47 ppm) and barium (75-90 ppm).

15.2.4 Results of 1995 Surface Soil Sampling

The surface soil sampling of the 1995 field season consisted of four grids as described in the introduction to Askra. The four grids are 25 m by 25 m, sampled at 5 m intervals giving 25 samples per grid. The first and second grid is in the core of the city as depicted by sherd densities of 2 or more per square metre. Grids three and four are in areas of lower sherd densities. Particle size analysis shows that there is on average a higher percentage of particles below 212 μm in samples from grid 2 to 4 than from grid 1 (figure 15.4). This is due to a wider range of values for grid 1 than the other grids and grid 1 is the only grid to contain samples with are less than 15 % particle size below 212 μm . This would suggest that human activity lowers the percentage of fine particulates in the soil.

The elements sodium and yttrium are excluded from further discussion as they exhibit ranges within the range of reproducibility error (table 15.5). Scandium is excluded as it exhibits insufficient range. Of the remaining elements all but copper are positively skewed. Potassium, phosphorus, copper and zinc are the only elements not to exhibit “possibly anomalous” values (table 15.6). The elements aluminium, magnesium, calcium, cerium, cobalt, manganese, lead and barium exhibit “anomalous” values.

Correlation coefficients (table 15.7) show three groups of elements: (1) an aluminium group containing aluminium, iron, magnesium, calcium, chromium and nickel, (2) a potassium group containing potassium, phosphorus, strontium, lead and zinc, and (3) a cerium group containing cerium, cobalt and barium.

The potassium group shows the clearest association with the archaeological evidence of human activity. The elements potassium, phosphorus, lead and zinc exhibit higher concentration in grids one and two than in grids three and four. In the case of each element the higher concentration populations (table 15.8) are associated with grids one and two and the lower concentration populations are associated with grids three and four. The remaining element of the potassium group, strontium also shows a decline with distance from the core of Askra but has its highest values in grid 3.

The cerium group of elements, with the addition of the element lanthanum show an increase with distance from the core of Askra. Cerium, lanthanum and barium all exhibit higher values in grids three and four than grids one and two. The greatest values of these elements is in grid three. Cobalt does not peak in grid three and shows a gradual rise in concentration from grids one to four. These elements may be demonstrating a dilution effect on the geological signal in the soil. A change in geology may occur in grid three giving rise to elevated values of cerium, lanthanum and barium.

The greatest values for the elements aluminium, iron, magnesium, calcium chromium, copper, manganese, nickel and vanadium occur in grid three. With the exception of copper and manganese, all these elements would exhibit a decline in concentration with distance from the core of Askra if the results for grid three were excluded. This would suggest that they are increased by the human activity at Askra, the results of grid three being explained as geological interference in the human activity signal from the presence of ultrabasic rocks.

15.2.5 Results of 1995 Soil Pit Sampling

The soil pit sampling (figures 15.5a - p) was conducted in two pits, one in the core of Askra near grid one and the other near grid four where lower sherd densities indicate less human activity. Both pits were excavated to a depth of 50 cm with samples being collected from the 0-5 cm, 10-15 cm, 20-25 cm, 30-35 cm and 40-45 cm depth.

The elements of the potassium group exhibit higher values in the grid one soil pit than in the grid four soil pit reflecting greater human activity in grid one. With the exception of potassium, the elements display a relatively constant concentration throughout the samples of the grid one soil pit, whereas the samples of the grid four soil pit exhibit a decline in concentration with depth.

The elements of the cerium group display slightly greater concentration in the samples of grid four soil pit than grid one soil pit. They also display a peak in concentration at the 20-25 cm depth. This distribution is also displayed for manganese and vanadium.

The aluminium group of elements with the exception of vanadium and manganese display slightly greater values in grid one soil pit samples than grid four soil pit samples. The elements magnesium and calcium displays larger concentrations in the bottom sample of the grid one soil pit suggesting a geological influence.

Copper is greater in concentration in the grid four soil pit than the grid one soil pit and shows a increase in the bottom sample of the grid four soil pit (figure 15.5j).

15.2.6 Summary

The elements potassium, phosphorus, strontium, lead and zinc display greater values in surface soils over the core of the city than away from the core of the city. In the

grid one soil pit these elements were constant in concentration throughout the profile suggesting a developed city soil profile, where as in the grid four soil pit the concentration decreases with depth. The other elements produced less distinct associations, though aluminium, magnesium and nickel appear to be linked with the intense activity of the city.

15.3 VM4

15.3.1 History of VM4

The history of VM4 given here is from Bintliff (1996) and Bintliff (pers.comm.). The earliest evidence of extensive settlement at VM4 is in the Late Bronze Age (Mycenaean period), when a sizeable population existed on the site and possibly reflects a relocation of the Askra community from the Early Bronze Age. The site also has some evidence suggesting the existence of a small nucleated Classical community. The extant ruins of settlement at VM4 have their origins in the Frankish period, with the giving of the lands of ancient Askra as a fief to a non-noble Frankish soldier of fortune, who erected a tower residence and resettled his new serfs below the tower in the 13th century AD. In the first Ottoman census of 1466 the population of VM4, called Panayia, was 400 people. It appears to have acted as a Greek refuge from the troubles of increased warfare between the Franks, the Byzantines and the Ottomans in the 14th and early 15th centuries AD. Its population had increased to 1100 people by the Ottoman census of 1570. The main source of this influx of people may have been the abandonment of the medieval settlement of Erimokastro-Thespieae, several kilometres to the east. During the first 150 years of the Ottoman empire, under the Pax Ottomanica, the region was freed from warfare and the ravages of disease, and existed within a low-tax regime that allowed villages considerable autonomy, under which population and economy grew. According to the records (Kiel, 1997), Panayia at first kept to a low stock farming practice, focusing on wheat, barley, vine and cotton cultivation. The stimulus of the new regime encouraged a reduction in the cultivation of the vine and cotton in favour of a major shift to sheep. In 1506 the village of Panayia had 30 head of sheep, by 1570 this had increased to 3,800 head. Another indicator of a more extensive farming practice was the expansion in honey production from 60 hives

in 1506, to 192 hives in 1570. The prosperity of Panayia in this period is reflected in its ability to establish a small monastery in 1540, and a second in 1570.

The decline of this site coincided with the decline of the Ottoman empire in the 17th century AD, when piracy and insecurity led to a decline in populations in Eastern Boeotia. Panayia was broken up into some dozen serf-estates and by 1642, two-thirds of its population had disappeared, with the population down to c.335 people. By this point the site had shifted east half a kilometre to its present locality.

15.3.2 Surveys of VM4

Surface soil sampling of VM4 was performed in the 1995 field season. Samples were collected at 20 metre intervals along three 320 metre transects (figure 15.6). The transects started in the village area below the Frankish Tower and progressed east out of the village.

In addition to soil sampling, a soil resistivity survey of part of the area was conducted (figure 15.7). Some of the results (figures 15.8a and b) of this survey simply confirm the extant remains of the village, such as the features D and F which are terraces. The remains of the church (C), which are still visible, were detected with an additional high resistance feature to the south (E), which is interpreted as a boundary wall to the church. Two structures, A and B, possible medieval houses were clearly visible in the soil resistivity results as high resistance features. Feature A is a D-shaped enclosure with attached 5m square structure on its east side. Feature B is interpreted as an L-shaped structure with possible wall extending out to the north-west. Feature G is an area of high

resistance and is interpreted as near surface geology, which is Upper Cretaceous limestone with some overlying flysch.

15.3.3 Results of the Surface Soil Sampling

The results of sample particle size are well defined by surface terraces (figure 15.9 and overlay 5). The lowest percentages (< 15 % below 212 μm) are found in the east of the survey area, beyond the terrace at 210 m. The highest values (> 25 %) are confined to the village area which is the highest altitude terrace in the survey area.

Initial analysis of the results (table 15.10) eliminates sodium and scandium from further interpretation as both exhibit an insufficient range in values to be of use. All other elements (table 15.11) display values which are outside 4 x S.D. suggesting that they contain “possibly anomalous” values. Magnesium, phosphorus, cerium, yttrium, cobalt, chromium, nickel and zinc exhibit “anomalous” values (values outside 6 S.D.). The elements magnesium, cerium, yttrium, chromium, nickel and vanadium are positively skewed and phosphorus negatively skewed.

The correlation of elements (table 15.12) shows a negative correlation between percentage particle size below 212 μm and the elements aluminium, iron, manganese and vanadium. The table allows the grouping of the elements into four groups: a calcium group including calcium, lanthanum and strontium, a nickel group including nickel, cobalt, chromium and magnesium, a phosphorus group including phosphorus, copper and zinc, and an aluminium group including aluminium, iron, cerium, yttrium, manganese, vanadium and barium. The aluminium group is negatively correlated to the calcium group. Lead is also negatively correlated to the calcium group and is most closely correlated to the aluminium group and therefore will be included within that group.

Using overlay 5 it can be seen that the higher soil concentrations of elements of the calcium group are associated with the western end of the survey grid. The greatest values are associated with the church. The church is also the area of the greatest concentration (table 15.13) of the nickel group. These two associations are interesting as both groups are indicators of rock types underlying the soil. It is likely that one group does represent the underlying geology, the other group may represent the building stone of the church. In the case of the calcium group it may also represent burials around the church.

The higher concentrations of the phosphorus group are associated with the western end of the survey grid and between the terraces at 110 m and 210 m. Potassium although not correlated with this group, exhibits a similar pattern (figure 15.10i). This may represent the intensive manuring of plots or rubbish accumulation in the vicinity of the village.

The final group, the aluminium group, displays its greatest concentrations in the east of the survey grid and its lowest populations over the village and church in the west of the survey grid.

15.3.4 Summary

Only the elements phosphorus, copper and zinc exhibit a general elevation over the village and possibly reflect the manuring or rubbish accumulation at the village. The nickel group and the calcium group are associated with the church of the village, the nickel group probably reflects some underlying ultrabasic rocks. The calcium group may represent the building fabric of the church and interments of the churchyard.

15.4 Rhadon

15.4.1 History of Rhadon

The remnants of the houses and terraces of this Albanian village are still visible today. Apart from the ubiquitous scatter of Classical ceramic the surface material observed corresponds well with the historical evidence for the Albanian settlement. The first record of the settlement occurs in the Ottoman census of 1466 when the population was 90. By the census of 1506 it was 120. The village reached its peak in 1642 when the population reached c.260. The settlement shows signs of some decline by 1688 with a reduction in population size to 234. The next record is in 1810 when the population had dropped to 75 and by 1879 the village had been abandoned due to banditry.

15.4.2 Surface Soil Survey of Rhadon

The surface soil sampling of Rhadon was conducted in the 1995 field season. It consisted of three 160 metre transects running from west to east (figure 15.11). Surface soil samples were collected at 10 metre intervals. The transects start in the village where the walls of the various buildings can still be seen and progress east out onto agricultural terraces.

The village of Rhadon sits at the foot of a north-east facing slope overlooking a valley filled with Quaternary alluvium. The village resides on rocks of mid to lower Jurassic age, which include shales intercalated with marly limestone. The hillside above the village is composed of Upper Cretaceous limestone. The junction between the rocks of the hillside and the rocks beneath the village is marked by the presence of conglomerates of Upper Cretaceous age and tuffs of basic igneous rocks.

15.4.3 Results of Surface Soil Sampling

The results of the particle size analysis show a greater percentage ($> 22\%$) below $212\ \mu\text{m}$ in samples from the lower terrace of the village in the west of the survey area, continuing eastwards and following the line of the eastern terrace (figure 15.12 and overlay 6).

The element yttrium is excluded from the interpretation as the range of values falls within reproducibility error (table 15.15). Of the remaining elements only aluminium does not exhibit values which are “possibly anomalous” (table 15.16). Only the elements sodium, cerium, cobalt, manganese and lead exhibit “anomalous” values. The elements sodium, cerium, cobalt and nickel show a large positive skewness.

Correlation coefficients (table 15.17) allow the grouping of elements into four groups. These are: a calcium group including calcium, lanthanum and strontium, a nickel group including nickel, cobalt and chromium, a potassium group including potassium, phosphorus and zinc and a aluminium group including aluminium, iron, magnesium, scandium and vanadium. Lead is negatively correlated with the calcium group.

The calcium group display their greatest concentrations over the village in the west of the survey grid and in the eastern end of the survey grid. Calcium and lanthanum both have their greatest value population (table 15.18) or greatest values associated with the eastern end of the survey grid. However, strontium has its greatest population over the lower terrace of the village, which possibly reflects the human activity of wood burning in the village, as strontium is elevated by such activity (see chapter 12).

More clearly associated with the village is the potassium group of elements. All of these elements has its greatest population over the village. Whereas phosphorus and zinc are greatest in concentration over both the upper and lower terrace of the village,

potassium is only great in value over the lower terrace of the village. This may reflect different activities in the village: potassium indicating areas of wood burning, and phosphorus and zinc indicating waste disposal of animal and human wastes in addition to wood burning.

The elements of the nickel group have their greatest concentration populations in the upper village terrace and in the central south of the survey grid. The anomalies of these elements are thought to indicate the presence of ultrabasic rocks.

The elements of the aluminium group are greatest in concentration in the east of the survey grid. The reason for these elements being greatest in concentration in the east is not known.

Of the elements not ascribed to groups, cerium and sodium show a similar distribution with low values over all the survey grid except one sample. Lead is only elevated in the south central part of the survey grid where the nickel group exhibited higher values. Copper displays a distribution similar to that of the particle size analysis of samples. Manganese exhibits a large concentration population over the lower terrace of the village and the eastern end of the survey grid. Barium displays its greatest population over the lower terrace of the village and may relate to the human activity in this area.

15.4.4 Summary

Potassium, phosphorus, zinc, manganese, strontium, and barium all display an association with the village. Phosphorus and zinc are more elevated on the upper terrace than the lower terrace. The other elements are more elevated on the lower terrace. This may represent different use areas in the village but this is not discernible from the available information. The nickel group elements (nickel, cobalt and chromium) are associated with the upper terrace of the village and reflect the presence of ultrabasic rocks.

CHAPTER 16

FARM SITES

16.1 Introduction

The sites described in this chapter represent some of the range of rural sites found in the Boeotian archaeological landscape. They range in size from a Classical farmstead (VM70) with a sherd halo of 1.50 hectares to the small site of VM87 which has no sherd halo. Two of the sites, VM70 and VM87 are in the Valley of the Muses, the other site CN11 is in the hinterland of Hyettos city.

16.2 VM70

16.2.1 Introduction

VM70 was discovered in 1984. It is situated on the eastern slope of Strongyli hill in the Valley of the Muses. The site has a sherd halo of 1.5 hectares, which is of the size produced by a small farmstead. The diagnostic sherds (table 16.1) collected from the site date it to the Classical period (5th and 4th centuries BC), although sherds from the geometric era and the Late Roman period are also present. The site has been the subject of a surface soil ceramic density survey, a surface soil tile density survey, a topography survey, a rubble survey, two twin-probe resistivity surveys, a magnetic susceptibility survey and a soil survey (figure 16.1 and 16.2). The tile, rubble, magnetic susceptibility and initial resistivity survey (figure 16.1) were carried out by Chris Gaffney as part of his doctoral thesis (Gaffney, 1990). The topography and later resistivity survey (figure 16.2) were carried out in 1995 by Dr. Mark Gillings with the assistance of students of the Department of Archaeology, University of Durham.

The topography survey (figure 16.3) shows three features. The remnant field wall (feature B) and the terrace (feature C) are features which can still be seen by any visitor to the site. The third feature (feature A) is a slight alteration in the slope angle at the north-western end of the field wall and is interpreted as a house platform.

Visibility corrected sherd densities show a central area of very high sherd densities about the field-wall and to the west of the house platform (figure 16.4). This area is surrounded by medium to high sherd densities. Gaffney's surveys of the site show that the house platform correlates with the area of high rubble concentration (figure 16.5) and high tile concentrations (figure 16.6a). The soils of the house platform also have some of the higher magnetic susceptibility values on the survey area (figure 16.6b). These results all

support the interpretation of the house platform as the main structure of the site. Additional structures on the site may exist in the east of Gaffney's survey grid, as indicated by further tile and magnetic susceptibility anomalies (figures 16.6a and b).

The two resistivity surveys have been combined (figures 16.7a and 16.7b). They show a number of high resistance and low resistance features. The clearest feature is high resistance feature A, a rectilinear feature, of approximately fifteen metres by fifteen metres, within which some internal divisions can be observed. This is interpreted as the main dwelling structure on the site and correlates with the house platform (feature A) of the topography survey. Two additional high resistance features are detectable to the east of feature A, they are interpreted as additional structures of the site but possess no discernible form. They may relate to the tile and magnetic susceptibility anomalies of Gaffney's survey (figures 16.6a and 16.6b). High resistance feature C is the remnant field wall (feature B of the topography survey). Low resistance features were detected in the north-west, north-east, south-west and south of the survey area and are interpreted as ditch features enclosing the structure and its farmyard or garden (Bintliff, 1997b). These ditches are also the limit of medium to high sherd densities (figure 16.4 and overlay 7)

16.2.2 Soil Survey

Soil samples were collected from the site in both the 1994 and 1995 field seasons. In the 1994 season a 10 m interval grid of 60 m by 60 m was placed over the geophysical survey grid of Gaffney (figure 16.2). Samples were collected from the grid intersections

In the 1995 field season a second 10m interval grid was placed over the 1994 survey grid extending it a further twenty metres to the east (eighty metre by sixty metre area) and sampled at the grid intersections. Samples were collected at 10 m intervals on transects extending east, south and west from the main survey area (figure 16.2). In

addition five soil pits (figure 16.2) were excavated across the site to assess profile development and observe how elemental concentrations varied in the profile.

16.2.2.1 Surface Soil Survey of 1994

The analysis of the percentage of the soil sample with a particle size below 212 μm shows (use overlay) that samples in the area east of the house of VM70 and to the north of the remnant field-wall exhibit lower percentages than the area to the west and south (figure 16.8). The house and field-wall act as the point of change between the high and low percentages.

Initial analysis of the results for surface soil composition showed that the elements sodium, phosphorus and vanadium had ranges which fell within the range of reproducibility error and they are therefore omitted from further discussion (table 16.3). Of the remaining elements all exhibit “possibly anomalous” values (table 16.4). The elements aluminium, iron, calcium, cerium, scandium, strontium, chromium, copper and manganese all exhibit ranges which include “anomalous” values. The elements calcium, cerium and strontium exhibit strong positively skewed distributions. The elements iron, scandium, chromium, copper and lead are all strongly skewed in the negative direction.

The elements have been grouped according to their correlation coefficients (table 16.5). These indicated a distinct calcium group which included calcium, lanthanum and strontium. The other elements are difficult to separate into groups, as with the exception of particle size, magnesium and cerium, all the results exhibit a good positive correlation with each other and a negative correlation with members of the calcium group. They are therefore considered to be a single group, the aluminium group, with sub-groups. The sub-groups are an iron group including iron, scandium and chromium where the correlation

coefficient with iron exceeds 0.95, and a cobalt group including cobalt, manganese, nickel, lead and zinc where the correlation coefficients with cobalt exceed 0.90.

The calcium group of elements are all greatest in concentration in samples along the western edge of the survey grid and lowest in concentration in samples from the eastern half of the grid. The association of these elements suggest that they reflect the subsurface geology of the site. The levels of these elements in the soil reflect the influence of geology on the soil's composition. The lower values in the east of the survey grid reflect the dilution of the geological signal through the addition of materials. Lanthanum, in addition to displaying the pattern of the calcium group also has a single large valued sample to the south of the house (overlay 8 and figure 16.9m).

The results of the aluminium group of elements are opposite to those of the calcium group. The greatest concentration populations (table 16.6) are over the eastern half of the survey grid and lowest along the western edge of the survey grid. The sub-grouping of the correlation coefficients was not exhibited by the surface expression of results, with the exception of the iron sub-group which displayed its high values over the eastern area of the survey grid. The greatest values were displayed in the area of high soil resistance to the east of the house. Another characteristic of this group is that the juncture between the house and field-wall displays lower values than surrounding samples. This pattern is also exhibited by aluminium, potassium and nickel. The elements lead, copper and zinc display high values over the area of densest sherd concentrations. The greatest values of manganese and barium are well defined, being confined to the area north of the field-wall, east of the house and south of the additional tile concentration in the east of the survey grid. The aluminium group elements are thought to be increased due to the addition materials by human activity at the site.

Cerium displays little variation across the survey grid, exhibiting a single sample with a high value, this is situated to the east of the structure and may be related to the

human activity at the site, though this cannot be confirmed by a single anomalous value. Results for magnesium exhibit high values over the south-west and south areas of the survey grid.

16.2.2.2 Comparison of Values From the 1994 and 1995 Surface Soil Surveys

The 1995 surface soil survey grid overlays the survey grid of 1994 and allowed the comparison of 49 samples (table 16.7). The results of this comparison show lower values for all elements in the 1995 survey than the 1994 survey. Most elements show a positive correlation between the two surveys (figure 16.10a - 16.10t). The elements calcium, strontium, yttrium, manganese and lead show particularly strong positive correlation between the two surveys. The elements aluminium, potassium, lanthanum, cobalt, zinc and barium are positively correlated between the two surveys. Copper and nickel exhibit poorer positive correlations. The remaining elements have poor correlations. The poor correlations for iron, chromium and vanadium can be explained by their poor reproducibility which mean a good positive correlation cannot be expected. Cerium and scandium have a limited range of values and the results presented by the ICP-AES are rounded to the nearest whole integer, this results in a lack of correlation. The lack of correlation between the two surveys for phosphorus and magnesium can be explained by a few samples displaying very different results. This is best seen in the comparison for phosphorus (figure 16.10f), where the majority of samples are clustered but a few samples display higher values for one of the sampling years whilst being a low value in the other sampling year, thus resulting in a lack of correlation.

The results of this comparison show how results will vary with each batch of analysis. It also shows how some of the elements can be directly compared if they display a

positive correlation and linear relationship, whereas others cannot be compared as they exhibit no correlation.

16.2.2.3 1995 Surface Soil Survey

The particle size analysis of samples from the 1995 surface soil (figure 16.11) shows lower percentages of particles below 212 μ m in samples from the central grid and west transect than the transects to the west and south. These are the areas of potentially greatest soil development from additions of human activity and would suggest a lowering of the percentage fine particulates as a result of human activity, perhaps due to the presence of building materials and sherds in the samples.

Analysis of the element composition of samples shows that only the range of values for sodium falls within the range of reproducibility error and is therefore omitted from the discussion (table 16.9). All of the remaining elements have ranges which contain “possibly anomalous” values and all but calcium, potassium, strontium, yttrium and lead display ranges which contain “anomalous” values (table 16.10). Only phosphorus exhibits a strong positively skewed distribution. The elements aluminium, cerium, cobalt, chromium and nickel exhibit strong negatively skewed distributions.

Correlation coefficients (table 16.11) show a calcium group containing calcium, lanthanum and strontium as in the 1994 soil survey. The rest of the elements can be further divided than they could in the 1994 survey, the result of a greater number of samples. The groupings are: a nickel group containing nickel, cobalt, chromium and manganese, a barium group containing barium, yttrium, cobalt, manganese, lead and zinc, and an aluminium group containing aluminium, iron, scandium, copper, vanadium and zinc. Manganese and zinc fall into two groups, manganese is more positively correlated with the

nickel group than the barium group. Zinc is more positively correlated with the barium group than the aluminium group.

The calcium group of elements (use overlay 9 and figure 16.12) display their highest valued population (table 16.12) in the west transect. and their lowest populations over the main archaeological features of the main survey grid. The elements of this group, as in the 1994 samples, reflect the influence of calcareous rocks on the soil's composition. The lower values over the main grid, east and south transects reflect the dilution of the influence of calcareous rocks through the addition of materials by human activity, probably by an increase in soil depth. Strontium also displays high values in samples from the south transect, south of the terrace.

The aluminium group exhibit the group pattern of low values in samples from the west transect and the greatest concentration populations at the southern end of the south transect. The elements also exhibit mid-range or middle populations relating to the house and associated features to the east. The elements zinc and copper also have high values at the end of the east transects. The results for these elements may be reflecting both geology in the south transect and the human activity at the site.

The nickel group of elements would suggest the presence of ultrabasic rocks and these are evident in the soil as well-rounded pebbles. The results for the nickel group are greatest in value in the soils of the house and associated features over the site and at the end of the east transect. The high values at the end of the east transect probably reflect an ultrabasic geology. The results in samples from the house and surrounds could be due to geology or human activity, though the terrace and ditch defined (except in the east transect) pattern of the elements nickel and manganese would suggest that the results over the site are due to human activity.

The barium group have their greatest concentration populations in samples from the house and associated archaeological features, and their lowest value populations in the

west transect. The group displays a pattern where higher values are contained within the area bounded by the ditches and the terrace to the south, though not to the east. The higher values of this group of elements appears to be due to the human activity at the site.

Of the remaining elements, magnesium has its highest values in the south of the southern transect and in ditch samples. The same association with the ditches is displayed by phosphorus, though the pattern is dominated by two samples over 12 %. The results of phosphorus are notably low over the house and area to the east suggesting that the frequent archaeological tool of total phosphate analysis is not the best method for smaller sites. Potassium displays elevated values over the area of the house as defined by the ditches and terraces and certainly relates to the human activity on the site. Cerium is highest in value in the west transect and may be associated with the calcium group.

16.2.2.4 Soil Pit Survey

The soil pit survey was carried out in 1995 and consisted of five pits across the site (figure 16.2). The observations made on the soil profile are colour, root depth, archaeological material, particle size, organic matter and element composition (Results are summarised in tables 16.13a and b). The colour, root depth and archaeological material reflect the development of the soil profiles. Soil pit one (figure 16.13), in the area of the highest calcium group values, had a 20 cm deep soil profile overlying a soft limestone. Root depth was to a depth of 10 cm and archaeological material was only apparent in the top 5 cm, where the darkest soil also occurred. Soil pit 2 (figure 16.14) is in the area of the house platform, the role of human activity in its development is reflected by the presence of archaeological material and the dark colour of the soil throughout the excavated 50 cm profile. Root depth is greater in this profile than in soil pit one, reaching 23 cm. Soil pit 3

(figure 16.15), had archaeological material in the top 20 cm of the 40 cm profile and this was also the part of the profile with the darkest soils. Root depth reached 20 cm. Whereas in soil pits 2 and 3 the underlying geology was not reached, in soil pit 4 (figure 16.16) the underlying soft limestone geology was reached at 45 cm. Archaeological material was evident only to 8 cm and root depth was only to 12 cm. The soil colour also was dark only in the top 20cm of the profile. The final soil pit, soil pit 5 (figure 16.17) was situated down slope from the terrace and was excavated to a depth of 30cm. No archaeological material was evident in the profile and root depth was limited to the top 5 cm. The soil colour changed at 15 cm where the soil pit started to be excavated through an illuviated horizon above an underlying limestone geology. The soil pits reflect the development of the soil through human activity at the site, the greatest development occurs in the soil of the house platform. The soils derived from human activity are dark in colour (Munsell colour 10YR 4/3), contain archaeological material and have a greater root depth than the soils with a lower human impact.

The dark colour colour of the human activity derived soils suggests a greater proportion of organic matter. Analysis of the profile samples for loss of weight on ignition (LOI) confirm this (figure 16.18). Pits 2 and 3 samples have the greatest loss at depth, exceeding 4 %. Pits 1 and 5, the shallow soils, show the greatest decline in LOI with depth, being 3 % or less in the lowest sample. The pattern is reversed for the particle size analysis of samples (figure 16.19), the soils of pits 2, 3 and the upper samples in pits 4 and 5 are all below 15 % particle size below 212 μm . The samples from pit 1 and the bottom sample from pits 4 and 5 all exceed 15 %.

The calcium group of elements from the 1995 surface soil survey thought to reflect the underlying limestone geology is confirmed by the profiles of these elements (figure 16.20d, g and i). All three elements are greatest in concentration in soil pit 1 and the lower depth samples of pits 4 and 5. The addition of material through human activity has led to a

dilution of this geological signal. This is most clearly seen in pit 4, where the upper sample is derived from human activity and the lower sample is developed from the geology. In this profile one can see that calcium (CaO) increases from 3 % in the upper sample to 11 % in the lower sample, lanthanum from 13 to 22 ppm and strontium from 11 to 33 ppm.

The aluminium group of elements (figures 16.20a, b, h, m, r and s) are greater in concentration in samples from pits 2, 3 and 4 than pits 1 and 5, except in the upper sample of pit 5. The higher values in the upper sample of pit 5 suggests that soil from the site is washed downslope and over the terrace. The pit profiles are similar for all the elements of this group and all profiles show a general decline in concentration with depth suggesting that the origin of these elements is from human activity and not geology.

The nickel group of elements (figures 16.20k, l, n and o) are like the aluminium group greater in pits 2, 3 and 4 than in pits 1 and 5. Nickel, manganese and chromium are greatest in concentration in the house platform soil pit (soil pit 2). Cobalt is greatest in pit 3. The pit profile of these elements mostly shows little change with depth. The exceptions are pit 1 and the cobalt results for pit 3 which all show an increase with depth and would suggest that these elements are controlled to a limited degree by the underlying geology.

The barium group of elements (figures 16.20j, k, n, q, s and t) are again greatest in concentration in samples from pits 2, 3, and 4 than pits 1 and 5. Like the aluminium group, the surface sample of pit 5 is comparable in concentration to the concentration in samples of pits 2, 3 and 4 suggesting the movement of soil downslope. All the profiles show a decreasing concentration with depth for all these elements which would suggest that the higher concentrations are the result of human activity.

Of the remaining elements, magnesium (figure 16.20c) exhibits an increase with depth for pits 3,4 and 5 suggesting a geological source as the origin of these elements in the profile. The greatest values of magnesium are found in pit 1. Potassium (figure 16.20d) is greatest in concentration in the surface samples of soil pits 2 and 3 reflecting the greater

influence of human activity on soil development. Potassium shows a decline in concentration with depth in all soil pits supporting the evidence for its accumulation being the result of human activity. Phosphorus and cerium (figures 16.20e and f) show very little variation in their soil profile concentrations. Phosphorus is greatest in concentration in pits 1 and 5. Cerium shows no distinct pattern, but can be said to bear no relation to the calcium group as hypothesised in the 1995 surface soil survey.

16.2.2.5 Sequential Extraction of Soil Pits One, Two and Three

The profile samples of soil pits one, two and three were subjected to a sequential extraction. The majority of elements are only above detection limits in three or fewer extracts (table 16.14). Only manganese was detectable in all seven extracts, nickel in six, calcium and barium in five and aluminium, iron and vanadium in four.

The calcium group of elements display higher values of the exchangeable extract for soil pits 2 and three 3 than soil pit 1 and for the fulvic fraction calcium (figures 16.21a - e) displays higher values in soil pit 3. Soil pit one is higher in calcium than the other two soil pits for the carbonate bound fraction, secondary manganese oxide fraction and pseudo-total fraction. This may be a reflection of different sources of the calcium group, the exchangeable calcium and fulvic fraction calcium being created by the human activity at the site and the other fractions being the influence of underlying limestone rocks. In soil pit 3 the carbonate bound fraction, secondary manganese oxides and pseudo-total showed increasing values with depth indicating an increased input from the limestone rocks at depth. Lanthanum and strontium (figures 16.22a - c and 16.23a - c) show similar results to calcium for the exchangeable and carbonate bound fractions. Strontium shows similar results for the pseudo-total extract, but lanthanum shows no variation.

Potassium (figure 16.24) was only detectable in the pseudo-total fraction where it exhibited the greatest values in soil pit 2 reflecting the greater contribution from human activity in the development of this soil profile. Soil pit 3 showed an increase with depth.

The barium group displayed higher values for soil pits 2 and 3 than pit 1 for most detectable extracts reflecting the greater human impact on these soil's development. The pseudo-total fraction of lead (figure 16.25c) shows little variation between the pits and would suggest that the low values of lead detected in the surface soil survey were not real, but the effect of a major ion interference at the analysis stage, probably calcium. With the removal of the major ion at an earlier extraction stage the lead in the pseudo-total fraction is detectable. The carbonate bound and secondary manganese oxide for barium (figures 16.26b and c) are constant for all three soil pits.

The aluminium group (figures 16.27a - d, 16.28a - d, 16.29a, 16.30a - b, 16.31a - d and 16.32a - b) are greater in concentration for samples from soil pits 2 and 3 than pit 1. These elements also exhibit an increasing concentration with depth in many of the extracts for soil pits 2 and 3 reflecting a possible geological source of these elements.

The nickel group (figures 16.33a - c, 16.34a - b, 16.35a - g and 16.36a - f) display higher values in soil pits 2 and 3 than in soil pit 1. The carbonate bound fraction is an exception to this rule as values are greater in soil pit one than the other two and whereas manganese exhibits a general increase with depth in pit 2, the carbonate bound and exchangeable decrease in concentration with depth. The increasing values with depth suggests that the underlying geology is the source of these elements. The decreasing values with depth may reflect the fact that manganese is correlated with both this group and the barium group and the greater values in these two fractions of the soil are due to human activity.

Phosphorus shows little variation in concentration through the profiles (figure 16.37a - c) and only with the humic fraction is there any distinct feature to the profiles, as values in pits 2 and 3 increase with depth.

Cerium was detectable in two extracts (figure 16.38a and b). Carbonate bound cerium was greatest in pit one than the other pits. In pit 2 values decreased with depth and in pit 3 they increased with depth. Pseudo-total cerium was greater in pits 2 and 3 than pit 1 and there was little change in concentration throughout the profile.

16.2.2.6 Summary

- In both surveys the ditch enclosed area containing the house platform displayed a lower percentage particle size below 212 μ m than the surrounding area. This result was confirmed by the analysis of the soil pits which also show deeper soil profiles within the enclosure than without, as well as the soils tending towards dark brown, having a greater root depth, being greater in their organic matter content and the presence of archaeological material throughout the profile. These observations suggest that the soil within the enclosure has developed these characteristics as a result of human activity.

The greatest surface soil concentrations of the calcium group were to the west of the main survey grid, which was a reflection of the shallow soils developed over soft limestone geology. Values were lowest in the surface soils within the enclosure due to the accumulation of material, resulting in a dilution of the geological signal through the increase in soil volume and the greater dissolution of the limestone in a more organic rich soil. Sequential extraction of samples from soil pits 1, 2 and 3 showed that the calcium signal within the enclosure differed from that to the west. In soil pit 1 carbonate bound, secondary manganese oxide bound and residual (pseudo-total) were greater in concentration than in soil pits 2 and 3, and reflect the influence of the underlying geology.

Exchangeable cation and fulvic fraction concentration of calcium was greater in soil pits 2 and 3 than soil pit 1, which either reflects an archaeological source of calcium or the greater dissolution of the limestone.

The barium group of elements best reflects the archaeological evidence being greatest in surface soil concentration within the enclosure. The results from the soil pits confirm this observation and adds that the concentration of these elements decreases with depth suggesting that the source of these elements is in the accumulated material that constitute these deeper soil profiles. Sequential analysis of the lead soil concentration shows the observed greater soil values in the enclosure are the product of an analytical interference of calcium.

The nickel and aluminium groups also display some of their greatest soil concentrations within the enclosure, which suggests that they may be derived from the human activity at the site. However, the soil pit evidence provides contradicting or mixed evidence. The soil concentration of the nickel group increases with depth reflecting a possible geological source. The soil concentration of the aluminium group decreases with depth in the pseudo-total analysis, but shows an increase with depth in the extracts of the sequential analysis.

16.3 CN11

16.3.1 Introduction

Unlike the other farm and villa sites (which are situated in the Valley of the Muses), CN11 is located in the Hyettos survey region in the north of Boeotia. It was discovered in 1992. The presence of loom weights and quern stones defines this site as a domestic farm site. Diagnostic material from the site dates it from the Archaic period to the Hellenistic period (600 BC - 100 BC). The site has been the subject of a ceramic count survey, a tile count survey, a twin-probe resistance survey and a soil survey (figure 16.39).

The twin-probe resistance survey was carried out in the 1994 field season by Dr. Gillings assisted by students of Durham University. The presentation and interpretation of the results was performed by myself on the computer software Insite 1.0 (figures 16.40a and b). The values of soil resistance are low over the majority of the surveyed area, only feature A with a larger resistance values suggests the presence of any sub-surface remains. Additional larger resistance features are visible on the south-western edge and the south-eastern corner of the surveyed area, though these I attribute to the presence of the track to the south of the survey area and the resultant increase in resistance due to the compaction of the soil by agricultural machinery.

The visibility corrected tile concentrations (figure 16.42) show that the area of high resistance (feature A) correlates with a peak in tile concentrations and would therefore suggest a structure in this area. The largest tile concentrations are to the south of the survey area next to the track suggesting another structure there. The largest ceramic concentrations (figure 16.41) in the survey area correspond to the areas of highest tile density. However, the peak densities of ceramic have a different focal point to the tile densities, with the highest densities occurring in the south-west corner of the survey grid.

16.3.2 The Soil Survey

Samples for the soil survey of this site, which overlies limestones of the Upper Cretaceous, were collected during the 1994 field season. A 10 m interval grid of 40 m by 40 m was laid over the area of the resistivity survey (figure 16.39). Samples were collected on the intersections of the 10 m interval grid. In addition two 100 m transects extending north from this grid were sampled at 10 m intervals. They have been analysed for their particle size and their elemental composition.

The particle size (figure 16.43) of soil samples shows a higher percentage of the finer particles ($< 212 \mu\text{m}$) in the area of resistance feature A and associated tile peak, and also in the area of large tile values in the south of the survey area.

For the elemental composition of the soil the elements iron, sodium, phosphorus, scandium, chromium and vanadium had ranges which did not exceed the range that could be attributable to reproducibility error (table 16.16). In addition the element lead had a number of negative values suggesting a major ion interference in the analysis, possibly due to the large calcium values at this site. Of the remaining elements, all except zinc have ranges that contain “possibly anomalous” values (table 16.17). The elements calcium, cerium, lanthanum, strontium, manganese and nickel contain “anomalous” values. The results for the elements calcium, cerium, lanthanum, strontium, nickel and barium are strongly skewed in a positive direction. The elements manganese and nickel are strongly skewed in the negative direction.

Correlation coefficients (table 16.18) allow the grouping of elements into two groups: a calcium group containing calcium, lanthanum and strontium, and an aluminium group containing aluminium, magnesium, cerium, yttrium, cobalt, copper, manganese, nickel and zinc. The two groups are negatively correlated with each other.

The calcium group exhibit their greater concentration population over the suggested structure and may indicate the use of limestone as a building material. Equally this may indicate that the high resistance feature is due to the presence of calcareous rocks nearer the surface than in other areas of the survey grid. The high values of calcium would suggest that the latter is the most likely suggestion.

The elements of the aluminium group have a pattern which appears to be the negative of the distribution displayed by the calcium group and it is suggested that this may be due to calcium interference in the analysis of these samples due to the large amounts of calcium in the samples (up to 22.5 % CaO). The lowest concentration populations of the aluminium group are therefore associated with the suggested structure and the greatest concentration population is associated with the area to the west and the transects. Cerium, yttrium and nickel have their highest values at the northern end of the transects.

The elements potassium and barium which are excluded from either grouping display different distributions to the other elements. Potassium displays its greatest values in the south-east corner of the survey grid. Barium displays its greatest concentration population in the south-east of the survey grid and may reflect the concentration of tile and ceramic found there.

16.3.3 Summary

The results at CN11 are dominated by the high values of calcium which are probably reflecting the underlying calcareous rocks of this site. The majority of the other elements display a negative correlation to the calcium group, which may be the result of calcium interference in the analysis as a result of the high values. Only potassium and barium display a different pattern, displaying their greatest soil concentrations in the south-east of the survey area and are associated with a peak of surface tile and ceramic.

16.4 VM87

16.4.1 Introduction

VM87 was discovered in 1984. It is an unusually small site for the Valley of the Muses and exhibits no sherd halo. The limited number of diagnostic sherds were an inadequate sample to define the date of the site, although those found suggest a possible emergence in the Archaic period, with the site's main period of use in the Classical and Hellenistic periods. The presence of Late Roman evidence is interpreted as off-site material.

The site has been the subject of a ceramic and a soil survey (figure 16.45). The soil survey was carried out in the 1994 field season. The ceramic survey (figure 16.46) shows a very distinct peak in sherd densities in the northern centre area of the ceramic survey grid.

16.4.2 Surface soil survey

The soil survey was carried out over a 30 m by 30 m area centred over the ceramic survey grid (figure 16.45). This area was divided by a 5 m interval grid with samples being collected at the grid intersections. The soils of the site overlie flysch deposits, which in turn overlie Upper Cretaceous limestones.

The contour plot of percentage particle size below 212 μm shows no distinct patterns (figure 16.47). The area of highest sherd densities possibly has a slightly lower percentage of fine particles than the surrounding area.

The small nature of this site is reflected in the lower number of elements with values outside the range of reproducibility error than other sites (table 16.21). Aluminium,

iron, sodium, phosphorus, scandium, chromium, copper and vanadium are excluded for this reason. Yttrium is excluded as it exhibits an insufficient range. Of the remaining elements (table 16.22) all exhibit “possibly anomalous” values. Only calcium and lanthanum possess “anomalous” values and are strongly, positively skewed.

Correlation coefficients (table 16.23) allow the grouping of the elements into two groups: a calcium group of calcium, lanthanum and strontium, and a nickel group of cerium, cobalt, manganese, lead and nickel.

The elements of the calcium group have their greatest concentration populations (table 16.24) over the western side of the grid. The nickel group has its greatest concentration populations over the central and eastern areas of the survey grid. Of the other elements cerium and zinc exhibit a similar pattern to the nickel group, and barium exhibits high values in the north of the grid, though the fact that the boundary between higher and lower values is in the same order as the samples were analysed suggests a change in instrumental sensitivity to barium during analysis.

The results require further archaeological information to interpret them further. It is suggested that the lack of any positive features in the soil concentrations of elements is a reflection of the small size of the site or an insufficiently large grid. The calcium group probably reflects the presence of calcareous rocks in the west of the survey grid.

16.4.3 Summary

The lack of any positive archaeological association of the elements may reflect this sites small size, but it may also reflect the lack of archaeological information with which to link soil concentrations of the elements. Only the calcium group display a clear pattern, reflecting the presence of calcareous rocks under the soil in the west of the survey area. The clear pattern displayed by barium is thought to be the result of analytical problems.

CHAPTER 17

DISCUSSION OF RESULTS

17.1 Introduction

This chapter has four aims: (1) to summarise the results so far presented, (2) to draw conclusions by considering the results as a whole, (3) to compare the results to previous work in Boeotia and elsewhere and (4) to compare the results to predictions made in the model (chapter 7). The first two aims will be considered together and will start with a discussion of the physical characteristics of the soil samples and then move on to their elemental character.

17.2 Physical Characteristics

The physical characteristics of the soil samples include particle size, colour, organic matter content (loss on ignition), profile depth and presence of archaeological material in the soil profile.

The simple particle size analysis of soil samples proved more interesting than expected. The results of the two control areas were remarkably similar in both their range and their average value (table 17.1). The sites too produced consistent results. The surveys of Classical settlement, with the exception of the two small farmsteads CN11 and VM87, display lower values for the percentage particle size below 212 μm over the core of settlement than the surrounding countryside, suggesting that the activities at the core promoted this lowering (perhaps through the aggregation of soil particles or the addition of sherds to the soil). The more modern settlements of VM4 and Rhadon display the opposite result, with the highest percentage particle size below 212 μm in these surveys occurring

over the settlement. The results of the two sampling years differ, with results for 1994 being lower percentages than 1995. This is probably due to weather conditions which for the two sampling years were very different, the summer of 1994 being very dry with daytime temperatures around 40°C. The summer of 1995 was wetter with lower daytime temperatures. The drier, hotter temperatures of the 1994 season would have promoted the upward movement of moisture in the soil profile and through subsequent evaporation the formation of a hardened soil surface. When disaggregated in the laboratory the samples from these hardened soil surfaces would not have broken down so readily and would lead to a reduction in the average percentage of particulates for sites sampled in the 1994 season. This may in part explain the higher percentages on the village sites, however the 1994 survey of Askra also produced an average percentage in excess of 20 % and therefore it is believed that the above classification of the sites in relation to the control areas is correct. To clarify these results a wet method of particle size analysis, such as the hydrometer could be used. The difference in the average percentage between village sites and farmsteads could be explained by different waste disposal practices.

Depth of profile, depth to which archaeological material is present, root depth, soil colour and organic matter (by loss on ignition) were observed in the soil pits of VM70. The results stress the role of human activity in the development of the soil profile. The soil profile depth was increased in comparison to soil pits dug outside the ditched enclosure at VM70. A similar increase in profile depth was observed at the soil pit excavated in Hyettos city. The reason for the increase in profile depth is the accumulation of material, principally organic matter but with sherds evident throughout the profile. The effect of this addition is to raise the organic matter content of the soil above 4 %, whereas the soils around the site were of 3 % or less organic matter by loss-on-ignition, and to change the colour of the soil to a brown (Munsell soil colour 10YR 4/3) or dark brown (10YR 3.5/3). Root depth was also greater in these anthropogenic soils.

17.3 Element Characteristics

Twenty one elements were of a sufficient quality that they could be discussed in the results chapters. Of these, the number of elements usable on each site varies. The number of elements available for discussion can be seen as a reflection of the size of the site. Either by increasing the element concentration or by diluting the geological signal, the anthropogenic addition of material to the soil caused a large enough variation in the element ranges to make them outside reproducibility error. Hyettos, Askra, VM4, Rhadon and VM70 have at least 16 elements with ranges outside that which could be accounted for by reproducibility error and it is only the two small sites of CN11 (14 elements) and VM87 (12 elements) which have less.

The elements potassium, phosphorus, manganese, lead, zinc and barium consistently display a population relating to the archaeological evidence of manuring or habitation (table 17.2). The elements are consistently increased in soils on archaeological sites, an increase predicted in the model (chapter 7) as being the product of manuring or rubbish accumulation with material from several sources. The only exception in observation versus prediction is the element lead, which may reflect the use of this metal on the sites. In general the degree of increase is related to the size of settlement. This is most clearly seen in the results for barium, with clear populations for city (90-120 ppm), village (54-95 ppm), farmstead (25-36 ppm) and control areas (15-30 ppm). The other elements display less clear patterns. Potassium, phosphorus and zinc are the most mobile of this group of elements in the soil environment and therefore time since abandonment will play a part in present soil concentration. The villages were chosen to investigate this proposition. Askra has the lowest concentrations for these elements of the three villages (table 17.2) and VM4 the greatest concentrations. Despite being more recently abandoned the values at Rhadon are lower than VM4, which reflects the size of the settlement (Maximum population at Rhadon = c.260 , at VM4 = c.1100). The greatest values observed at VM4 and Rhadon are comparable with the greatest values observed at Hyettos, and in the case of potassium at VM4 exceed those of Hyettos. Manganese has an unclear picture due to

the presence of ultrabasic rocks which have high manganese contents in the survey area. On the three sites where a distinct anthropogenic element population is observable the clearest trend is that the city site (Hyettos) displays a population distinct from and well elevated above that of the control areas. The village site VM4 and the farmstead VM70 display values which range from those comparable with the control areas and to those comparable with values observed at Hyettos city. This reflects the intensity of occupation at the city causing a more consistent enhancement to manganese across the landscape. Lead shows clear distinction between values observed on Hyettos city and the villages, but less clear between VM4 and the farmstead VM70, although VM70 displays much lower values. The low lead values at VM70 were suspicious, and lead results in general tended to display a strong negative correlation to calcium, especially when calcium values were high. As the lead results from the ICP-AES are corrected for an interference from calcium, a further calcium interference effect is suspected. The sequential extraction of samples allowed this theory to be tested. The combined values for each of the extractions were compared to the values obtained from the pseudo-total nitric acid extraction (table 17.3). Other elements of this group which also displayed a weaker negative correlation to calcium were compared. The two samples compared were the surface sample from soil pit 1 at VM70, where calcium concentration was 14.5 % CaO, and the surface sample from soil pit 2 at VM70, where the calcium concentration was 2.4 % CaO. The results show that lead is the only element to display a suppression in value due to high calcium content. Comparing the lead and calcium results for 1995 samples suggests that this occurs for samples above 4 % CaO (Figure 17.1).

Other elements display a less consistent association with the archaeology. These include copper, yttrium and strontium. Copper, highlighted by previous work as being elevated on sites in Boeotia (chapter 3), only displays a clear association with the city core of Hyettos. This would suggest that it is only a good indicator of past human activity where the intensity of the activity is at the city scale. A further problem with copper is its use in a fungicide on vines in the area. Higher values of yttrium appear to be associated with the city core of Hyettos and with the enclosure of the farmstead VM70. The values

however are too low to be confident of this association, and further analysis using a more accurate yttrium determination should be employed to verify this result. Strontium is noted as being elevated in concentration in the core of Askra. This element was predicted as being elevated through the use of hearth waste in the material added to the soil. However, the signal from human activity suffers interference from the signal from the limestone parent material. Askra is notable in that the calcium concentration is lower than the majority of the other sites suggesting a lower influence in the soil signal by limestone. Strontium may be useful in non-limestone areas.

Another feature noted at Askra is the smoothing effect for the elements lanthanum, cobalt, manganese, lead and barium. This is probably the effect of the divorcing of the surface soil element concentration from the influence of the underlying geology through the addition of material from human activities. If samples were collected across a soil developed over a series of rock types then the signature would display sharp peaks and troughs (figure 17.2). The addition of material from human activities will smooth out this signature through the raising of troughs and flattening of the peaks.

The results also displayed the usefulness of multi-element analysis in separating out anomalies which relate to signals of geology. Two rock types were observed as influential throughout the results: ultrabasic and limestone. The ultrabasic was characterised by the association and correlation of the elements magnesium, nickel, manganese, cobalt and chromium. The limestone was characterised by the association and correlation of the elements calcium, lanthanum and strontium.

Ultrabasic rocks were most evident at Hyettos, where a soil pit excavated in grid 4 found them present at 15cm depth, and analysis of all samples found high values of these elements (1995 maximum values are nickel 2500 ppm, manganese 1500 ppm, cobalt 170 ppm, chromium 365 ppm, whilst magnesium exceeded the instruments' detection range). They were also elevated in samples lying over the farmstead at VM70 and samples collected from soil pit 2 showed an increase in concentration with depth which suggests ultrabasics under the farmstead. Manganese, as mentioned above, appears to have populations which relate to both the archaeology and the geology. The problem is one of

separation of the two signals. Results from sequential extraction suggest that this may be a useful tool to separate the two signals. At Hyettos the analysis of manganese showed that the exchangeable cation, carbonate bound and residual (pseudo-total) extraction were greater over the city than over the ultrabasic suggesting that these were elevated by human activities associated with the city, whereas the secondary iron and manganese extracts were greater over the ultrabasic suggesting that these extracts are controlled by the geology. Sequential analysis at VM70 supported this. In soil pit 2, over the structure at VM70, the exchangeable cation and carbonate bound extracts decreased with depth, whilst all the other elements associated with ultrabasic rocks increased in concentration with depth.

Limestone is characterised by the association and correlation of the elements calcium, lanthanum and strontium. A soil developed on limestone will have 5 % or more calcium (CaO), and Lanthanum values between 20 and 30 ppm. Strontium has a dual origin in the soils of Boeotia, both the model (chapter 7) and observations at Askra suggesting it is also increased by human activity. The model suggests that even on soils developed over limestone the influence of human activity should cause a detectable increase in soil strontium values if the period since abandonment is less than one thousand years. However, observations at VM4 and Rhadon, which are within one thousand years since abandonment suggest strontium is associated with the elements calcium and lanthanum, and therefore with the underlying limestone (though anthropogenic strontium could be associated with a geological calcium and lanthanum signal by circumstance. Where human activity has resulted in the accumulation of material through manuring or rubbish accumulation over limestone rocks the activity could be detected by a dilution of the concentration of these elements in the surface soil. This dilution is probably the product of a number of factors including (1) increased soil volume due to the addition of material and (2) increased dissolution of limestone due to increased soil acidity through the addition of organic material. At VM70, soil pits 2, and 4 which were excavated through this accumulated material, showed an increase with depth in these elements. Sequential extraction also showed an increase in concentration with depth of the carbonate bound, secondary manganese oxide and residual (pseudo-total) extractions. However, it also

showed that there was a decrease with depth for the exchangeable cation and fulvic extractions suggesting that human activity increases the concentration in these portions, probably through the accumulation of organic material.

17.4 Comparison to Previous Studies

Previous work in Boeotia had highlighted the elements lead, copper and zinc as being elevated in the soils on occupation sites. Lead was associated with the structure, copper with the area around the structure and zinc with the enclosure at PP17 (chapter 3). All three elements were confirmed to produce higher values over sites than in the landscape. However, the lead signal in analysis was suppressed by the presence of large amounts of calcium in the sample and as calcium was lowest over the site this tended to accentuate the archaeological association of lead. Copper was subject to interference from modern agriculture through the use of fungicide containing copper on vines. The other observation of previous Boeotian studies, that the degree of enhancement was a reflection of the settlement size and intensity was confirmed by the results of this thesis.

In addition to copper and zinc, work elsewhere in the world had suggested that the presence of midden heaps would be indicated by higher values of phosphorus, calcium, magnesium and manganese (chapter 2). In this thesis phosphorus and manganese were confirmed as being elevated over the settlements, though phosphorus was not a useful indicator at the farmstead scale and manganese was masked by large values from ultrabasic rocks. Calcium was not found to be enhanced over settlements. This is due to the presence of limestone rocks under much of the survey area, and calcium actually tended to be diluted over the settlement. Magnesium was not found to be of use as an archaeological indicator, partly due to its presence in large quantities in ultrabasic and limestone rocks.

The potential of sequential extraction in the study of element composition of soils on archaeological sites was confirmed. Previous studies had concentrated on the fractionation of phosphorus. However, the values of phosphorus were frequently too low in

this study to be analysed with accuracy. Sequential extraction proved useful in the characterisation of the elements. In particular this was shown at Hyettos city for manganese which was elevated in the soil over both the ultrabasic rocks and the city. The city samples had greater concentrations of manganese in the exchangeable cation, carbonate bound and residual fractions than those over the ultrabasic rocks. Greater concentrations were found in the secondary iron and manganese oxides for soils over the ultrabasic rocks than those in the city.

17.5 Comparison to Model

The model in chapter seven had suggested that the elements potassium, copper, manganese, nickel and barium would be the most useful indicators for sites abandoned 3000 years ago or more. If the time since abandonment was less then calcium, sodium, phosphorus, strontium and zinc might also be useful. The model also suggested that the elements sodium, potassium, phosphorus, strontium, copper, manganese, zinc and barium would be elevated in concentration by rubbish accumulation and manuring. The elements iron, cobalt, chromium and nickel would be diluted by manuring and rubbish accumulation if the underlying geology was ultrabasic. The elements calcium, cerium and lanthanum would be diluted if the underlying geology was limestone.

The results from the sites confirm that potassium, phosphorus, zinc, barium and manganese are found in elevated concentrations in soils on settlement sites. However, the degree of elevation for potassium was dependent on the period since abandonment. Zinc and phosphorus levels were also dependent on the time since abandonment as predicted. At Hyettos, the elements iron, chromium and nickel were lower over the city than the outside due to a dilution of the geological signal as predicted. Calcium and lanthanum were diluted by the accumulation of rubbish and manuring at sites overlying limestone.

Calcium and strontium could not be used as indicators at sites due to interference from limestone rocks. Likewise, nickel suffered a geological interference due to the

presence of ultrabasic rocks. Sodium does not appear to be a good indicator at sites, which is probably due to it being relatively mobile in the soil when compared to the other elements. Analysis of samples for copper did not produce a clear association with sites possibly due to the use of a fungicide containing copper on vines.

The model had not predicted the observed elevated concentrations of lead in soils over some of the sites. Though the observed elevation in lead values at VM70 (farmstead) can be attributed to the depletion of calcium in the soil due to human activities, the observed elevation at Hyettos city can not. More sophisticated models should be developed which may account for lead anomalies at large sites and their absence at smaller sites.

17.6 Summary

- The observations from previous work in Boeotia and other areas, of increased values for the elements lead, zinc, phosphorus and manganese (anthropic elements), in soils associated with past human activity (resulting in accumulation of material) compared to surrounding soils is confirmed by this study. Previous work also highlighted calcium, magnesium and copper, but due to high values in the local geology for calcium and magnesium, and interference from modern agriculture for copper these elements were not useful for observing increased soil concentration due to past human activity.
- This thesis showed that potassium and barium have greater surface soil concentrations where there has been evidence of past manuring or rubbish accumulation.
- The degree of increase observable for the above elements due to past human activity (as a result of manuring or rubbish accumulation) is related to the size of the settlement and to the time since abandonment. City sites have higher concentrations of these elements

than villages, and villages have greater concentrations than farmsteads. Barium in particular appears useful as it displays distinct concentrations for city, village and farmstead sites. For potassium, phosphorus and zinc the observable increase is dependent on the time since abandonment, as these elements are more mobile in the soil environment than the other elements observed to be elevated in these situations.

- The increase in the anthropic elements is associated with other observable soil features, such as higher organic matter contents, a tendency to a dark brown soil colour, presence of archaeological material, and a deeper soil profile than the surrounding countryside.
- The increase in the anthropic elements is retained in the top 20 cm of the soil and tends to decrease with depth.
- The ability to detect the elements increased by human activity is dependent on the composition of the soil prior to the activity and therefore is largely dependent on the underlying geology. As shown in the models (chapter 7) the presence of a limestone parent material means that the application of material by human activity dilutes the concentration of calcium in the soil, whilst the same addition to a soil overlying ultrabasic rocks would result in an increase in the soil concentration of calcium.
- In addition to the elevation of element concentrations in the soil, human activity dilutes the concentration of certain elements through the addition of material to the soil which cause the dilution of the influence of the underlying parent material on the soil's composition. This has been observed for calcium and lanthanum over limestone parent materials.

- The use of a multi-element technique has the advantage over a single element technique, that it can highlight associations of elements which can aid the separation of geological anomalies from those of past human activity.
- Sequential extraction of samples can help separate the influence of past human activity from that of geology. Manganese can be elevated by both, though the exchangeable cation and carbonate bound extracts of manganese display an association with rubbish accumulation or manuring evidence of past human activity.
- Methods such as geophysical investigation, soil particle analysis, soil colour, soil organic matter content, tile distribution, and sherd distribution provide complementary information to the element analysis of soils, improving interpretation.
- The model-predicted indicator elements potassium, phosphorus, zinc, barium and manganese were confirmed by analysis of samples from Boeotia. The other predicted indicator elements calcium, strontium, nickel, sodium and copper were not found to be elevated at sites due to a range of factors, including interference in signal from geology and land-use, and mobility in the soil environment. Predicted element dilution due to the accumulation of anthropogenic material was confirmed for iron, nickel and chromium over ultrabasic rocks and calcium and lanthanum over limestones.

CHAPTER 18

CONCLUSIONS AND DIRECTIONS FOR FUTURE WORK

This thesis has successfully confirmed that element signals can be detected in the soil which relate to the archaeology. In particular the elements potassium, phosphorus, manganese, lead, zinc and barium were consistently elevated where associated with the available archaeological information. The second aim of the thesis, to ascertain the extent to which the signal reflects the intensity and nature of past human activities on archaeological sites and in archaeological landscapes, was partially successful. The relationship to the intensity and size of settlement was confirmed with the larger settlements producing greater concentrations of the above elements than the farmstead sites. However, there was no clear association of the elements with the archaeological information pertaining to non-settlement sectors of the landscape and the best indicator of past land-use through manuring and other “offsite” activities remains the sherd density. This is due to a combination of factors which result in the archaeological signal being indiscernible. These factors include the inherent variability in the element composition of the soil, the insufficient input from the archaeological activity and the influences of later land-use removing elements in the form of crops or masking them by residues from agrochemicals. Likewise the nature of the activity is not discernible from the element concentration of the soil. These two aims will require further work to ascertain to what extent element soil analysis can address such goals. This thesis added new dimensions to soil analysis in relation to archaeological sites, including dilution effects of added material, and the potential of sequential extraction in defining the origin of the elements in the soil.

Soil element analysis requires further development and research before being used more widely in the archaeological community. These requirements can be divided into three areas (1) the development of analytical techniques, (2) the development of sampling strategies and (3) improved modelling.

Development of the analytical technique should focus on the archaeological indicator elements and elements which reflect the local geology. A reduction in the number of elements being studied will allow the researcher to concentrate on the accuracy of analysis of the remaining elements. Sequential extraction of the elements could, with further research, allow the nature of a deposit to be defined further and could be particularly useful where an archaeological signal is masked by a geological signal. This technique should be used in conjunction with other complementary techniques of soil analysis such as particle size analysis, soil colour, pH, organic matter content, soil profile to assess profile development (in particular the influence of geology) and with geophysical methods of investigation. The method of particle size analysis should be a wet method to avoid the influence of weather conditions on the results of samples.

Sampling methodology should in future focus on small contiguous blocks of landscape or on sites. This allows the researcher to provide a greater control on the influences of geology and land-use and to disentangle these signals from those of the archaeology. The technique is not suitable for the location of archaeological features, rather it is a technique suitable for the characterisation of a deposit from a known context. . The method of landscape sampling used in the study of modern pollution (Davies, 1980) is not suitable for the study of archaeological landscapes due to the smaller degree of change affected by human activities such as manuring and rubbish accumulation. The alterations to the element composition of the soil within areas of intensive human activity (i.e. archaeological “sites”) discovered in this thesis are comparable to the elevation of element concentration in garden soils noted by Davies (1980). At the present stage of this

technique's development, its use should be limited to sites where there is already a quality of archaeological information that allows hypothetical functional differentiation of land-use to be determined prior to an analysis of the element composition of the soil. Sampling in this thesis focused on grid, transect and pit samples. Where archaeological information allows the defining of functional differentiation of land-use then samples could be collected from these areas (e.g. from within and without a habitation structure, or an animal yard).

Modelling should be improved by the development of more sophisticated and detailed models, using data which are derived from the local environment of the study and which therefore have an element composition which reflects that local environment, rather than the more general composition used in this thesis. The erosion and accumulation of the soil should be included in the model to assess better how specific soil environments will affect the observed element composition in the present day. Models should be tested in situations where the activity carried out on the soil is known. It has already been mentioned that it is necessary at this stage to sample only where there is a high quality of archaeological information which allows the function of an area to be hypothesised; in addition models can be tested where the activity is known. These include experimental agricultural plots receiving different amendments (e.g. Rothamstead experimental station and various university test plots), reconstructed archaeological settlements (e.g. Butser Ancient Farm Project and Castell Henllys), historical settlement and ethnoarchaeological studies. However, it should be pointed out that such test sites will have to have been in use for a long enough period to ensure a detectable signal. Such Historical examples include crofting settlements being studied by Entwistle *et al.* (1998) and the nineteenth century small-holdings in the Pennines associated with the lead mining industry. The ideal sites would be of single occupation, with no previous or subsequent use and whose soils overlie a uniform geology. These improvements would allow different activities to be identified by

analysis of the element composition of the soils they affected, a goal discussed in this thesis which is not possible without these improvements.

For the archaeologist who wants to use this technique as the primary means of investigation of archaeological landscapes or in the analysis of samples from an excavation I would recommend that it is not ready for such a purpose. In fact the use of this technique at the large landscape study level appears too problematical to make it a viable investigatory tool. The technique of coprostanol analysis developed by Evershed *et al.* (1997) may be more appropriate to landscape studies, though as yet this remains unproved at the level of testing to which elemental analysis has been subjected in this thesis. The immediate future of this technique in archaeology will be one of analysing samples from soils which have a high quality of archaeological information, so that their element composition can be calibrated against function.

In conclusion, multi-element analysis of soils is a technique which has a proven potential, but requires further investigation before it can be used as a general investigatory tool in the archaeologist's armoury.

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BOEOTIAN GEOLOGICAL SAMPLES

LIMESTONE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0.07	0.03	0.19	32.25	0.01	0.01	0.01	0.00	0.07	24	56	7	1	38	1	32	10	4	3	2	64	15	-35	14	3	3	3	7	277
2	0.08	0.03	0.20	33.77	0.01	0.01	0.01	0.00	0.07	26	59	7	1	40	1	32	11	4	3	2	65	17	-37	18	3	7	3	8	271
3	0.05	0.03	0.21	33.55	0.01	0.01	0.01	0.00	0.07	25	58	7	1	37	1	32	13	4	3	1	67	16	-37	-1	3	5	3	7	296

ULTRABASIC (HYETTOS)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.03	2.81	0.00	0.10	0.00	0.01	0.00	0.03	0	1	0	2	1	0	24	58	57	2	235	23	1095	22	69	11	33	7	2	165
2	0.03	2.87	0.00	0.09	0.00	0.01	0.00	0.03	-1	1	0	2	1	0	25	59	58	2	237	23	1120	24	67	11	35	7	2	171
3	0.03	3.07	0.00	0.08	0.00	0.01	0.00	0.03	0	1	0	2	1	0	26	61	61	2	249	24	1161	24	84	12	33	7	2	177

ULTRABASIC A (VM70)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	6.19	1.86	3.03	1.99	0.17	0.14	0.00	0.04	5	9	35	3	14	1	22	48	3	26	114	34	346	44	46	26	25	6	39	311
2	6.13	1.91	3.08	1.92	0.17	0.14	0.00	0.04	5	9	36	3	14	1	21	63	4	27	109	34	366	46	50	26	29	6	38	317
3	6.01	1.90	3.11	1.87	0.16	0.14	0.00	0.04	5	9	35	3	13	1	21	27	4	26	98	35	376	45	62	25	31	6	37	323

ULTRABASIC B (VM70)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	5.50	0.55	1.11	2.35	0.33	0.14	0.00	0.03	4	10	12	2	62	1	20	92	8	3	73	31	103	40	42	8	10	3	11	272
2	6.01	0.54	1.11	2.57	0.37	0.14	0.00	0.04	5	10	13	2	68	1	21	82	7	4	71	33	103	43	24	8	10	3	12	291
3	2.62	0.13	0.29	1.20	0.20	0.02	0.00	0.02	3	6	4	0	35	0	18	22	1	2	16	19	28	22	12	1	6	1	7	171

ULTRABASIC C (VM70)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	3.10	0.37	0.56	1.57	0.05	0.01	0.00	0.03	4	8	4	1	3	0	19	19	13	3	33	24	32	25	26	5	7	2	4	207
2	3.37	0.30	0.46	1.68	0.05	0.00	0.00	0.03	4	8	4	1	3	0	18	11	11	2	25	23	29	27	18	3	5	2	3	209
3	2.40	0.20	0.31	1.19	0.04	0.00	0.00	0.02	3	6	3	0	2	0	18	6	7	1	14	18	21	21	17	2	4	2	2	171

RED SHALE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0.36	0.45	0.49	0.19	0.00	0.00	0.02	0.00	0.05	1	2	1	0	2	0	23	100	5	3	55	9	18	10	18	3	12	1	6	63
2	0.36	0.45	0.50	0.19	0.00	0.00	0.02	0.00	0.04	2	2	1	0	2	0	23	99	5	3	56	9	17	10	15	3	13	1	5	62
3	0.33	0.41	0.46	0.18	0.00	0.00	0.01	0.00	0.04	2	2	1	0	2	1	24	96	5	3	51	9	17	11	33	3	12	2	5	63

BOEOTIAN ARCHAEOLOGICAL ARTEFACTS

BOEOTIAN POTTERY

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	2.69	0.69	0.51	0.96	0.03	0.03	0.11	0.02	0.05	22	18	5	3	15	8	20	98	41	17	489	20	117	31	14	14	21	3	66	169
2	2.85	0.66	0.48	1.01	0.04	0.04	0.11	0.02	0.05	22	18	5	3	16	8	22	102	38	36	443	20	105	32	9	15	31	3	62	190
3	2.73	0.62	0.44	0.97	0.03	0.03	0.11	0.02	0.05	21	18	5	3	15	8	21	99	36	29	420	19	98	29	10	14	26	2	60	182

IRON SLAG (VM4)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	2.29	21.77	1.21	5.19	0.16	1.48	0.04	0.24	22	22	14	3	81	5	27	36	53	25	414	75	71	22	79	28	10	41	243	493
2	2.20	23.42	1.27	5.13	0.16	1.40	0.04	0.20	22	22	14	3	79	5	29	42	60	26	396	77	83	21	102	29	9	43	202	510
3	1.91	19.94	1.22	5.14	0.14	1.10	0.03	0.15	21	21	13	3	77	4	26	44	50	23	354	72	82	21	68	24	10	37	148	481

LIME SLAG (VM4)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	6.12	1.18	0.34	6.59	0.35	0.20	0.04	0.07	18	22	11	11	2	138	4	27	117	11	8	232	42	19	43	6	11	35	5	69	340
2	4.53	0.83	0.20	4.71	0.26	0.10	0.02	0.07	15	18	7	1	96	3	29	70	9	5	160	37	12	35	8	8	23	3	50	297	
3	4.54	0.83	0.20	4.69	0.26	0.10	0.02	0.07	15	18	7	1	96	3	29	69	9	5	159	37	12	35	14	8	22	4	50	286	

CASTELL HENLLYS EARTHWATCH HUT SAMPLES

FIRE SURFACE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
FIRE SURFACE	3.92	1.16	3.29	15.11	0.95	4.30	0.05	1.38	25	39	38	3	709	4	26	13	76	266	###	63	30	40	65	31	275	6	625	509

FIRE SUBSURFACE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
FIRE SUBSURFACE	2.70	2.31	1.66	6.20	0.17	1.11	0.02	0.62	15	20	35	2	277	3	22	11	53	152	4996	45	26	47	54	20	145	6	337	401

INSIDE SURFACE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
North 1m	2.23	3.16	0.52	0.18	0.01	0.08	0.00	0.08	7	3	21	2	9	1	19	10	18	22	657	14	18	29	14	21	48	6	33	119
North 2m	2.50	3.34	0.61	0.10	0.01	0.07	0.00	0.08	8	4	22	2	5	2	18	11	19	22	684	14	22	32	45	22	53	6	33	113
North 3m	2.44	3.31	0.63	0.16	0.02	0.07	0.00	0.08	9	4	22	2	7	2	18	10	19	23	624	14	21	32	30	22	50	6	38	116
South 1m	2.55	3.40	0.59	0.67	0.08	0.21	0.01	0.37	12	9	25	2	31	3	19	13	20	48	1985	23	18	41	46	20	69	7	104	205
South 2m	2.71	3.73	0.49	0.26	0.03	0.16	0.01	0.47	11	6	24	2	17	3	18	13	18	41	1903	18	17	39	34	19	59	7	116	163
South 3m	2.55	3.51	0.50	0.33	0.05	0.13	0.01	0.43	11	7	22	2	17	3	19	13	18	38	1834	18	17	42	29	18	58	7	101	151
West 1m	2.70	3.52	0.58	0.73	0.08	0.27	0.01	0.50	12	9	25	2	37	3	19	12	20	54	2165	25	18	39	52	20	74	7	143	220
West 2m	2.23	3.18	0.62	0.36	0.03	0.12	0.00	0.17	20	10	24	2	14	6	17	15	18	33	1099	19	23	39	20	21	73	6	63	166
West 3m	2.67	3.61	0.54	0.31	0.06	0.12	0.01	0.31	10	6	27	2	14	3	17	11	18	39	1210	18	18	38	34	19	56	7	69	154
East 1m	2.57	4.53	0.46	0.10	0.01	0.05	0.00	0.27	6	3	27	1	5	2	17	9	20	23	666	16	15	28	22	24	50	8	36	113
East 2m	2.57	3.62	0.46	0.22	0.03	0.11	0.00	0.34	6	4	24	1	12	1	19	12	19	20	916	16	16	32	22	22	57	7	75	139
East 3m	2.35	3.07	0.73	1.24	0.08	0.26	0.01	0.23	11	10	26	2	50	2	19	11	21	36	1231	27	20	36	29	24	74	6	88	244

Distance from fire.

INSIDE SUBSURFACE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
North 2m	2.63	3.36	0.62	0.14	0.00	0.06	0.00	0.08	9	4	21	3	7	2	19	9	20	21	359	14	21	33	24	23	52	6	26	123
South 2m	2.57	3.61	0.65	0.52	0.03	0.14	0.00	0.33	9	6	30	1	25	2	18	11	18	32	1190	21	18	37	24	18	60	7	74	189

Distance from fire.

OUTSIDE SURFACE

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
North 2m	2.05	2.96	0.49	0.05	0.00	0.04	0.00	0.07	9	4	21	1	3	2	18	8	15	14	601	11	17	29	42	18	40	5	27	99
North 4m	2.80	3.24	0.52	0.14	0.00	0.05	0.00	0.35	9	4	27	1	8	2	18	11	17	29	731	14	18	40	25	18	50	6	46	135
North 6m	2.02	2.86	0.43	0.07	0.01	0.04	0.00	0.12	10	4	20	1	4	3	17	9	14	27	774	10	15	34	27	17	44	5	27	94
North 8m	2.30	2.74	0.40	0.09	0.00	0.05	0.00	0.28	8	4	19	1	5	3	16	10	14	32	702	11	14	42	23	14	40	5	29	117
South 2m	2.11	3.57	0.32	0.04	0.00	0.02	0.00	0.18	6	3	20	1	3	2	18	8	15	20	903	13	11	25	31	19	36	6	27	98
East 2m	1.67	3.13	0.27	0.26	0.01	0.05	0.01	0.23	8	5	14	1	11	3	15	13	11	25	600	15	14	42	35	15	40	6	45	125
West 2m	2.40	2.77	0.55	0.06	0.01	0.06	0.00	0.07	10	4	24	2	3	2	17	12	16	21	745	11	19	33	35	18	52	5	24	96
West 4m	1.79	2.52	0.39	0.05	0.00	0.03	0.00	0.09	8	3	19	1	2	2	17	8	13	18	592	10	13	33	18	16	40	4	16	76
West 6m	2.07	2.96	0.48	0.04	0.00	0.03	0.00	0.09	9	4	23	1	2	3	17	11	14	21	951	10	16	47	9	17	46	6	17	99
West 8m	2.21	3.00	0.45	0.06	0.00	0.03	0.00	0.17	7	3	24	1	3	2	17	10	14	24	761	11	16	31	32	15	40	5	15	103

Distance from wall of hut.

TOW LAW SAMPLES

COW MIDDEN

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.03	0.04	0.55	1.52	0.24	1.94	0.00	0.44	4	7	1	0	34	0	16	2	0	69	210	20	182	12	29	1	92	1	55	169

HEN MIDDEN

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.25	0.38	0.77	1.28	0.07	1.00	0.00	1.08	4	7	2	0	29	1	17	2	4	25	233	21	15	45	21	7	213	1	37	169
2	0.27	0.40	0.76	1.29	0.07	1.02	0.00	1.07	5	7	2	0	30	1	17	2	4	33	237	20	112	46	21	7	221	2	38	168
3	0.26	0.37	0.73	1.35	0.07	1.14	0.00	1.04	5	8	2	0	32	1	16	2	4	72	243	20	180	47	25	7	241	2	41	174

BURNT HEN MIDDEN

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.74	0.60	3.88	10.16	2.12	15.14	0.01	2.39	17	26	13	1	171	2	24	6	8	43	1097	51	15	24	35	12	514	4	197	328
2	0.75	0.61	3.93	10.25	2.14	15.24	0.01	2.42	17	26	13	1	173	2	24	6	8	43	1109	51	15	25	57	12	522	4	194	319
3	0.74	0.60	3.87	10.09	2.11	15.01	0.01	2.41	17	26	13	1	171	2	24	6	8	42	1091	50	15	25	61	12	512	4	197	305

CHARCOAL CLAMP AND POTTERY KILN SAMPLES FROM CASTELL HENLLYS

CHARCOAL CLAMP

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
Inside	2.80	3.59	0.59	0.33	0.05	0.19	0.01	0.18	0.18	10	27	3	23	4	19	11	18	13	986	19	20	42	42	28	73	7	50	160
Outside	1.87	2.76	0.47	0.16	0.01	0.06	0.00	0.09	0.15	7	19	2	7	5	18	10	15	19	648	14	18	33	21	19	49	5	39	111

POTTERY KILN

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
Inside	1.79	2.73	0.41	0.05	0.00	0.06	0.00	0.12	0.12	5	17	1	3	3	17	8	14	19	610	10	14	36	22	18	52	5	31	82
Outside	1.68	2.59	0.38	0.14	0.00	0.06	0.01	0.20	0.11	5	15	1	12	3	17	9	13	24	968	12	15	34	38	17	61	5	56	100

ROAD TRANSECT SAMPLES

TRANSECT 1		sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
		5m	1.66	2.60	1.51	11.16	0.03	0.16	0.00	0.14	22	28	16	6	23	4	0	16	169	429	19	1276	39	1553	21	34	20	49	6	44	242
		10m	1.29	1.53	1.08	6.88	0.03	0.24	0.00	0.27	22	23	9	3	15	5	0	13	120	213	25	1096	30	898	24	6	18	54	4	49	218
		15m	1.26	1.36	1.12	6.46	0.04	0.24	0.00	0.30	24	23	8	3	20	6	0	13	77	154	29	932	30	602	25	15	19	56	4	56	219
		20m	2.84	1.80	2.23	5.28	0.38	0.21	0.00	0.21	21	21	12	4	25	8	0	13	51	91	31	1147	31	322	33	38	25	37	4	60	250
		25m	1.93	1.95	2.80	4.90	0.09	0.27	0.00	0.33	22	21	12	4	22	7	0	14	76	166	29	1118	32	644	31	37	23	56	5	56	238

TRANSECT 2		sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
		5m	1.76	2.48	1.67	10.71	0.03	0.19	0.00	0.16	22	27	15	6	19	4	0	16	191	420	22	1372	38	1795	22	44	18	49	6	48	244
		10m	1.13	1.23	0.97	6.78	0.03	0.23	0.00	0.28	23	24	8	2	16	6	0	14	103	161	23	1064	31	705	23	28	17	54	4	51	212
		15m	1.34	1.17	1.27	5.82	0.04	0.29	0.00	0.24	25	23	8	3	18	8	0	13	47	88	27	839	29	340	23	29	20	41	3	57	207
		20m	1.84	1.80	2.30	5.16	0.07	0.25	0.00	0.29	24	22	11	4	20	8	0	13	83	150	30	1188	31	602	27	32	22	46	4	55	232
		25m	1.27	1.55	2.84	5.72	0.04	0.25	0.00	0.37	21	21	11	3	26	6	0	13	72	152	26	1082	32	611	28	43	18	60	4	54	244

Distance from road.

CONTROL AREA 1

	%<212 um	Al	Fe	Mg	Ca	Na2O	k20	TiO2	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	6.78	4.85	5.25	4.85	6.24	0.03	0.13	0.01	0.08	17	19	27	12	23	7	-34	36	50	443	28	716	15	891	27	29	39	44	-3	38	46
2	9.76	4.99	5.30	4.20	3.49	0.03	0.17	0.01	0.09	17	16	25	11	17	8	-34	33	51	428	31	647	13	867	35	37	44	51	-3	34	99
3	11.73	3.49	3.72	9.22	13.91	0.02	0.10	0.01	0.10	13	25	27	9	50	4	-34	38	41	367	31	510	18	722	2	37	31	33	-1	13	22
4	7.90	4.33	5.19	3.67	5.38	0.02	0.12	0.01	0.10	31	25	28	9	20	11	-34	35	30	212	35	677	14	463	27	31	47	60	-3	43	90
5	9.75	3.77	4.77	3.41	4.82	0.02	0.13	0.02	0.10	30	23	25	8	22	10	-34	36	30	194	30	704	14	415	26	32	39	57	-3	38	87
6	6.42	3.10	4.01	1.93	0.74	0.01	0.08	0.00	0.08	22	13	16	7	9	10	-34	33	25	166	58	729	8	359	28	31	34	48	-3	39	71
7	18.15	3.65	4.33	2.03	4.53	0.02	0.16	0.03	0.11	32	24	25	7	32	10	-34	34	17	95	44	531	13	164	25	31	48	59	-3	43	82
8	9.83	4.74	5.25	4.75	9.46	0.02	0.12	0.01	0.08	19	23	29	12	30	7	-34	36	58	451	26	849	17	923	19	38	35	43	-3	35	70
9	15.38	2.87	4.09	5.75	16.36	0.02	0.01	0.01	0.09	22	32	33	7	47	5	-34	38	36	246	22	440	18	623	0	39	27	38	-2	16	13
10	13.58	3.89	4.50	4.96	11.00	0.02	0.09	0.02	0.09	25	27	29	9	38	7	-34	37	36	260	28	618	17	592	17	33	38	46	-2	31	49
11	16.01	4.29	5.11	3.51	4.20	0.02	0.18	0.03	0.09	30	23	26	9	19	10	-34	35	33	239	31	776	13	493	30	32	48	56	-3	39	86
12	8.91	4.22	5.13	2.64	0.98	0.01	0.22	0.03	0.09	28	17	21	9	12	11	-34	35	30	219	70	918	10	434	37	35	54	62	-4	45	90
13	10.08	3.47	4.79	2.07	1.03	0.01	0.16	0.01	0.11	32	18	20	7	14	11	-34	34	24	123	38	776	9	255	33	28	48	67	-4	42	79
14	15.46	3.58	4.78	1.87	0.88	0.01	0.12	0.02	0.09	32	18	21	7	12	12	-34	34	18	97	44	615	9	168	32	25	50	63	-4	40	77
15	8.52	4.92	4.27	5.64	8.35	0.02	0.21	0.00	0.10	16	21	26	11	25	6	-34	35	63	404	29	741	16	902	27	35	21	56	-2	33	78
16	6.26	5.66	5.75	3.47	1.38	0.02	0.30	0.01	0.07	20	13	23	14	13	10	-34	32	75	482	27	1229	11	951	54	35	48	71	-4	58	103
17	14.31	5.59	5.05	4.18	1.86	0.02	0.28	0.01	0.08	17	13	25	14	12	9	-34	33	77	465	30	1015	12	1054	51	35	44	71	-3	49	107
18	10.60	5.72	5.89	4.75	1.52	0.02	0.32	0.01	0.08	18	13	25	14	13	9	-34	34	76	505	31	1197	12	1028	53	38	42	75	-4	50	104
19	19.32	4.85	4.54	4.74	13.11	0.03	0.21	0.01	0.11	17	25	26	12	30	6	-34	37	62	423	31	579	18	880	14	38	35	50	-2	27	43
20	14.00	5.92	5.39	4.52	4.44	0.02	0.25	0.01	0.10	17	17	28	14	16	9	-34	34	72	496	32	872	14	1036	42	36	47	59	-3	42	95
21	15.12	3.59	4.90	1.91	0.81	0.01	0.14	0.02	0.09	34	18	22	7	13	11	-34	33	19	91	39	665	9	161	34	35	50	67	-4	39	75

Samples collected from a 7 x 3 sample grid. Numbering starts from top left corner of grid and progresses along the long horizontal axis (1, 2, 3, 4, 5, 6, 7).

CONTROL AREA 2

	% <212 um	Al	Fe	Mg	Ca	N2O	K2O	TiO2	P2O5	Ce	La	Li	Sc	Sr	Y	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	10.22	4.45	4.78	10.80	3.81	0.02	0.13	0.01	0.07	14	16	26	11	19	6	54	439	36	789	17	875	44	42	37	56	-2	33	89
2	12.89	4.51	4.93	10.80	5.06	0.02	0.19	0.01	0.07	13	18	29	10	34	5	56	532	36	789	20	1014	39	40	29	48	-2	34	86
3	22.47	4.09	4.75	3.73	9.36	0.02	0.07	0.01	0.10	31	30	29	8	65	9	33	211	32	562	18	505	22	25	40	62	-2	34	58
4	11.46	3.49	3.68	9.34	13.42	0.02	0.12	0.01	0.09	17	27	30	9	30	5	43	320	29	515	20	642	9	35	30	43	-1	18	25
5	9.96	4.51	4.78	8.64	6.79	0.02	0.24	0.01	0.10	17	20	28	12	12	7	53	427	33	816	19	842	34	35	37	59	-2	27	79
6	11.99	6.00	6.52	7.93	1.35	0.02	0.23	0.02	0.06	17	13	26	15	21	8	72	592	35	1094	15	1073	57	37	49	66	-3	41	103
7	11.61	4.99	4.75	8.86	5.36	0.02	0.15	0.01	0.08	14	18	26	12	15	6	69	507	30	790	18	992	40	41	36	62	-2	28	85
8	11.63	4.60	4.24	7.32	3.54	0.02	0.11	0.00	0.07	14	15	23	11	16	7	70	452	31	871	16	977	42	33	32	59	-1	33	87
9	7.33	5.04	4.80	6.95	3.57	0.02	0.16	0.01	0.07	14	15	25	12	16	7	56	470	29	957	15	990	39	45	38	53	-3	34	96
10	7.82	5.79	5.79	6.21	3.10	0.02	0.22	0.01	0.08	15	15	27	14	13	8	58	521	29	860	14	994	45	36	43	59	-4	34	106
11	13.32	5.83	5.67	6.52	2.43	0.02	0.24	0.01	0.07	14	14	25	15	10	8	80	548	31	982	14	1160	43	34	40	66	-3	38	103
12	10.5	4.49	4.12	5.27	1.37	0.02	0.15	0.00	0.06	14	11	20	10	12	7	67	402	26	1027	11	968	43	32	34	55	-2	39	86
13	9.27	5.57	5.60	5.32	1.71	0.02	0.34	0.01	0.07	16	13	24	13	24	8	71	500	31	1091	12	1031	48	39	44	70	-3	44	108
14	11.12	4.56	4.27	5.32	8.96	0.02	0.16	0.01	0.09	15	21	24	11	12	6	50	404	25	524	16	783	21	34	37	48	-2	25	68
15	9.24	5.52	5.03	4.10	1.91	0.02	0.21	0.01	0.06	16	13	26	14	11	9	69	478	29	988	12	1052	44	34	41	57	-3	55	105
16	9.7	5.32	4.41	4.35	2.00	0.01	0.14	0.00	0.06	17	14	27	14	13	10	77	453	30	1069	12	1202	40	35	35	55	-2	45	97
17	10.62	6.34	5.58	5.09	2.61	0.02	0.20	0.01	0.06	14	14	29	15	13	8	71	553	34	1031	13	1230	43	34	40	57	-3	43	110
18	10.33	5.81	5.87	4.33	3.68	0.02	0.19	0.00	0.07	17	17	27	14	13	10	58	554	34	866	14	1124	36	36	42	52	-4	41	110
19	12.27	5.82	5.48	4.88	1.89	0.02	0.24	0.01	0.07	15	13	26	14	13	8	68	514	32	1113	12	1150	45	33	41	57	-3	45	108
20	8.42	3.99	3.88	3.63	2.46	0.01	0.16	0.00	0.08	14	13	20	9	11	7	54	342	29	908	11	901	36	36	33	52	-2	40	91
21	13.18	4.66	4.33	2.72	1.75	0.01	0.13	0.00	0.06	20	14	19	13	19	11	78	390	25	1226	11	924	41	31	39	49	-3	59	95
22	20.11	5.45	4.05	4.25	11.11	0.02	0.20	0.01	0.09	16	23	26	14	11	7	65	410	37	823	16	920	25	35	35	49	-2	33	61
23	8.93	5.34	5.10	3.61	1.51	0.01	0.25	0.00	0.07	18	13	24	13	14	10	74	439	32	1263	11	955	48	29	44	66	-3	57	101
24	13.33	6.79	6.29	4.38	2.76	0.02	0.29	0.01	0.10	17	15	30	17	13	9	84	558	37	992	14	1160	48	38	50	64	-4	48	117
25	11.73	6.66	6.63	4.54	2.42	0.02	0.29	0.01	0.09	17	15	30	17	21	9	82	580	35	1037	13	1153	46	39	51	62	-4	47	122

Samples collected from a 5 x 5 sample grid. Numbering progresses along the horizontal axis (1, 2, 3, 4, 5).

1994 HYETTOS SURFACE SAMPLES

Sample	% <212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	11.88	3.51	7.86	8.91	1.18	0.01	0.36	0.00	0.31	25	17	11	11	17	8	-13	44	94	506	45	1201	16	1524	62	37	36	96	-5	117	90
2	8.26	3.44	7.69	8.32	1.25	0.01	0.33	0.00	0.23	24	15	11	11	16	7	-13	44	90	501	39	1136	16	1520	62	31	35	89	-5	116	92
3	12.39	2.91	6.75	8.08	1.03	0.00	0.29	0.00	0.20	25	16	10	9	15	8	-13	44	90	441	34	1151	15	1484	54	32	29	80	-4	118	78
4	7.98	3.11	7.33	8.97	0.98	0.00	0.28	0.00	0.18	25	16	10	10	14	8	-13	43	99	494	36	1244	15	1612	58	35	30	85	-5	125	85
5	6.28	3.19	5.93	9.03	0.90	0.01	0.35	0.00	0.11	25	16	11	10	14	7	-13	44	97	425	36	1200	14	1661	57	33	6	88	-3	117	77
6	9.42	2.51	1.31	9.81	1.25	0.00	0.24	0.00	0.03	24	15	10	9	12	7	-14	42	102	267	27	1204	11	1739	47	25	3	77	1	109	54
7	12.44	3.77	8.70	10.22	0.64	0.00	0.34	0.00	0.11	24	16	13	12	14	7	-13	45	95	585	32	1057	18	1722	52	33	31	77	-6	97	93
8	8.73	2.97	7.28	>10.8	0.56	0.00	0.31	0.00	0.10	20	13	10	11	11	7	-13	44	91	516	28	957	16	1749	50	37	17	72	-5	81	70
9	7.18	2.57	6.22	>10.8	0.57	0.00	0.22	0.00	0.06	17	12	8	10	10	6	-14	40	81	510	25	799	14	1747	42	30	6	66	-4	74	62
10	5.06	2.69	7.73	>10.8	0.61	0.00	0.19	0.00	0.10	15	11	7	11	9	6	-13	41	65	576	27	575	15	1612	40	34	37	62	-5	60	67
11	5.03	2.87	8.67	>10.8	0.40	0.00	0.21	0.00	0.11	15	11	9	12	11	5	-13	42	76	667	30	640	16	1814	44	38	27	67	-6	61	78
12	5.21	2.47	8.26	>10.8	0.34	0.00	0.19	0.00	0.08	12	9	6	11	8	5	-13	42	78	610	26	727	15	1726	39	40	37	59	-6	60	71
13	7.53	2.32	8.59	>10.8	0.39	-0.01	0.19	0.00	0.08	8	8	5	12	7	4	-13	43	95	667	24	852	15	1741	34	40	36	53	-6	51	74
14	6.50	2.59	8.92	>10.8	0.28	0.00	0.24	0.00	0.09	13	9	7	12	8	5	-13	42	111	612	26	1085	16	1830	38	44	35	60	-6	73	74
15	8.50	1.93	7.87	>10.8	0.31	-0.01	0.18	0.00	0.06	12	8	5	10	7	4	-13	42	107	622	20	1076	14	1847	35	40	25	55	-5	71	62
16	11.51	1.91	8.23	>10.8	0.36	-0.01	0.19	0.00	0.07	12	8	4	11	9	4	-13	42	112	678	21	1151	15	1844	39	43	28	57	-6	71	60
17	9.37	2.05	9.04	>10.8	0.27	-0.01	0.18	0.00	0.08	9	7	4	12	8	3	-13	44	134	672	22	1246	16	1917	35	43	38	51	-6	56	74
18	5.88	2.01	9.17	>10.8	0.29	-0.01	0.16	0.00	0.08	7	7	4	12	7	3	-13	43	128	634	21	1054	15	1799	30	41	38	49	-6	44	68
19	5.63	2.84	10.26	>10.8	0.28	-0.01	0.21	0.00	0.07	13	9	7	13	8	5	-13	42	100	740	24	902	15	2006	36	41	37	63	-7	63	73
20	4.04	2.26	9.41	>10.8	0.27	-0.01	0.15	0.00	0.07	12	8	5	12	7	5	-13	42	128	706	24	1250	15	2053	36	42	36	57	-7	66	82
21	6.24	3.02	6.91	8.44	1.42	0.00	0.31	0.00	0.29	26	17	10	10	17	8	-13	41	97	473	38	1242	17	1500	58	36	34	86	-4	121	95
22	6.39	3.26	7.29	8.57	1.08	0.00	0.37	0.00	0.21	25	16	10	10	15	8	-13	41	95	493	38	1218	16	1545	59	38	39	87	-5	121	94
23	5.11	3.52	7.82	9.26	1.04	0.00	0.33	0.00	0.19	26	16	11	11	15	8	-13	41	101	526	39	1299	16	1629	58	37	41	91	-5	132	97
24	6.43	3.13	7.23	8.99	0.89	0.00	0.36	0.00	0.17	24	15	10	10	13	7	-13	41	94	496	34	1208	15	1511	55	36	34	86	-5	121	96
25	5.04	3.30	7.39	9.32	0.89	0.01	0.33	0.00	0.12	23	15	10	11	13	7	-13	42	93	505	33	1127	15	1534	52	36	41	78	-5	113	94
26	9.75	3.71	8.09	9.99	1.75	0.00	0.33	0.00	0.13	24	17	13	12	18	7	-13	43	95	544	37	1112	18	1600	48	37	44	74	-5	109	99
27	8.41	2.69	7.14	>10.8	0.62	0.00	0.26	0.00	0.10	20	12	8	10	10	7	-13	41	96	520	29	1074	15	1621	46	43	36	64	-5	90	77
28	5.98	3.37	8.85	>10.8	0.59	0.00	0.30	0.00	0.13	20	13	10	13	11	7	-13	42	97	646	31	1033	16	1808	49	44	43	73	-6	89	95
29	5.25	2.64	7.59	>10.8	0.62	0.00	0.20	0.00	0.10	18	12	8	11	10	7	-13	42	84	569	36	791	15	1748	44	43	37	66	-5	74	78
30	5.00	2.72	8.16	>10.8	0.61	0.00	0.20	0.00	0.09	16	12	8	11	10	6	-13	43	78	609	27	682	15	1798	45	43	34	66	-5	67	80
31	5.77	2.14	7.50	>10.8	0.42	0.00	0.17	0.00	0.08	10	9	5	11	8	4	-13	43	72	607	24	607	15	1661	37	46	37	55	-5	50	79
32	4.50	1.83	7.30	>10.8	0.34	-0.01	0.14	0.00	0.07	9	8	4	10	7	4	-13	43	86	602	21	796	14	1664	36	46	35	50	-5	54	73

1994 HYETTOS SURFACE SAMPLES

33	5.79	2.25	8.48	>10.8	0.30	-0.01	0.19	0.00	0.09	11	8	5	12	7	5	-13	43	103	636	21	1003	16	1777	36	43	40	53	-6	60	78
34	20.90	1.57	7.48	>10.8	0.31	-0.01	0.15	0.00	0.07	11	7	3	10	7	3	-13	43	114	640	19	1132	15	1963	40	49	36	56	-5	62	77
35	9.69	1.85	8.44	>10.8	0.32	-0.01	0.17	0.00	0.07	10	8	4	12	7	4	-13	44	143	694	21	1359	15	1946	35	52	39	50	-6	59	79
36	7.74	1.74	7.99	>10.8	0.28	-0.01	0.15	0.00	0.07	10	7	4	11	7	4	-13	45	141	628	18	1269	14	1883	33	43	37	48	-5	59	75
37	6.41	1.99	8.50	>10.8	0.30	-0.01	0.18	0.00	0.08	10	7	5	12	7	4	-13	45	143	697	20	1367	15	1956	33	50	40	51	-6	57	77
38	4.23	2.77	9.71	>10.8	0.32	0.00	0.19	0.00	0.07	16	10	8	13	7	6	-13	43	114	709	22	1061	16	1975	37	47	43	60	-7	73	86
39	6.36	2.19	8.87	>10.8	0.30	-0.01	0.17	0.00	0.07	12	8	5	12	7	4	-13	43	125	647	20	1130	15	1997	34	50	38	55	-6	62	83
40	6.11	2.02	8.86	>10.8	0.32	-0.01	0.15	0.00	0.08	11	8	5	12	8	4	-13	43	139	625	19	1301	15	1971	34	46	39	52	-6	58	76
41	3.78	2.45	5.72	8.06	1.04	0.00	0.27	0.00	0.18	25	15	8	8	13	8	-13	42	93	416	32	1204	14	1414	51	35	33	74	-3	118	80
42	3.97	3.74	8.33	8.40	1.11	0.00	0.38	0.00	0.18	28	17	12	12	15	8	-13	42	103	566	38	1288	17	1671	55	41	42	87	-5	123	104
43	6.11	2.96	7.01	9.06	0.93	0.00	0.28	0.00	0.14	26	15	10	10	13	8	-13	42	100	499	33	1270	15	1549	53	42	33	80	-4	121	90
44	3.00	3.32	7.58	9.63	0.85	0.00	0.38	0.00	0.13	23	14	10	11	13	7	-13	42	93	532	35	1119	15	1541	54	43	42	81	-5	109	98
45	7.26	3.55	8.42	>10.8	0.85	0.00	0.34	0.00	0.11	23	14	11	12	12	7	-13	43	99	586	32	1140	16	1680	52	41	43	76	-5	104	96
46	4.27	3.11	8.30	>10.8	0.66	0.00	0.31	0.00	0.14	21	13	10	12	12	7	-13	44	106	601	31	1168	16	1793	50	45	36	75	-5	96	91
47	7.64	2.45	6.96	>10.8	0.55	0.00	0.21	0.00	0.08	20	20	7	10	9	7	-13	44	95	531	27	1018	15	1665	45	49	34	65	-4	89	76
48	6.32	3.21	8.91	>10.8	0.57	0.01	0.28	0.00	0.10	20	13	10	13	10	7	-13	44	97	661	29	984	16	1900	49	47	37	73	-6	88	94
49	5.31	2.71	8.06	>10.8	0.50	0.00	0.23	0.00	0.08	17	11	8	12	9	6	-13	42	90	618	27	905	15	1718	43	46	38	63	-5	77	85
50	4.04	2.68	8.25	>10.8	0.49	0.00	0.21	0.00	0.11	15	10	8	12	10	5	-13	43	83	645	26	802	16	1702	42	42	38	61	-6	68	88

Samples collected from a 20 x 3 sample grid (only 10 samples collected in third line).
The numbering starts from the top right of the grid and progresses along the long horizontal axis.

1995 HYETTOS SURFACE SAMPLES

GRID 1

sample	% < 212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	23.29	1.75	3.15	6.64	3.16	0.02	0.22	0.47	23	20	9	5	27	7	15	64	197	33	1111	31	910	68	49	24	63	6	107	217
2	18.10	1.63	3.01	6.68	4.54	0.04	0.26	0.51	23	22	9	4	34	7	15	59	189	33	1028	33	856	71	43	24	60	6	100	224
3	14.40	1.70	3.36	7.23	2.57	0.04	0.26	0.48	22	18	9	5	21	7	15	66	215	37	1142	31	979	64	44	26	65	6	104	213
4	14.37	1.67	3.30	6.93	2.17	0.04	0.30	0.48	20	17	8	4	22	6	15	62	210	38	1088	28	938	65	50	27	73	6	103	213
5	18.21	1.76	3.30	6.72	2.84	0.04	0.25	0.46	23	19	9	5	24	7	15	65	205	36	1087	31	938	62	48	26	62	6	102	217
6	18.18	1.66	3.27	7.02	2.08	0.04	0.26	0.46	22	17	8	5	21	7	15	66	210	34	1113	28	964	65	36	26	65	6	102	204
7	17.47	1.82	3.55	7.51	2.24	0.04	0.25	0.49	22	18	9	5	21	7	15	68	226	37	1149	30	1021	70	37	27	68	6	109	214
8	15.77	1.82	3.51	7.61	2.25	0.04	0.25	0.53	23	19	8	5	23	9	17	69	224	40	1165	31	1009	73	45	26	74	8	113	212
9	15.73	1.69	3.25	6.82	2.41	0.03	0.26	0.47	21	18	9	5	22	7	15	64	206	35	1077	31	938	62	30	26	64	6	100	208
10	16.31	1.89	3.80	8.00	2.13	0.03	0.26	0.49	22	18	9	6	21	7	16	69	242	37	1153	30	1065	69	36	28	72	7	107	226
11	19.12	1.21	2.23	4.48	2.08	0.04	0.24	0.43	19	16	6	2	20	6	13	54	148	31	984	26	708	58	29	22	65	4	92	184
12	19.97	1.85	3.59	7.53	2.23	0.04	0.27	0.54	22	18	9	5	22	7	15	67	227	37	1147	30	1010	70	47	27	73	7	110	206
13	16.52	1.55	2.82	5.62	2.80	0.04	0.28	0.53	22	19	8	3	26	7	14	62	179	41	1122	29	842	72	47	26	73	6	105	204
14	14.54	1.81	3.52	7.42	2.41	0.03	0.25	0.51	22	18	9	5	23	7	15	66	225	40	1123	30	1006	71	47	27	69	7	105	205
15	16.63	1.89	3.72	7.72	2.47	0.03	0.25	0.49	22	18	10	5	23	7	16	67	236	36	1131	31	1035	72	45	27	69	7	105	215
16	23.60	1.72	3.16	6.90	3.53	0.02	0.22	0.58	23	20	9	5	30	7	15	63	199	37	1106	32	934	70	49	23	67	6	111	218

GRID 2

sample	% < 212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	24.67	1.84	3.33	6.99	7.21	0.02	0.30	0.72	24	26	13	5	62	6	17	58	195	41	992	38	907	66	45	26	81	7	115	229
2	17.22	1.76	3.21	7.21	4.15	0.03	0.29	0.65	23	22	10	5	36	8	17	62	201	41	1052	35	944	71	46	24	81	7	111	218
3	20.59	1.80	3.35	7.34	3.13	0.02	0.28	0.63	22	20	10	5	30	7	15	63	212	39	1094	32	987	69	37	25	79	6	109	225
4	24.00	1.84	3.52	7.43	3.44	0.04	0.28	0.61	22	20	10	5	32	7	16	66	220	38	1054	34	1045	70	46	24	74	7	105	224
5	21.79	1.91	3.42	7.21	6.71	0.02	0.38	0.73	24	25	13	5	57	6	17	58	200	44	1006	37	929	70	46	26	85	7	117	231
6	26.83	1.85	3.35	7.62	3.87	0.02	0.27	0.63	22	21	11	5	35	7	16	62	203	39	1063	35	984	73	44	24	79	7	117	220
7	20.56	1.63	3.03	6.63	3.90	0.06	0.32	0.59	20	20	9	4	34	6	15	54	190	37	967	33	883	67	50	24	82	6	94	223
8	16.77	1.87	3.63	8.17	2.31	0.03	0.22	0.47	21	17	9	5	24	7	16	65	228	34	1007	31	1079	68	43	25	68	7	103	221
9	22.42	2.00	3.48	7.08	6.07	0.02	0.31	0.64	24	24	14	5	52	7	17	59	197	41	1017	36	939	65	38	26	83	7	125	245
10	22.91	1.58	3.19	7.53	2.73	0.08	0.46	0.52	19	17	9	4	25	6	15	57	201	33	973	30	950	69	52	24	77	6	97	219
11	21.69	1.85	3.45	7.93	3.14	0.02	0.21	0.51	21	19	10	5	30	7	16	60	213	33	911	33	1004	63	50	24	68	6	100	220
12	20.06	1.49	2.66	6.26	3.47	0.01	0.20	0.44	21	20	8	4	30	7	15	57	173	30	867	30	853	56	45	19	53	5	96	203
13	19.76	1.51	2.73	6.99	4.32	0.03	0.20	0.54	20	21	9	4	38	6	15	56	180	33	895	33	850	60	48	20	62	5	101	216
14	16.79	1.58	3.40	8.47	4.38	0.01	0.21	0.40	20	21	10	5	36	6	16	59	226	32	829	35	979	47	52	24	55	6	83	216
15	20.75	1.48	2.68	6.51	5.68	0.02	0.20	0.47	21	23	9	4	46	6	16	55	176	30	809	35	831	51	50	19	54	5	92	215
16	21.23	1.45	2.57	6.08	3.99	0.02	0.19	0.41	21	20	8	4	32	6	15	57	166	28	878	32	829	63	46	19	51	6	97	218

1995 HYETTOS SURFACE SAMPLES

GRID 3

sample	% < 212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	16.93	1.39	3.41	8.88	1.48	0.01	0.16	0.16	16	14	6	5	15	6	15	70	225	22	852	27	1225	44	50	19	42	6	70	189
2	11.71	1.30	3.46	9.12	1.07	0.02	0.14	0.10	15	12	5	5	13	5	15	63	231	19	692	25	1209	41	63	19	38	6	57	172
3	11.65	1.37	3.71	9.51	1.06	0.04	0.17	0.10	15	12	5	5	13	5	16	64	247	20	698	26	1244	41	59	21	40	6	57	175
4	18.15	1.27	3.36	8.81	1.08	0.01	0.16	0.09	13	12	5	5	12	5	15	48	228	18	459	24	1117	39	60	18	35	6	47	179
5	13.88	1.32	3.71	9.79	1.01	0.03	0.12	0.09	14	11	5	5	11	5	16	67	241	21	702	25	1291	40	54	20	39	6	60	173
6	11.68	1.28	3.60	9.47	1.01	0.01	0.11	0.09	14	12	5	5	11	6	16	68	238	19	737	25	1256	41	58	20	39	7	60	182
7	17.07	1.29	3.50	8.86	1.83	0.03	0.13	0.10	14	14	6	5	13	5	15	55	235	19	550	28	1162	40	46	20	36	6	51	205
8	13.67	1.40	3.80	9.22	1.13	0.02	0.15	0.10	13	12	6	5	11	5	16	51	257	18	496	26	1181	38	49	21	37	7	50	183
9	12.84	1.27	3.59	9.33	0.91	0.01	0.10	0.07	14	11	5	5	10	5	15	72	239	18	805	24	1277	40	46	20	37	6	64	176
10	15.21	1.39	3.76	9.35	1.07	0.01	0.12	0.09	14	12	6	6	11	5	16	66	249	19	706	25	1260	39	59	21	37	6	59	186
11	11.93	1.38	3.81	9.15	0.99	0.03	0.15	0.10	14	11	5	5	11	5	15	64	255	19	680	25	1253	38	55	22	37	7	59	179
12	11.73	1.40	3.75	9.04	0.93	0.02	0.14	0.10	14	11	5	5	10	5	15	65	251	19	696	24	1243	38	55	22	37	6	60	181
13	12.78	1.47	4.09	9.89	0.86	0.03	0.14	0.09	14	11	5	6	10	5	15	77	270	20	853	25	1382	41	61	23	40	7	69	176
14	12.08	1.33	3.64	8.93	0.85	0.03	0.12	0.10	14	11	5	5	11	5	14	73	244	19	823	24	1279	38	43	22	37	6	69	168
15	12.17	1.44	4.00	9.40	0.84	0.03	0.13	0.09	14	11	5	6	10	5	15	74	268	22	790	25	1353	40	55	23	41	7	67	177
16	12.49	1.45	4.01	9.24	1.06	0.04	0.15	0.10	16	13	6	6	11	7	17	70	271	24	719	27	1317	38	48	23	41	8	63	177

GRID 4

sample	% < 212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	23.18	1.17	4.23	11.38	1.63	0.02	0.11	0.06	9	11	5	7	8	2	17	170	312	16	1387	31	2492	36	66	19	44	8	42	197
2	24.74	0.90	5.24	0.00	0.35	0.02	0.09	0.06	6	6	2	7	7	3	18	148	364	15	1436	25	1703	33	80	25	34	9	42	151
3	23.2	0.85	4.88	0.00	0.38	0.00	0.08	0.05	6	6	2	7	6	2	17	117	345	13	1176	25	1621	31	62	23	32	8	40	157
4	25.55	0.92	4.80	0.00	0.62	0.02	0.22	0.05	8	8	3	7	8	3	17	100	345	16	1104	26	1614	33	58	22	34	8	49	160
5	28.33	1.06	3.94	10.61	1.82	0.02	0.12	0.09	10	11	5	7	8	3	16	169	284	15	1392	31	2366	34	67	19	43	7	45	206
6	28.41	0.90	5.16	0.00	0.41	0.02	0.11	0.06	6	6	2	7	7	3	18	153	355	14	1532	25	1684	32	70	25	34	9	45	163
7	22.5	0.89	5.11	0.00	0.35	0.02	0.11	0.06	7	6	2	7	7	3	18	121	351	14	1248	24	1594	32	73	25	34	8	45	158
8	20.74	0.85	5.17	0.00	0.37	0.02	0.13	0.06	6	6	2	7	7	3	18	114	349	13	1169	25	1670	31	69	24	34	9	41	153
9	34.17	0.61	3.48	11.29	1.68	0.01	0.06	0.05	8	10	3	5	7	2	17	130	223	10	1266	29	1679	26	56	15	31	6	37	192
10	18.84	0.96	4.33	0.00	0.46	0.01	0.10	0.04	10	8	4	6	6	4	16	122	310	13	1122	23	1482	32	63	21	35	8	54	189
11	19.89	0.88	5.05	0.00	0.28	0.02	0.11	0.06	8	6	3	6	7	3	17	119	365	15	1155	24	1518	34	70	25	38	9	51	192
12	20.53	0.63	4.82	0.00	0.25	0.01	0.06	0.05	5	5	2	6	6	2	18	156	347	11	1371	24	1612	30	70	23	34	9	33	177
13	23.97	0.74	4.66	0.00	0.53	0.02	0.07	0.04	9	7	4	6	7	2	17	170	282	13	1493	25	1827	37	61	19	42	8	46	193
14	20.07	0.88	4.22	0.00	0.38	0.02	0.11	0.05	9	7	4	5	6	3	17	127	336	13	1252	23	1395	33	58	21	36	8	51	171
15	23.87	0.68	4.87	0.00	0.24	0.01	0.08	0.06	6	5	2	6	6	2	18	128	336	11	1184	24	1599	37	81	23	35	9	37	176
16	24.05	0.62	5.14	0.00	0.23	0.01	0.07	0.05	5	5	2	6	5	2	19	137	355	11	1098	25	1694	29	68	24	35	9	28	181

1995 HYETTOS PIT SAMPLES

SOIL PIT 1

depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	1.52	3.10	6.55	2.00	0.03	0.20	0.00	0.41	23	17	8	4	19	7	0	15	67	216	33	994	30	887	67	50	24	65	6	104	231
10-15cm	1.61	3.21	6.46	2.05	0.02	0.17	0.00	0.40	23	18	8	4	19	7	0	15	68	218	33	1026	29	900	69	59	23	66	6	109	239
20-25cm	1.39	2.72	5.27	1.77	0.01	0.13	0.00	0.34	22	18	7	4	17	8	0	17	60	186	29	863	28	766	60	40	19	56	7	92	221
30-35cm	1.55	2.96	5.57	2.23	0.01	0.16	0.00	0.40	23	18	9	4	20	7	0	15	64	202	31	951	30	828	61	50	22	59	6	101	236

SOIL PIT 2

depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	0.84	4.72	0.00	0.40	0.01	0.07	0.00	0.06	7	6	3	6	7	3	0	18	129	371	18	1235	26	1454	34	61	24	36	9	47	189
10-15cm	0.70	4.44	0.00	0.24	0.00	0.03	0.00	0.04	5	5	2	6	5	2	0	18	131	357	14	1227	23	1442	30	67	23	32	8	39	178
20-25cm	0.49	4.09	0.00	0.19	0.00	0.02	0.00	0.03	2	4	2	5	4	1	0	19	98	292	12	898	23	1425	26	75	22	28	8	20	172

SEQUENTIAL EXTRACTION RESULTS FOR 1995 HYETTOS GRID 1 SAMPLES

Exchangeable cation

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.02	0.00	0.53	-0.02	0.00	0.00	0.04	-2	6	0	0	5	0	61	6	4	0	45	33	11	33	96	6	1	3	16	277
2	0.00	0.02	0.00	0.57	-0.02	0.01	0.00	0.04	-2	6	0	0	5	0	61	6	5	0	39	33	10	34	105	6	2	3	16	304
3	0.00	0.02	0.00	0.63	-0.02	0.02	0.00	0.04	-2	6	0	0	6	0	61	6	5	0	59	33	10	33	92	6	2	3	16	292

Carbonate Bound

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.00	1.08	0.37	7.17	0.19	0.00	0.14	1	2	0	0	3	0	18	2	0	0	63	12	14	7	36	0	2	0	16	145
2	0.00	0.00	1.19	0.47	7.19	0.21	0.00	0.15	1	3	1	0	3	0	18	2	0	0	69	14	13	8	25	0	2	0	17	154
3	0.00	0.00	1.43	0.48	7.05	0.21	0.00	0.14	1	3	1	0	3	0	18	3	0	0	87	14	12	9	25	0	3	0	15	159

Fulvic fraction

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.00	0.01	0.01	0.96	-0.04	0.00	0.02	2	1	0	0	0	0	0	46	1	1	2	3	1	6	2	33	2	0	0	4
2	0.00	0.00	0.00	0.01	0.88	-0.04	0.00	0.02	2	1	0	0	0	0	0	46	1	1	2	2	1	5	3	13	2	1	0	2
3	0.00	0.00	0.01	0.01	1.13	-0.03	0.00	0.02	1	0	0	0	0	0	0	45	1	1	3	4	0	6	3	17	2	1	0	2

Humic fraction

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.01	0.01	0.01	0.00	0.53	-0.01	0.00	0.68	-1	0	0	0	0	0	0	61	1	2	0	1	0	3	-1	22	0	0	0	0
2	0.01	0.01	0.01	0.00	0.50	-0.01	0.00	0.64	-1	0	0	0	0	0	0	60	1	2	0	1	-1	2	-1	3	0	0	0	1
3	0.01	0.01	0.01	0.00	0.55	-0.01	0.00	0.67	-1	0	0	0	0	0	0	60	1	2	0	1	0	2	-1	-7	0	0	0	4

Secondary Manganese Oxide

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0.00	0.00	0.06	0.06	0.20	0.00	0.00	0.02	0	0	0	0	0	1	0	16	2	-1	0	137	1	4	0	21	0	1	0	6	5
2	0.00	0.00	0.06	0.06	0.20	0.00	0.00	0.01	0	0	0	0	0	1	0	17	2	-1	0	106	2	3	0	3	0	1	0	6	7
3	0.00	0.00	0.07	0.07	0.20	0.00	0.00	0.03	0	1	0	0	0	1	0	17	2	0	1	94	1	6	0	14	0	1	0	6	10

Secondary Iron Oxides

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0.09	0.10	0.06	0.00	0.01	0.00	0.00	0.05	1	0	0	0	0	0	1	16	10	2	6	122	1	54	4	7	3	5	0	3	12
2	0.10	0.16	0.08	0.00	0.01	0.01	0.01	0.07	5	1	2	1	0	0	1	17	12	4	6	166	2	63	7	26	4	7	1	3	9
3	0.06	0.07	0.06	0.00	0.01	0.00	0.00	0.04	2	1	0	0	0	0	0	17	4	1	5	94	1	32	4	7	2	6	0	2	10

Residual (pseudo-total)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	2.13	4.66	6.42	0.36	0.01	0.19	0.00	0.11	18	10	9	7	5	5	21	48	278	26	488	28	941	62	70	25	71	9	44	230
2	2.18	4.75	6.41	0.41	0.01	0.21	0.00	0.09	19	11	9	7	6	5	21	47	284	26	442	29	944	61	52	25	71	9	45	228
3	1.69	3.59	4.98	0.36	0.01	0.16	0.00	0.10	16	9	7	5	5	4	21	43	213	28	427	25	756	55	64	20	65	7	38	209

SEQUENTIAL EXTRACTION RESULTS FOR 1995 HYETTOS GRID 4 SAMPLES

Exchangeable cation

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.02	0.00	0.40	-0.02	0.00	0.00	0.03	-2	5	0	0	0	3	0	61	6	5	0	31	31	11	33	94	6	1	3	5 269
2	0.00	0.02	0.00	0.27	-0.03	-0.01	0.00	0.03	-3	4	-1	0	0	3	0	62	6	5	0	32	30	15	33	99	6	1	3	7 257
3	0.00	0.02	0.00	0.28	-0.03	-0.01	0.00	0.03	-2	4	0	0	0	2	0	62	6	4	0	20	30	10	33	110	6	1	3	4 258

Carbonate Bound

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.00	1.18	0.48	7.13	0.21	0.00	0.02	2	3	1	0	0	1	0	18	3	1	0	71	13	24	7	19	0	1	0	7 158
2	0.00	0.00	1.02	0.06	7.16	0.21	0.00	0.01	0	0	0	0	0	1	0	18	2	1	0	41	6	21	4	21	0	1	0	6 93
3	0.00	0.00	0.80	0.61	7.10	0.16	0.00	0.02	2	4	0	0	0	1	1	18	2	1	0	47	13	20	10	36	0	1	1	7 164

Fulvic fraction

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.01	0.01	0.01	0.90	-0.04	0.00	0.00	2	0	0	0	0	0	0	45	1	1	1	3	0	5	3	8	1	1	0	0
2	0.00	0.01	0.01	0.00	0.75	-0.04	0.00	0.00	3	1	0	0	0	0	0	46	1	1	1	3	0	11	3	22	1	1	0	2
3	0.00	0.01	0.01	0.00	0.62	-0.04	0.00	0.00	2	1	0	0	0	0	0	46	1	1	0	2	1	3	3	21	1	1	0	2

Humic fraction

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.01	0.01	0.03	0.00	0.53	0.00	0.00	0.64	-1	0	0	0	0	0	0	61	2	2	-1	5	0	11	-1	-3	0	0	0	1
2	0.02	0.02	0.05	0.00	0.56	0.00	0.00	0.66	-1	0	-1	0	0	0	0	60	2	7	0	2	0	11	-1	-5	0	1	0	7
3	0.01	0.01	0.02	0.00	0.53	-0.01	0.00	0.66	-1	0	-1	0	0	0	0	59	1	2	0	1	0	7	-1	-1	0	1	0	4

Secondary Manganese Oxide

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.00	0.00	0.07	0.03	0.17	0.00	0.00	0.00	0	0	0	0	0	0	0	17	16	-1	0	296	1	27	0	27	0	2	0	4 3
2	0.00	0.00	0.06	0.01	0.17	0.00	0.00	0.00	0	0	0	0	0	0	0	17	6	-1	0	173	0	14	0	23	0	1	0	4 -1
3	0.00	0.00	0.06	0.04	0.13	0.00	0.00	0.00	0	1	0	0	0	0	0	17	21	0	0	360	2	54	1	8	1	2	0	6

Secondary Iron Oxides

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0.06	0.19	0.08	0.00	0.01	0.00	0.00	0.00	4	1	1	1	0	0	0	17	36	4	2	240	1	155	6	3	2	5	1	2 11
2	0.06	0.27	0.09	0.00	0.01	0.00	0.00	0.00	4	1	1	1	0	0	1	16	25	8	2	215	1	120	5	13	3	4	1	3 11
3	0.05	0.23	0.14	0.00	0.01	0.00	0.00	0.00	3	1	1	1	0	0	0	16	38	5	2	235	2	148	8	29	2	4	1	2 16

Residual (pseudo-total)

sample	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	BI	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	1.04	4.16	8.68	0.06	0.00	0.00	0.00	0.04	5	3	4	7	1	1	1	21	84	316	11	338	22	1836	31	67	16	39	8	16 172
2	0.97	4.91	10.95	0.04	0.00	0.00	0.00	0.04	5	3	3	6	1	1	1	23	50	351	10	333	24	1253	30	68	20	34	10	20 179
3	0.67	4.07	10.40	0.05	0.00	0.00	0.00	0.03	4	3	3	3	5	1	1	22	60	266	8	300	23	1416	44	71	15	31	8	11 170

1994 ASKRA TRANSECT SURVEY

Distance (m)	% <212um	Al2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0	20.36	2.10	1.10	0.94	0.00	0.27	0.01	0.19	24	15	11	5	12	11	-14	38	15	59	48	660	9	93	30	24	32	49	-2	65	61
10	9.11	2.50	1.13	0.93	0.00	0.38	0.01	0.23	29	17	12	6	14	13	-14	39	17	70	79	851	9	113	42	23	34	62	-2	72	64
20	9.26	2.97	1.14	1.08	0.01	0.47	0.03	0.28	30	18	13	7	17	13	-14	38	18	78	77	877	10	120	45	16	40	77	-2	81	76
30	11.65	2.68	1.08	1.17	0.01	0.44	0.01	0.33	29	18	12	6	17	12	-14	39	17	71	70	871	10	116	43	23	31	71	-2	78	74
40	5.73	2.89	1.15	1.58	0.01	0.47	0.01	0.45	30	19	14	6	20	12	-14	38	18	75	79	880	10	119	46	21	36	78	-2	86	79
50	13.66	2.89	1.18	1.59	0.01	0.47	0.02	0.45	30	19	14	7	21	12	-14	38	18	76	75	917	11	123	45	24	37	80	-2	90	78
60	13.44	3.10	1.14	1.35	0.01	0.48	0.03	0.36	31	19	14	6	19	13	-14	39	18	78	71	923	11	119	47	18	40	75	-2	88	77
70	16.39	2.68	1.13	1.50	0.01	0.45	0.02	0.34	29	19	13	6	18	12	-14	39	17	69	56	926	10	112	42	20	38	71	-2	89	72
80	12.31	2.56	1.06	1.09	0.01	0.36	0.01	0.23	31	19	12	6	15	14	-14	38	17	64	47	918	9	107	44	23	35	67	-2	90	72
90	16.78	2.71	1.01	0.89	0.00	0.39	0.01	0.18	33	19	12	6	13	15	-14	38	17	65	42	874	9	104	45	26	39	62	-2	85	69
100	9.90	2.86	1.10	0.97	0.01	0.39	0.01	0.16	31	18	13	7	13	13	-14	38	17	56	38	886	9	108	43	24	23	65	-1	85	73
110	11.61	3.11	1.29	1.27	0.01	0.40	0.02	0.28	31	19	15	8	16	13	-14	38	18	73	48	952	11	117	45	23	40	71	-2	96	84
120	14.14	3.92	1.43	1.40	0.01	0.42	0.01	0.32	36	22	19	9	18	14	-13	40	20	88	57	1081	12	134	58	29	43	81	-2	112	97
130	12.73	4.04	1.48	1.72	0.01	0.44	0.02	0.38	36	22	20	7	22	14	-13	40	20	89	62	1178	13	136	56	27	48	86	-2	125	101
140	15.70	3.15	1.11	1.05	0.01	0.44	0.02	0.25	33	19	14	6	15	14	-13	39	18	73	51	987	10	116	49	23	41	69	-2	102	76
150	15.72	3.00	1.02	1.02	0.01	0.40	0.01	0.22	33	19	13	5	14	13	-14	38	18	70	45	921	10	110	47	27	40	66	-2	96	79
160	14.54	2.59	0.89	1.00	0.01	0.39	0.01	0.18	30	17	11	7	14	11	-14	37	15	60	37	800	9	91	45	19	34	65	-2	85	74
170	11.66	3.39	1.28	1.35	0.01	0.42	0.01	0.23	32	19	16	1	18	12	-14	38	17	75	41	961	11	113	60	23	44	72	-2	103	89
180	16.92	1.50	1.19	0.99	0.00	0.21	0.00	0.02	15	11	10	9	11	8	-14	37	13	13	12	973	6	82	18	22	1	45	1	89	44
190	14.73	3.55	1.77	3.24	0.00	0.25	0.03	0.14	34	24	20	7	19	15	-13	40	22	106	38	930	15	146	36	27	52	55	-2	89	95
200	17.07	2.64	1.44	3.60	0.00	0.23	0.01	0.14	36	26	16	7	20	18	-13	39	18	68	39	1012	13	114	29	23	41	51	-2	87	77
210	17.22	2.62	1.25	1.02	0.00	0.26	0.00	0.12	35	21	13	6	12	19	-14	38	17	67	37	1084	9	118	34	28	42	51	-2	105	73
220	17.13	2.86	1.06	0.76	0.00	0.33	0.01	0.09	30	16	13	2	11	12	-14	37	17	59	42	791	9	102	36	21	28	51	-2	89	77
230	18.66	2.08	0.84	0.47	0.00	0.19	0.00	0.05	32	16	8	7	11	13	-14	37	17	23	39	858	6	95	25	20	6	48	0	124	46
240	17.86	3.22	1.03	0.55	0.00	0.24	0.02	0.10	33	17	13	1	12	13	-13	39	18	71	51	997	8	98	38	25	46	47	-2	141	75
250	17.83	1.14	0.86	0.50	0.00	0.22	0.00	0.03	32	16	5	2	10	12	-14	37	16	10	18	760	5	85	16	21	4	43	0	89	30
260	22.90	1.60	1.36	0.74	0.00	0.15	0.02	0.05	29	16	8	7	13	13	-14	38	17	24	27	765	7	102	19	26	12	47	0	100	49
270	22.60	2.71	1.19	0.66	0.00	0.18	0.02	0.09	33	17	13	2	12	15	-13	39	19	68	47	734	10	103	33	23	49	45	-2	96	69
280	23.76	1.70	0.91	0.57	0.00	0.27	0.00	0.02	35	18	9	5	10	13	-14	36	18	15	28	854	5	99	23	17	3	42	0	100	44
290	29.69	1.90	0.66	0.33	0.00	0.25	0.01	0.07	31	15	7	5	6	12	-14	36	15	51	54	591	6	81	27	22	36	34	-2	68	46
300	28.72	2.26	0.68	0.35	0.00	0.27	0.01	0.07	32	15	9	5	7	13	-14	37	17	59	68	672	6	87	29	27	38	40	-2	72	54
310	26.92	2.09	0.59	0.29	0.00	0.27	0.00	0.06	32	15	8	1	6	12	-14	38	16	54	78	617	6	78	29	16	33	38	-2	70	48
320	28.11	0.85	0.44	0.29	0.01	0.14	0.00	0.01	23	12	3	6	5	9	-34	34	12	6	23	581	3	60	10	1	2	28	0	52	21
330	26.48	1.95	0.48	0.31	0.01	0.21	0.00	0.06	33	15	7	4	6	12	-34	35	16	44	50	734	5	73	28	9	23	35	-1	65	40
340	26.71	1.93	0.50	0.34	0.01	0.20	0.00	0.07	32	15	7	4	7	12	-34	12	17	47	59	707	5	73	27	12	30	36	-2	67	39
350	25.47	2.03	0.47	0.30	0.01	0.17	0.01	0.06	31	14	7	4	7	11	-34	6	16	48	54	664	5	70	27	6	28	34	-2	66	37
360	23.93	1.80	0.45	0.31	0.01	0.14	0.00	0.06	29	14	7	5	6	10	-34	37	14	44	52	585	5	65	26	11	26	34	-1	62	33
370	23.82	2.11	0.50	0.37	0.01	0.21	0.00	0.14	33	16	7	5	8	12	-34	37	16	51	64	492	6	75	32	9	32	40	-2	81	43
380	17.22	2.46	0.57	0.46	0.01	0.15	0.00	0.09	39	17	8	6	10	13	-34	38	21	59	69	790	6	91	34	11	38	41	-2	99	46
390	16.78	2.74	0.60	0.51	0.01	0.18	0.00	0.08	36	18	9	6	10	14	-34	37	20	63	71	954	7	94	63	7	41	43	-2	117	49
400	12.12	2.80	0.60	0.49	0.01	0.14	0.00	0.07	35	17	9	6	10	13	-34	38	19	62	82	763	6	90	38	4	38	44	-2	94	49
410	16.26	2.67	0.63	0.58	0.01	0.16	0.00	0.08	36	18	9	9	11	14	-34	38	20	62	101	828	7	90	34	9	39	45	-2	97	50
420	15.66	3.65	1.00	0.69	0.01	0.17	0.00	0.07	34	20	13	8	13	17	-33	38	22	82	78	753	9	118	36	11	47	54	-3	112	63

1994 ASKRA TRANSECT SURVEY

430	12.96	3.71	0.90	0.75	0.02	0.16	0.00	0.08	35	19	13	6	14	14	-34	39	23	81	80	954	9	118	39	8	40	58	-3	118	63
440	18.30	2.59	0.89	0.80	0.05	0.09	0.02	0.12	26	15	9	5	15	10	-34	38	20	60	58	799	8	77	29	15	43	52	-2	95	59
450	20.91	2.31	0.76	0.57	0.02	0.06	0.01	0.08	28	15	8	5	11	11	-34	38	19	56	59	904	7	76	28	9	39	43	-2	105	48
460	16.28	2.51	0.64	0.50	0.01	0.09	0.00	0.06	32	17	10	5	10	13	-34	39	18	57	52	869	7	81	34	10	36	44	-1	107	50
470	18.88	2.79	0.58	0.61	0.01	0.11	0.00	0.05	36	19	11	5	11	13	-34	39	19	58	56	961	6	85	38	8	31	45	-2	110	57
480	18.14	2.87	0.54	0.57	0.01	0.14	0.00	0.05	35	18	11	5	10	13	-34	39	18	55	48	936	6	81	35	7	32	44	-2	108	50
490	16.05	2.75	0.65	0.75	0.01	0.12	0.00	0.05	39	21	12	6	12	15	-34	38	20	58	51	1051	8	94	35	12	34	47	-2	125	55
500	12.98	3.77	0.75	0.84	0.01	0.20	0.00	0.06	41	22	17	6	13	15	-34	40	21	78	53	1092	8	107	43	11	38	55	-2	131	70
510	14.51	3.99	0.82	2.18	0.02	0.23	0.00	0.07	43	25	19	5	22	14	-34	40	21	79	57	1124	11	108	43	13	38	57	-2	134	80
520	16.93	3.08	0.72	1.08	0.01	0.20	0.00	0.08	36	20	14	5	13	12	-34	39	19	59	88	988	9	89	37	11	36	49	-2	118	62
530	11.55	2.76	1.35	1.53	0.01	0.15	0.00	0.07	32	19	13	7	18	10	-34	39	19	69	84	880	10	118	32	18	37	41	-2	100	65
540	7.81	3.16	0.98	0.84	0.02	0.14	0.00	0.07	33	18	14	6	15	13	-34	39	17	68	50	630	8	94	35	17	44	45	-2	76	62
550	7.29	2.72	1.09	1.89	0.02	0.10	0.00	0.07	32	20	14	7	22	13	-34	39	16	60	50	626	10	89	32	15	42	44	-2	79	66

1995 ASKRA SURFACE SAMPLES

GRID 1

sample	% <212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Se	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	35.83	1.27	1.31	0.64	1.20	0.01	0.17	0.00	0.20	27	17	-2	3	13	11	0	26	14	29	29	800	15	75	36	36	21	35	2	82	116
2	27.33	1.47	1.50	0.74	1.37	0.01	0.19	0.00	0.26	29	18	-1	3	15	12	0	26	15	34	33	897	17	86	40	29	24	43	3	91	123
3	25.4	1.27	1.32	0.61	1.03	0.01	0.15	0.00	0.19	27	16	-3	3	12	11	0	26	15	30	26	844	14	76	41	27	21	34	2	82	103
4	13.02	1.59	1.67	0.82	1.35	0.01	0.19	0.00	0.27	29	19	-1	4	16	13	0	27	17	37	30	965	17	93	42	35	24	45	3	94	129
5	22.8	1.40	1.45	0.69	1.18	0.01	0.16	0.00	0.22	28	18	-2	3	14	12	0	27	16	33	30	922	15	84	41	23	22	40	2	88	112
6	26.93	1.30	1.35	0.62	1.02	0.01	0.16	0.00	0.17	26	16	-2	3	12	11	0	26	14	30	25	807	14	74	39	20	21	33	2	85	102
7	31.4	1.28	1.34	0.61	0.93	0.01	0.16	0.00	0.16	28	18	-2	3	11	13	0	29	16	31	26	797	16	74	38	31	21	35	4	83	107
8	26.65	1.36	1.44	0.65	0.99	0.01	0.17	0.00	0.18	27	16	-2	3	12	11	0	26	15	31	26	836	13	78	38	29	22	36	3	86	105
9	22.12	1.56	1.68	0.75	1.17	0.01	0.19	0.00	0.24	28	17	-1	3	14	12	0	27	16	37	29	902	16	88	42	35	25	43	3	87	115
10	19.58	1.42	1.52	0.68	1.10	0.01	0.17	0.00	0.21	28	17	-2	3	13	12	0	27	15	33	28	883	16	83	41	41	23	39	3	86	119
11	27.98	1.19	1.24	0.55	0.88	0.01	0.14	0.00	0.13	25	15	-3	2	10	10	0	27	13	26	22	734	13	67	37	17	20	28	2	81	104
12	27.52	1.20	1.23	0.56	0.88	0.01	0.14	0.00	0.13	25	15	-2	2	11	10	0	27	13	26	22	726	12	68	33	31	20	29	2	83	102
13	22.69	1.22	1.26	0.57	0.90	0.01	0.14	0.00	0.14	25	15	-3	2	11	11	0	28	13	27	25	748	14	69	36	30	20	30	2	82	92
14	20.65	1.51	1.62	0.74	1.26	0.01	0.18	0.00	0.25	28	18	-1	3	14	12	0	28	16	35	30	883	16	88	44	43	24	44	3	86	125
15	19.57	1.41	1.50	0.66	1.04	0.01	0.16	0.00	0.19	28	17	-2	3	13	12	0	28	16	33	28	879	14	82	42	32	22	38	3	85	110
16	23.55	1.15	1.21	0.54	0.85	0.01	0.13	0.00	0.12	23	14	-3	2	10	9	0	28	12	25	22	666	12	64	33	26	19	28	2	77	96
17	30.12	1.18	1.23	0.58	0.92	0.01	0.14	0.00	0.13	27	17	-2	2	11	12	0	31	15	29	24	708	15	68	40	27	20	30	4	79	99
18	24.01	1.25	1.31	0.59	0.99	0.01	0.15	0.00	0.16	26	16	-2	2	11	11	0	30	14	28	24	766	13	75	40	24	21	32	2	82	115
19	30.53	1.56	1.71	0.74	1.22	0.01	0.18	0.00	0.25	29	17	0	3	14	11	0	31	16	37	30	875	16	89	50	33	25	44	3	86	117
20	21.97	1.29	1.39	0.60	0.96	0.01	0.15	0.00	0.16	28	16	-2	3	11	11	0	32	15	31	25	841	14	79	47	33	22	33	2	80	105
21	13.41	1.30	1.41	0.66	1.09	0.01	0.14	0.00	0.15	26	16	-1	2	12	10	0	32	14	30	22	708	14	75	40	34	22	32	3	81	111
22	35	1.31	1.43	0.66	1.21	0.01	0.14	0.00	0.17	27	16	-1	2	13	11	0	33	14	31	25	749	15	78	45	41	23	34	3	82	117
23	9.87	1.41	1.55	0.73	1.43	0.01	0.15	0.00	0.25	29	18	0	3	14	11	0	35	16	34	29	829	17	89	52	35	25	40	3	86	123
24	23.85	1.51	1.69	0.77	1.41	0.01	0.17	0.00	0.25	29	18	0	3	15	11	0	35	16	36	28	855	18	92	59	44	25	43	3	88	125
25	21.72	1.32	1.48	0.65	1.08	0.01	0.15	0.00	0.17	28	17	-1	3	12	11	0	36	16	32	24	847	16	83	47	34	23	35	3	81	116

GRID 2

sample	% <212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	26.45	1.08	1.40	0.73	0.92	0.01	0.19	0.01	0.21	24	14	-2		3	10	10	0	37	14	34	54	693	14	81	38	33	20	35	3	52	106
2	29.1	1.37	1.56	0.93	0.97	0.01	0.23	0.01	0.21	22	15	8		3	12	11	0	10	14	38	50	734	15	86	31	10	22	42	3	62	135
3	33.62	1.49	1.69	1.09	1.15	0.01	0.22	0.01	0.22	23	16	9		3	14	11	0	10	15	40	68	781	17	90	33	12	24	44	3	69	153
4	29.18	1.56	1.78	1.18	1.37	0.01	0.20	0.01	0.21	23	17	10		4	14	11	0	11	14	41	59	777	19	91	30	20	26	41	4	80	157
5	30.94	1.65	1.91	1.32	1.17	0.01	0.20	0.01	0.21	23	16	11		4	13	12	0	10	15	44	59	823	18	94	34	25	28	41	4	76	154
6	37.84	1.07	1.24	0.68	0.75	0.01	0.18	0.01	0.19	20	13	6		2	11	10	0	9	12	31	52	648	11	70	30	9	18	35	2	54	116
7	34.9	1.12	1.30	0.72	0.80	0.01	0.20	0.01	0.19	19	13	6		2	11	10	0	9	12	31	58	675	14	74	29	20	18	37	3	62	117
8	33.74	1.31	1.49	0.84	0.97	0.01	0.23	0.01	0.23	23	15	7		3	13	11	0	10	14	37	67	761	14	83	35	10	22	43	3	76	145
9	31.1	1.33	1.56	0.90	0.94	0.01	0.22	0.01	0.21	22	15	8		3	13	10	0	10	14	37	60	727	15	82	32	21	22	42	3	72	134
10	28.57	1.39	1.61	0.98	1.01	0.01	0.24	0.01	0.23	23	16	9		3	13	11	0	10	14	39	60	760	16	87	33	22	24	43	3	72	141
11	35.84	1.29	1.48	0.79	0.92	0.01	0.23	0.01	0.22	24	15	7		3	13	11	0	11	14	36	65	776	14	83	35	25	21	43	3	64	131
12	34.77	1.16	1.32	0.73	0.87	0.01	0.20	0.00	0.21	23	15	7		3	13	11	0	12	14	34	56	729	15	76	33	9	20	41	4	63	126
13	31.66	1.20	1.37	0.76	0.93	0.01	0.22	0.00	0.22	22	14	7		3	13	11	0	10	14	34	64	792	14	80	35	24	20	41	3	69	132
14	26.17	1.21	1.40	0.74	0.84	0.01	0.21	0.01	0.20	21	14	7		3	13	10	0	10	13	34	56	735	14	78	33	28	20	41	3	70	124
15	27.43	1.21	1.38	0.77	0.88	0.01	0.23	0.00	0.21	23	15	7		3	13	11	0	11	14	34	61	783	14	82	33	14	21	41	3	71	125
16	29.22	1.26	1.40	0.77	1.00	0.01	0.23	0.00	0.25	23	15	7		3	13	11	0	10	14	36	52	770	15	84	37	27	21	44	3	72	133
17	36.85	1.15	1.30	0.70	0.84	0.01	0.21	0.00	0.22	22	14	7		3	12	10	0	10	13	33	60	735	13	75	33	15	20	41	3	68	126
18	36.26	1.18	1.32	0.71	0.97	0.01	0.24	0.00	0.23	22	15	7		3	14	11	0	11	13	34	50	753	14	78	33	19	21	42	3	68	123
19	28.57	1.27	1.45	0.78	0.92	0.01	0.24	0.01	0.23	23	15	7		3	13	11	0	11	14	36	56	814	15	84	36	21	21	43	3	69	129
20	33.33	1.33	1.48	0.83	1.09	0.01	0.26	0.00	0.27	25	16	8		3	15	12	0	11	15	37	64	879	16	89	38	22	22	49	3	81	143
21	34.99	1.16	1.32	0.70	0.99	0.01	0.20	0.00	0.27	22	14	7		3	13	10	0	11	13	33	53	744	14	79	34	20	19	43	3	76	123
22	36.4	1.21	1.36	0.72	1.02	0.01	0.23	0.01	0.28	24	17	7		3	15	12	0	13	15	36	63	742	17	78	37	11	20	46	4	68	134
23	32.64	1.18	1.35	0.72	1.05	0.01	0.22	0.00	0.27	23	15	7		3	14	10	0	11	13	34	71	764	15	80	38	19	20	45	3	70	140
24	33.18	1.32	1.49	0.78	1.03	0.01	0.23	0.01	0.27	23	15	7		3	14	11	0	12	14	37	70	767	16	83	39	19	21	48	3	70	141
25	31.29	1.25	1.38	0.74	1.06	0.01	0.23	0.01	0.27	23	16	7		3	15	11	0	12	14	35	68	817	15	81	37	25	21	46	3	72	127

1995 ASKRA SURFACE SAMPLES

GRID 3

sample	%<212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	36.4	1.35	1.57	0.75	0.85	0.01	0.12	0.00	0.06	29	17	-2	3	9	13	0	25	15	31	56	739	14	79	24	18	27	22	2	92	102
2	34.88	1.58	1.84	0.89	0.94	0.01	0.15	0.00	0.07	30	18	0	4	10	14	0	26	16	38	66	751	15	91	25	16	30	26	3	94	111
3	32.09	1.58	1.84	0.91	0.94	0.01	0.14	0.00	0.07	29	18	0	4	9	14	0	26	16	38	69	729	15	94	26	21	30	26	3	92	106
4	18.1	1.23	1.34	0.36	0.55	0.01	0.09	0.00	0.05	39	20	-5	3	8	14	0	25	21	26	53	952	11	66	26	14	24	16	2	132	75
5	31.3	1.60	1.85	0.92	1.06	0.01	0.15	0.00	0.07	27	17	0	4	11	13	0	26	15	38	70	775	16	89	26	24	29	27	3	90	115
6	29.07	1.04	1.08	0.50	0.66	0.01	0.06	0.00	0.03	47	23	-4	3	9	17	0	28	23	24	34	914	14	69	26	23	25	15	4	142	85
7	27.85	1.16	1.24	0.58	0.74	0.01	0.06	0.00	0.03	51	22	-3	3	8	17	0	25	24	26	37	1085	12	79	26	18	28	15	2	152	91
8	29.29	1.25	1.36	0.76	0.93	0.01	0.06	0.00	0.04	27	18	-2	3	7	14	0	26	15	28	35	748	13	88	22	23	23	17	2	98	103
9	24.78	1.56	1.62	1.06	1.48	0.01	0.06	0.00	0.05	27	21	1	4	10	16	0	26	15	36	43	757	18	111	24	26	26	23	3	108	136
10	25.08	1.58	1.60	1.14	1.98	0.01	0.06	0.00	0.06	26	19	1	4	11	14	0	26	15	37	44	712	20	103	23	30	24	22	3	100	145
11	26.15	0.96	0.96	0.44	0.61	0.01	0.06	0.00	0.03	45	21	-5	3	8	16	0	26	17	19	27	599	10	58	24	7	24	11	1	98	74
12	25.85	1.12	1.16	0.55	0.70	0.01	0.07	0.00	0.03	53	22	-4	3	8	16	0	26	22	24	36	881	11	73	28	13	29	14	2	131	90
13	25.16	1.32	1.40	0.74	0.87	0.01	0.08	0.00	0.04	28	19	-2	3	7	15	0	26	16	30	46	845	14	92	23	26	26	19	2	103	101
14	21.76	1.63	1.62	1.19	2.83	0.01	0.07	0.00	0.06	26	20	2	4	12	12	0	27	14	38	40	613	22	106	22	35	23	23	3	93	166
15	25.51	1.89	1.93	1.43	3.49	0.01	0.08	0.00	0.07	27	22	4	5	15	15	0	27	16	46	46	710	25	114	23	35	29	24	4	104	174
16	28.98	1.05	1.12	0.51	0.60	0.01	0.06	0.00	0.03	41	21	-4	3	7	16	0	28	19	25	31	616	13	65	26	16	24	15	4	93	87
17	25.23	1.03	1.05	0.48	0.64	0.01	0.06	0.00	0.03	36	20	-4	3	8	14	0	25	16	22	34	575	10	63	23	14	23	13	2	98	80
18	29.66	1.19	1.27	0.66	0.78	0.01	0.06	0.00	0.04	30	17	-3	3	7	13	0	25	21	27	46	1228	13	98	23	23	25	16	2	139	89
19	27.38	1.65	1.68	1.08	2.98	0.01	0.08	0.00	0.06	25	20	2	4	11	11	0	27	14	38	38	533	22	97	22	38	23	23	3	78	168
20	26.88	1.94	1.93	1.47	5.17	0.01	0.08	0.00	0.08	26	24	5	5	16	13	0	28	14	45	46	571	28	110	21	33	29	24	4	89	193
21	33.81	1.00	1.05	0.45	0.61	0.01	0.06	0.00	0.03	34	18	-5	3	7	13	0	26	16	21	25	559	10	62	21	21	21	11	2	82	74
22	27.34	1.09	1.15	0.52	0.67	0.01	0.06	0.00	0.03	39	24	-4	3	8	19	0	29	20	26	38	722	13	75	26	17	25	16	4	102	81
23	27.02	1.31	1.45	0.69	0.91	0.01	0.09	0.00	0.05	33	19	-2	3	8	14	0	26	19	31	52	891	14	94	24	34	29	18	2	104	103
24	26.29	1.68	1.72	1.07	3.11	0.01	0.09	0.00	0.06	28	22	2	4	12	13	0	28	15	39	44	657	23	104	24	29	25	23	3	88	161
25	20.52	1.78	1.84	1.29	5.37	0.01	0.08	0.00	0.07	26	24	4	4	17	12	0	28	14	41	41	504	28	108	19	29	26	23	4	82	184

GRID 4

sample	%<212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	29.45	0.86	0.86	0.30	0.53	0.00	0.09	0.00	0.04	26	14	-5	2	7	10	0	24	15	18	47	723	8	49	21	6	16	13	1	79	62
2	29.89	1.19	1.20	0.36	0.63	0.01	0.09	0.00	0.12	33	18	-4	3	15	14	0	24	16	25	53	741	11	55	24	-3	22	18	2	103	78
3	22.96	1.19	1.27	0.39	0.57	0.00	0.10	0.00	0.05	34	18	-4	3	9	12	0	25	18	26	50	805	10	61	24	5	22	17	2	98	77
4	30.22	1.28	1.40	0.75	0.94	0.01	0.12	0.00	0.06	25	16	-1	3	10	12	0	25	13	29	58	722	13	75	22	9	24	22	2	82	102
5	23.75	1.04	1.08	0.32	0.48	0.00	0.09	0.00	0.05	32	17	-5	3	7	12	0	24	17	22	51	759	9	54	24	6	20	15	2	88	65
6	37.62	0.89	0.90	0.30	0.55	0.00	0.10	0.00	0.04	27	14	-5	2	8	10	0	24	15	19	44	764	9	49	21	7	17	15	1	82	68
7	25.44	1.04	1.08	0.34	0.58	0.01	0.09	0.00	0.05	30	16	-5	2	8	11	0	24	16	21	46	808	9	56	24	-1	19	16	2	93	72
8	22.64	1.10	1.23	0.35	0.55	0.00	0.09	0.00	0.05	37	19	-5	3	8	13	0	24	22	23	52	1015	10	62	24	12	23	16	2	104	79
9	21.97	1.06	1.12	0.32	0.52	0.00	0.08	0.00	0.06	37	19	-5	3	9	14	0	25	20	22	45	903	9	55	23	3	21	13	2	105	72
10	24.44	0.99	1.04	0.30	0.46	0.00	0.08	0.00	0.04	33	17	-5	3	7	12	0	24	18	21	47	808	8	51	23	16	19	13	1	92	59
11	35.76	0.92	0.96	0.32	0.53	0.00	0.10	0.00	0.04	30	17	-5	2	8	12	0	27	17	22	41	791	11	53	24	3	17	18	4	82	65
12	33.13	1.09	1.13	0.35	0.63	0.00	0.10	0.00	0.06	29	16	-4	2	10	11	0	25	16	23	51	781	10	57	24	20	19	18	2	90	78
13	26.73	1.21	1.32	0.35	0.62	0.01	0.09	0.00	0.07	32	18	-4	3	13	13	0	25	18	25	43	843	11	61	25	15	23	16	2	122	87
14	23.36	1.07	1.13	0.34	0.52	0.01	0.08	0.00	0.04	35	19	-5	3	8	13	0	25	20	22	49	935	9	59	24	20	21	14	2	101	71
15	24.74	0.99	1.09	0.30	0.43	0.00	0.08	0.00	0.04	32	17	-5	3	7	11	0	25	19	21	44	832	8	52	23	5	19	14	2	93	62
16	33.91	1.00	1.03	0.34	0.57	0.00	0.09	0.00	0.04	29	15	-5	2	8	10	0	25	16	21	41	824	9	55	23	12	18	18	2	88	70
17	27.03	1.22	1.25	0.39	0.73	0.01	0.10	0.00	0.05	32	18	-4	3	10	13	0	25	18	24	44	933	12	65	27	7	21	19	2	103	88
18	25.79	1.19	1.30	0.38	0.59	0.01	0.09	0.00	0.05	36	19	-5	3	9	13	0	26	20	24	51	965	10	63	25	6	23	17	2	103	84
19	19.07	1.06	1.13	0.33	0.51	0.00	0.07	0.00	0.04	35	18	-5	3	8	12	0	25	20	22	48	922	9	57	25	10	21	14	2	99	72
20	21.15	1.18	1.28	0.35	0.53	0.01	0.09	0.00	0.06	34	19	-5	3	9	13	0	25	18	25	54	911	9	58	25	14	22	17	2	125	76
21	34.37	0.99	1.03	0.34	0.59	0.01	0.11	0.00	0.05	32	18	-5	2	9	13	0	27	16	23	47	809	12	55	26	8	18	25	4	92	74
22	27.93	1.29	1.34	0.43	0.87	0.01	0.14	0.00	0.07	32	18	-3	3	12	12	0	25	17	26	54	889	13	64	27	9	22	24	2	100	94
23	26.87	1.34	1.39	0.43	0.78	0.01	0.13	0.00	0.07	33	18	-3	3	11	12	0	25	17	27	53	917	13	64	26	17	22	23	2	103	92
24	21.76	1.18	1.26	0.38	0.64	0.01	0.10	0.00	0.05	32	18	-4	3	9	12	0	25	17	24	56	906	6	57	26	14	21	20	2	105	82
25	21.88	1.31	1.39	0.42	0.68	0.01	0.11	0.00	0.05	30	19	-3	3	9	13	0	25	15	26	51	925	13	59	26	21	22	21	2	105	85

1995 ASKRA SOIL PITS

SOIL PIT 1

depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
0-5cm	1.48	1.64	0.73	0.93	0.01	0.09	0.00	0.05	0.05	29	17	8	3	12	11	0	11	16	32	46	906	15	76	27	26	27	30	3	97	135
10-15cm	1.49	1.68	0.74	0.95	0.01	0.08	0.00	0.04	0.04	31	17	9	3	12	11	0	12	18	32	50	1038	15	78	34	17	28	31	3	109	132
20-25cm	1.48	1.66	0.73	0.99	0.01	0.06	0.00	0.04	0.04	33	18	9	3	13	12	0	11	20	31	49	1135	15	80	31	19	27	30	3	115	136
30-35cm	1.48	1.69	0.69	0.92	0.01	0.06	0.00	0.03	0.03	30	17	8	3	12	11	0	12	17	32	49	890	15	77	29	23	27	29	3	87	130
40-45cm	1.19	1.38	0.57	0.78	0.01	0.05	0.00	0.03	0.03	28	16	7	3	12	11	0	11	15	26	72	753	13	68	30	17	23	26	3	71	114

SOIL PIT 2

depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
0-5cm	1.53	1.65	0.86	1.05	0.01	0.19	0.00	0.18	28	18	18	9	3	12	13	0	12	16	38	35	908	17	93	38	19	24	44	3	79	147
10-15cm	1.58	1.73	0.86	1.05	0.01	0.18	0.00	0.19	28	18	18	9	4	12	13	0	12	16	39	33	903	17	92	38	10	25	45	3	82	145
20-25cm	1.54	1.68	0.85	1.09	0.01	0.17	0.00	0.19	27	18	18	9	4	12	13	0	12	16	38	32	908	17	90	38	14	24	44	3	81	143
30-35cm	1.55	1.69	0.85	1.07	0.01	0.17	0.00	0.18	27	18	18	9	4	12	13	0	12	16	38	34	910	17	91	38	30	24	45	3	82	144
40-45cm	1.53	1.65	0.90	1.40	0.01	0.14	0.00	0.18	26	18	18	9	4	13	12	0	12	15	38	28	908	18	92	39	14	23	42	3	77	155

VM4 SURFACE SAMPLES

sample	% <212 um	Al2O3	FeO3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1												No Sample																		
2	28.18	0.88	0.86	1.03	6.88	0.01	0.14	0.00	0.54	18	22	4	1	30	6	0	22	21	64	32	512	29	188	32	39	10	60	3	54	173
3	32.52	1.11	1.14	1.32	6.63	0.01	0.18	0.00	0.60	19	22	5	2	30	5	0	21	22	85	37	639	30	236	37	39	11	74	3	70	190
4	32.51	0.90	0.93	1.17	6.19	0.01	0.16	0.00	0.52	17	20	4	1	27	5	0	20	20	75	29	611	27	213	39	39	9	70	2	64	176
5	31.09	0.99	1.08	1.43	9.43	0.01	0.16	0.00	0.52	19	25	6	2	39	5	0	22	23	92	33	594	32	257	26	42	10	63	3	70	187
6	26.38	1.00	1.09	1.43	9.45	0.01	0.16	0.00	0.53	19	25	7	2	39	5	0	22	23	93	33	594	32	260	27	41	10	63	3	70	181
7	23.77	0.93	1.10	1.86	10.20	0.01	0.10	0.00	0.42	17	25	8	2	39	4	0	22	25	115	28	499	33	313	25	37	9	53	3	54	183
8	24.24	0.95	1.29	2.08	11.47	0.01	0.14	0.00	0.35	18	27	9	2	43	4	0	23	30	145	27	527	35	385	18	47	10	50	3	53	192
9	29.49	1.09	1.28	1.61	9.39	0.01	0.20	0.00	0.45	20	26	7	2	40	5	0	21	27	118	33	630	32	318	25	45	12	60	3	68	187
10	25.24	1.07	1.12	1.46	8.19	0.01	0.17	0.00	0.50	20	24	6	2	38	5	0	20	24	92	35	660	30	261	30	45	11	62	3	75	188
11	24.58	1.22	1.28	1.37	4.86	0.01	0.21	0.00	0.51	22	21	5	2	27	7	0	20	24	93	38	762	27	247	38	37	14	69	3	83	185
12	19.66	1.44	1.50	1.46	4.85	0.01	0.22	0.00	0.52	23	21	6	2	29	8	0	7	24	90	39	880	24	268	36	49	17	66	3	103	196
13	18.35	1.77	1.97	1.36	2.32	0.01	0.21	0.00	0.44	26	19	5	3	18	10	0	6	28	110	40	995	20	305	42	52	23	64	3	108	188
14	14.43	1.86	2.06	1.47	2.33	0.01	0.20	0.00	0.43	26	19	6	3	19	10	0	6	27	110	41	1009	20	304	46	42	23	69	4	111	194
15	15.99	1.69	1.87	1.40	2.34	0.01	0.18	0.00	0.43	25	18	5	3	18	10	0	5	27	110	46	1002	19	304	44	39	22	65	3	105	186
16	16.92	1.85	2.03	1.26	1.72	0.01	0.15	0.00	0.23	26	17	5	3	16	10	0	6	33	131	36	1043	18	346	44	44	25	59	3	88	171
17	16.90	1.87	2.10	1.42	2.00	0.01	0.19	0.00	0.32	28	20	5	3	17	11	0	7	33	132	43	1049	21	350	40	45	25	65	5	95	181
18	21.50	1.79	1.90	1.33	1.46	0.01	0.12	0.00	0.12	27	17	4	4	12	11	0	5	38	130	29	1107	17	373	35	43	24	44	3	84	177
19	25.11	1.39	1.43	1.55	11.59	0.02	0.23	0.00	0.50	20	25	9	2	53	5	0	8	23	87	39	618	29	270	13	46	14	69	3	75	190
20	28.12	1.38	1.42	1.48	10.86	0.02	0.27	0.00	0.52	22	25	9	2	56	6	0	8	21	82	40	673	28	243	20	41	14	70	3	79	201
21	31.38	1.28	1.36	1.39	10.61	0.02	0.24	0.00	0.62	21	25	8	2	58	6	0	8	18	75	41	680	28	221	26	40	14	73	3	88	195
22	27.90	1.22	1.37	1.57	10.82	0.02	0.20	0.00	0.61	21	25	8	2	49	6	0	8	22	89	36	707	28	273	21	42	13	68	3	81	180
23	30.43	1.23	1.58	2.07	12.88	0.02	0.19	0.00	0.50	20	26	10	2	49	5	0	10	25	125	35	640	31	363	15	44	13	65	3	77	197
24	19.05	1.19	1.92	3.32	14.94	0.02	0.15	0.00	0.36	17	27	14	3	46	3	0	11	32	196	25	523	33	529	8	40	13	50	4	51	199
25	27.34	1.31	1.55	2.05	10.88	0.02	0.25	0.00	0.50	20	25	9	2	47	5	0	9	25	117	36	705	29	345	23	46	14	66	3	86	199
26	21.04	1.41	1.61	1.72	8.48	0.02	0.24	0.00	0.52	21	23	8	2	40	6	0	9	25	108	36	775	27	319	22	38	15	70	3	85	194
27	26.06	1.75	1.86	1.86	6.48	0.02	0.23	0.00	0.64	25	23	9	3	40	8	0	9	24	96	44	869	26	283	35	37	19	83	3	107	213
28	21.68	1.69	1.83	1.60	4.05	0.01	0.23	0.00	0.54	25	20	8	2	27	9	0	7	24	91	40	971	23	269	39	53	19	77	3	110	192
29	21.49	1.88	2.06	1.59	3.50	0.01	0.25	0.00	0.55	27	21	8	3	24	10	0	8	25	98	42	1033	23	276	43	57	22	81	4	118	201
30	17.09	2.03	2.27	1.65	2.70	0.01	0.20	0.00	0.50	28	20	7	3	20	11	0	8	27	109	40	994	22	306	47	57	25	78	4	110	202
31	12.10	2.30	2.74	1.46	2.11	0.01	0.23	0.00	0.41	32	22	8	4	18	12	0	7	30	128	41	1111	21	328	49	53	31	76	4	120	204
32	15.27	2.00	2.32	1.35	2.32	0.01	0.20	0.00	0.39	30	21	7	3	19	12	0	7	28	110	42	1081	20	291	48	47	27	72	4	115	193
33	16.48	2.06	2.56	1.22	1.96	0.02	0.24	0.00	0.32	32	21	7	3	17	12	0	7	30	122	41	1137	20	304	43	43	31	68	4	113	195
34	13.37	2.24	2.73	1.23	1.81	0.01	0.19	0.00	0.29	34	22	7	4	16	13	0	8	31	127	38	1151	19	310	44	50	31	67	4	114	199
35	30.13	1.76	2.14	1.04	1.57	0.01	0.16	0.00	0.21	27	18	5	3	13	10	0	7	27	114	28	945	17	284	36	42	26	51	3	85	164
36	23.02	1.39	1.34	1.47	10.65	0.02	0.23	0.00	0.54	21	24	9	2	56	6	0	10	20	78	36	633	28	224	18	47	15	74	3	75	190
37	27.98	1.55	1.76	1.45	9.48	0.02	0.27	0.00	0.61	26	27	9	3	51	9	0	12	27	102	43	796	31	296	29	54	18	76	5	98	203
38	27.21	1.34	1.47	1.35	10.57	0.02	0.26	0.00	0.65	22	25	8	2	64	6	0	10	19	73	41	718	28	213	31	47	15	77	3	100	193
39	30.12	1.48	1.65	1.47	9.57	0.02	0.25	0.00	0.65	24	25	9	3	50	7	0	11	23	92	41	808	28	264	31	37	16	81	3	102	191
40	28.96	1.32	1.56	1.67	12.18	0.02	0.22	0.00	0.54	22	27	9	2	54	6	0	10	23	105	35	693	30	309	23	41	14	69	3	95	201
41	23.66	1.18	1.50	2.32	10.16	0.02	0.26	0.00	0.52	19	24	9	2	48	5	0	10	24	120	34	692	29	333	21	56	13	69	3	85	201
42	25.55	1.61	1.62	1.28	10.46	0.02	0.23	0.00	0.52	24	26	8	2	29	7	0	9	30	112	35	835	28	334	29	45	16	71	3	96	197
43	18.58	1.67	1.76	1.48	5.05	0.02	0.30	0.00	0.61	25	21	7	2	32	9	0	8	23	88	43	952	24	255	43	48	19	87	3	113	206
44	20.70	1.80	1.96	1.83	5.75	0.02	0.26	0.00	0.63	24	22	9	3	37	8	0	8	22	93	39	783	25	261	32	52	20	80	3	101	207
45	20.65	2.03	2.16	1.71	3.07	0.01	0.21	0.00	0.54	28	21	8	3	33	10	0	8	26	104	43	1052	22	297	48	42	23	83	4	120	204
46	18.00	1.68	1.81	1.37	4.59	0.01	0.26	0.00	0.56	27	22	7	3	31	10	0	8	23	83	39	987	23	240	35	45	20	76	3	118	196
47	23.39	1.81	2.08	1.02	2.03	0.01	0.18	0.00	0.39	32	22	5	4	17	14	0	10	27	92	37	977	20	234	46	48	25	65	5	109	178
48	18.98	2.10	2.60	0.71	1.53	0.01	0.20	0.00	0.18	38	23	6	5	15	15	0	7	29	99	32	1148	18	217	42	42	31	54	4	111	175
49	16.53	1.95	2.50	0.54	1.11	0.01	0.22	0.00	0.10	38	22	5	5	11	15	0	8	28	94	28	1087	15	188	43	40	30	45	4	99	153
50	16.38	1.89	2.45	0.54	1.18	0.01	0.25	0.00	0.11	38	23	5	5	12	16	0	8	27	90	30	1108	15	185	39	38	31	45	4	98	157
51	16.55	1.89	2.24	0.46	0.97	0.01	0.23	0.00	0.06	41	24	4	5	10	18	0	8	26	76	28	1254	13	154	38	39	30	39	4	106	135

RHADON SURFACE SAMPLES

sample	% < 212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	17.73	1.65	1.47	1.69	7.38	0.09	0.31	0.00	0.41	25	25	10	2	23	7	0	14	50	95	34	879	32	350	24	31	20	58	4	55	231
2	19.18	1.60	1.53	1.42	9.70	0.05	0.32	0.00	0.43	25	28	10	3	27	7	0	15	59	107	36	769	34	424	17	34	20	52	4	52	228
3	19.44	1.34	1.27	1.15	8.13	0.04	0.32	0.00	0.40	24	26	9	2	23	7	0	14	45	89	38	686	32	339	20	19	19	53	3	52	225
4	16.40	1.49	1.19	1.04	7.12	0.03	0.27	0.00	0.39	26	25	8	3	24	9	0	13	29	53	42	629	30	173	20	21	21	49	3	52	223
5	22.78	1.15	1.01	0.83	8.75	0.02	0.20	0.00	0.27	27	27	8	3	23	7	0	14	35	61	33	492	31	227	21	19	20	41	3	42	190
6	19.78	1.19	1.19	1.22	6.78	0.04	0.30	0.00	0.44	26	25	8	2	26	7	0	15	43	89	39	690	31	326	21	29	18	72	5	56	216
7	23.55	2.30	2.00	2.44	6.56	0.12	0.35	0.01	0.23	23	24	13	4	19	8	0	14	37	83	41	823	34	251	25	40	26	40	5	48	254
8	21.75	2.58	2.43	2.76	5.50	0.11	0.26	0.01	0.26	23	22	14	4	20	9	0	14	48	116	38	828	33	356	32	35	33	51	5	48	256
9	18.02	2.30	2.18	2.44	6.21	0.02	0.24	0.01	0.18	24	24	14	4	19	9	0	13	44	101	36	828	33	338	26	36	30	40	5	49	271
10	16.57	2.39	2.21	2.63	5.57	0.04	0.22	0.01	0.20	24	23	14	4	19	10	0	14	44	97	39	831	32	338	30	41	29	42	5	49	254
11	14.98	2.61	2.33	2.72	6.03	0.03	0.19	0.01	0.14	25	24	16	4	17	10	0	14	38	88	38	956	34	248	28	29	30	34	5	55	262
12	16.81	3.84	3.18	3.47	2.94	0.30	0.19	0.04	0.11	23	19	19	5	13	9	0	14	36	99	46	##	32	185	45	41	41	42	7	57	264
13	19.59	1.94	1.55	2.17	11.23	0.03	0.16	0.01	0.11	34	34	16	3	29	7	0	16	24	65	30	756	36	163	15	29	19	28	4	40	249
14	20.01	3.35	2.77	3.13	7.27	0.12	0.15	0.03	0.11	24	25	18	4	20	9	0	16	36	87	43	905	36	193	31	50	33	37	6	49	283
15														No Sample																
16														No Sample																
17	26.51	1.77	1.51	1.69	8.94	0.14	0.37	0.01	0.47	23	26	10	2	30	6	0	14	32	65	42	763	33	203	22	25	20	60	4	49	241
18	27.64	1.97	1.77	1.82	10.91	0.08	0.45	0.01	0.50	27	31	11	3	32	9	0	18	31	69	44	783	38	178	20	29	24	63	6	53	247
19	19.62	1.60	1.51	1.50	8.08	0.05	0.33	0.01	0.47	25	26	10	2	26	7	0	14	28	64	38	775	33	174	27	46	21	62	4	55	234
20	25.15	1.65	1.54	1.44	9.05	0.04	0.43	0.01	0.52	26	27	10	3	30	8	0	15	26	60	45	790	33	156	19	31	23	64	4	58	225
21	19.40	1.69	1.53	1.55	7.57	0.06	0.26	0.01	0.33	23	24	10	3	21	7	0	14	28	56	36	653	33	154	23	27	23	48	4	43	239
22	25.03	2.08	1.74	1.86	10.78	0.11	0.27	0.01	0.29	24	28	12	3	21	8	0	15	26	53	37	736	38	131	17	37	23	42	5	45	258
23	24.42	2.48	2.27	3.12	6.42	0.12	0.28	0.01	0.26	23	23	15	4	20	9	0	14	35	95	38	794	34	268	28	42	28	45	5	44	264
24	26.83	2.71	2.42	3.11	7.24	0.12	0.26	0.01	0.25	24	25	17	4	20	9	0	16	36	95	39	810	36	261	29	26	30	45	6	49	274
25	23.21	2.59	2.28	2.77	7.74	0.05	0.23	0.01	0.20	26	27	16	5	19	10	0	16	38	89	42	915	36	260	25	28	30	40	5	55	265
26	23.78	2.58	2.17	2.57	10.43	0.03	0.16	0.01	0.19	25	29	17	5	23	10	0	18	31	76	41	804	41	125	19	43	26	34	5	50	266
27	24.56	3.15	2.76	2.93	10.98	0.04	0.12	0.04	0.12	23	28	18	7	20	10	0	18	31	76	44	812	42	127	13	21	40	31	6	39	272
28	28.74	3.84	2.92	3.21	13.94	0.15	0.16	0.05	0.13	23	32	19	6	31	9	0	20	29	76	44	812	42	127	13	21	40	30	6	39	231
29	23.50	3.25	2.62	2.98	12.25	0.05	0.18	0.03	0.13	26	31	18	5	23	9	0	18	32	75	45	##	40	179	14	32	34	32	6	48	219
30	25.14	3.44	2.77	2.97	15.36	0.05	0.17	0.05	0.13	26	34	18	7	31	9	0	20	29	75	42	839	42	162	9	30	36	31	6	46	216
31	24.60	3.34	2.71	3.07	13.59	0.11	0.14	0.03	0.13	25	32	18	6	31	9	0	19	32	74	42	870	41	177	14	12	36	41	6	56	224
32	26.54	2.95	2.31	2.77	15.49	0.16	0.15	0.03	0.12	23	33	17	5	33	8	0	19	27	67	40	833	42	154	6	25	33	33	5	41	205
33	25.36	2.53	2.33	2.91	10.30	0.09	0.58	0.01	0.66	26	29	13	4	35	8	0	17	38	93	48	##	37	307	21	22	29	72	5	60	217
34	28.21	2.68	2.34	2.36	11.43	0.05	0.50	0.01	0.52	26	30	14	5	32	9	0	17	31	74	47	914	37	207	16	20	31	59	5	57	203
35	23.39	2.52	2.31	2.16	10.63	0.04	0.54	0.01	0.63	28	30	13	4	36	9	0	17	31	79	48	##	37	224	18	29	31	72	5	67	209
36	22.42	2.63	2.27	2.24	10.98	0.03	0.41	0.01	0.46	27	30	14	5	27	9	0	17	30	69	46	897	38	180	19	32	33	52	5	57	191
37	23.68	2.49	2.18	2.17	9.90	0.06	0.45	0.01	0.51	26	28	13	4	28	9	0	16	28	68	48	895	36	183	21	24	30	61	5	56	213
38	26.50	2.82	2.33	2.54	10.54	0.13	0.40	0.01	0.40	26	29	15	5	25	9	0	16	30	66	46	940	37	184	17	25	29	49	5	54	214
39	23.59	2.43	1.99	2.57	12.39	0.07	0.23	0.00	0.25	26	31	16	5	23	9	0	17	30	64	37	935	38	205	10	23	25	33	5	47	206
40	24.91	3.04	2.57	3.08	11.19	0.06	0.29	0.01	0.25	26	30	18	6	22	10	0	17	32	79	43	##	39	219	15	28	31	39	6	52	219
41	24.08	3.01	2.54	3.14	10.21	0.05	0.29	0.01	0.24	26	29	19	6	22	10	0	17	35	83	42	##	37	249	17	31	32	38	5	53	221
42	24.00	3.05	2.50	2.87	13.15	0.03	0.24	0.02	0.19	25	32	18	6	24	10	0	17	31	72	41	892	41	185	10	16	34	33	6	48	209
43	25.95	3.91	3.31	3.51	10.36	0.04	0.23	0.04	0.16	26	29	21	8	21	11	0	17	36	93	48	##	40	206	21	26	42	37	7	53	239
44	18.21	3.12	2.48	2.82	12.00	0.04	0.13	0.02	0.14	25	30	17	5	24	10	0	18	33	68	38	969	39	170	13	26	33	29	5	52	222
45	19.85	3.66	2.81	2.86	15.83	0.04	0.11	0.05	0.14	27	35	19	7	32	9	0	19	30	75	42	870	44	152	9	31	35	29	6	55	214
46	16.34	3.02	2.27	2.57	11.78	0.02	0.10	0.01	0.13	28	31	16	6	25	10	0	17	37	77	35	996	38	253	13	23	31	27	5	60	215
47	19.09	3.20	2.54	2.84	13.80	0.03	0.14	0.03	0.13	28	33	17	6	26	9	0	18	33	77	38	895	41	213	11	23	35	30	6	56	214
48														No Sample																

Samples collected from a 16 x 3 sample grid. Numbering starts from the bottom left corner and progresses along the long horizontal axis.

1994 VM70 SURFACE SAMPLES

Sample	% <212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	12.38	3.85	3.85	7.31	9.83	0.01	0.19	0.00	0.08	16	24	29	9	33	5	-13	44	49	384	29	554	19	846	23	37	26	39	-1	25	65
2	12.57	4.20	4.05	7.34	8.14	0.01	0.22	0.01	0.09	15	22	29	9	30	5	-13	43	53	398	31	605	20	877	29	34	29	42	-1	28	83
3	12.58	4.30	4.22	7.97	8.67	0.01	0.25	0.01	0.09	15	23	27	9	28	5	-13	43	52	431	31	594	19	877	29	42	31	44	-1	26	84
4	13.81	4.47	4.40	7.63	6.89	0.01	0.29	0.00	0.20	15	21	25	10	25	6	-13	43	57	456	33	714	19	960	34	32	26	51	-1	29	97
5	8.43	4.67	4.77	7.47	4.74	0.01	0.32	0.01	0.09	15	18	25	10	19	6	-13	42	60	481	33	802	19	1001	41	37	30	53	-2	31	109
6	14.11	4.48	4.39	7.80	8.07	0.01	0.27	0.01	0.09	15	22	25	10	28	5	-13	43	60	468	35	706	20	962	32	40	30	48	-1	26	89
7	13.31	4.46	4.21	7.80	8.08	0.01	0.23	0.00	0.09	15	22	24	10	28	6	-13	43	60	460	36	714	19	962	31	39	29	47	-1	26	84
8	11.16	2.67	2.92	7.65	15.96	0.01	0.11	0.01	0.08	16	31	26	6	50	3	-13	46	39	328	22	436	21	706	3	37	21	27	0	18	19
9	9.52	3.72	3.85	7.48	10.90	0.01	0.21	0.01	0.11	16	26	29	8	37	5	-13	44	47	391	30	532	20	815	21	37	29	40	-1	25	63
10	9.98	4.73	4.66	7.71	7.43	0.01	0.29	0.01	0.08	16	22	28	10	29	5	-13	42	54	460	30	683	20	940	33	34	32	47	-2	30	113
11	10.04	4.94	5.03	7.36	4.42	0.01	0.33	0.01	0.08	16	18	27	11	18	6	-13	41	60	498	32	799	19	1024	43	29	37	52	-2	33	106
12	7.31	4.55	4.59	6.96	3.54	0.01	0.29	0.01	0.08	16	33	25	10	16	7	-13	43	60	459	32	838	17	1004	43	39	34	51	-3	34	122
13	10.02	5.38	5.76	7.52	2.97	0.01	0.37	0.01	0.09	17	19	27	12	15	7	-13	44	64	542	38	895	19	1069	51	37	34	61	-2	36	114
14	10.21	5.66	5.61	7.61	4.97	0.01	0.37	0.01	0.10	18	20	28	13	22	8	-13	47	65	544	40	893	19	1066	49	36	41	64	0	39	0
15	15.97	2.16	2.76	8.01	18.54	0.01	0.07	0.01	0.08	16	34	29	5	58	3	-13	45	36	309	17	387	22	634	-6	37	18	24	-1	16	35
16	13.68	3.28	3.54	7.95	13.54	0.01	0.18	0.01	0.09	16	29	28	7	46	4	-13	42	45	373	23	528	21	782	12	42	25	34	-2	23	98
17	10.28	4.56	4.81	7.92	6.60	0.01	0.28	0.02	0.08	16	21	29	10	26	6	-13	42	57	479	29	732	19	994	35	41	34	47	-2	31	106
18	8.41	4.73	5.05	7.69	3.28	0.00	0.28	0.01	0.07	16	17	27	11	16	7	-14	42	62	490	31	850	17	1055	44	37	33	53	-3	36	118
19	7.49	4.06	4.22	6.63	3.42	0.01	0.25	0.00	0.07	16	17	24	9	16	7	-14	41	57	402	31	833	17	939	41	36	31	51	-2	37	108
20	5.58	4.29	4.39	5.98	3.95	0.01	0.29	0.01	0.08	18	19	24	9	17	7	-14	42	55	397	35	816	17	881	41	32	36	54	-3	39	121
21	7.86	5.37	5.53	6.33	2.74	0.01	0.42	0.00	0.10	18	17	27	12	15	8	-13	43	58	479	39	886	17	924	54	40	41	62	-2	42	89
22	15.32	2.93	2.93	7.22	16.02	0.01	0.11	0.01	0.08	16	31	27	7	48	3	-13	44	41	329	20	386	22	687	2	39	23	31	-1	20	62
23	12.86	3.75	4.17	7.87	11.01	0.01	0.20	0.01	0.08	16	26	29	9	40	5	-13	42	49	413	24	596	21	837	19	38	29	39	-2	28	98
24	11.31	4.31	4.79	7.22	4.78	0.01	0.25	0.00	0.08	15	18	27	10	20	6	-14	42	55	461	28	702	18	937	36	38	30	46	-2	31	102
25	7.34	4.66	5.16	7.80	3.60	0.01	0.28	0.01	0.08	15	17	28	11	17	6	-13	42	60	492	30	799	17	1031	41	32	52	-3	36	117	
26	7.24	5.11	5.61	7.40	2.10	0.01	0.32	0.01	0.07	16	15	27	12	12	7	-13	42	61	507	34	863	17	1012	48	38	41	55	-4	39	133
27	9.98	6.63	7.25	5.81	2.02	0.01	0.31	0.00	0.06	22	17	30	16	12	9	-14	42	78	631	36	###	18	1193	54	42	43	66	-2	52	115
28	6.37	5.03	5.16	6.38	2.64	0.01	0.32	0.00	0.08	17	16	26	11	14	7	-13	42	61	479	32	877	17	981	49	41	28	60	-2	46	92
29	9.68	3.96	4.24	6.88	11.66	0.01	0.23	0.02	0.08	17	27	28	9	38	5	-13	44	46	394	27	577	21	786	19	38	33	40	-2	28	89
30	9.46	4.67	5.02	7.34	8.46	0.01	0.29	0.02	0.08	17	24	29	11	33	6	-14	42	53	462	30	673	21	901	33	43	38	54	-2	39	108
31	7.99	4.72	5.13	7.57	4.91	0.01	0.33	0.01	0.08	16	19	28	11	22	6	-14	42	57	480	30	750	19	971	40	37	53	-2	36	109	
32	7.90	4.89	5.39	7.23	2.96	0.00	0.38	0.01	0.10	16	16	28	11	15	7	-14	40	58	492	31	781	18	989	46	41	30	55	-3	39	120
33	9.32	5.00	5.13	6.95	3.33	0.01	0.30	0.01	0.08	16	17	27	12	15	7	-13	41	61	490	31	786	17	1007	43	36	38	54	-3	37	127
34	5.08	5.74	6.12	6.97	2.56	0.01	0.35	0.01	0.08	17	16	29	13	13	8	-13	41	64	553	33	856	18	1050	49	38	40	59	-2	42	117
35	5.97	5.34	5.61	6.98	4.46	0.01	0.35	0.01	0.09	17	19	28	12	18	7	-14	43	62	522	32	762	19	995	43	35	35	58	-1		

Samples collected from a 7 x 7 sample grid. Numbering starts from the bottom left corner and progresses along the horizontal axis.

1995 VM70 SURFACE SAMPLES (MAIN GRID)

47	11.52	2.40	1.88	3.99	4.38	0.01	0.09	0.00	0.05	14	15	12	3	15	5	0	8	47	211	23	638	27	662	28	38	19	34	4	31	232
48	10.71	2.77	2.25	4.70	5.40	0.01	0.14	0.00	0.06	14	17	15	4	19	5	0	9	50	247	27	607	29	736	29	44	22	40	4	31	240
49	10.78	2.47	1.95	4.28	6.97	0.01	0.11	0.00	0.06	14	18	14	3	22	5	0	9	45	210	27	559	30	640	24	44	20	35	4	30	234
50	20.72	2.34	1.73	4.82	5.15	0.01	0.08	0.00	0.05	11	15	11	3	18	4	0	8	45	215	25	590	29	670	26	57	17	32	4	22	226
51	14.60	2.53	1.99	4.55	5.48	0.01	0.12	0.00	0.06	13	16	12	4	18	5	0	9	45	233	25	609	29	685	28	43	20	37	4	26	227
52	11.56	2.76	2.14	4.37	6.83	0.01	0.14	0.00	0.06	14	18	14	4	23	5	0	10	49	243	28	609	31	707	27	40	22	41	4	29	247
53	12.00	2.47	1.88	3.85	5.54	0.01	0.12	0.00	0.06	13	17	12	4	19	5	0	8	47	215	28	596	28	656	27	36	20	38	4	30	236
54	12.81	2.78	2.17	4.76	5.72	0.01	0.12	0.00	0.06	14	17	15	4	19	5	0	10	53	251	28	621	30	762	28	37	22	39	4	30	251
55	12.49	2.70	2.07	4.95	8.61	0.01	0.13	0.00	0.07	14	20	15	4	25	4	0	10	50	243	29	510	33	729	21	38	20	41	4	26	240
56	13.84	2.34	1.73	4.49	9.14	0.01	0.11	0.00	0.06	13	20	14	3	26	4	0	9	44	201	23	452	32	614	17	37	18	33	4	23	237
57	19.71	2.67	2.03	5.25	6.36	0.01	0.10	0.00	0.06	13	17	13	4	21	4	0	9	49	245	30	648	31	743	28	37	19	37	4	26	237
58	11.60	2.39	1.93	3.98	4.03	0.01	0.14	0.00	0.06	13	15	11	3	15	5	0	9	43	215	27	606	27	650	33	46	21	39	4	29	221
59	12.85	2.51	1.99	3.71	5.29	0.01	0.11	0.00	0.05	14	16	13	4	18	5	0	9	45	218	25	581	29	647	29	42	22	37	4	30	233
60	11.39	2.36	1.77	3.62	4.38	0.01	0.08	0.00	0.05	15	16	11	4	16	7	0	9	48	206	27	616	28	642	28	42	18	34	5	31	221
61	11.75	2.39	1.91	3.99	3.93	0.01	0.10	0.00	0.05	13	15	12	4	15	5	0	8	48	216	26	607	26	670	28	40	19	35	4	31	228
62	14.58	2.64	2.10	4.71	6.69	0.01	0.10	0.00	0.07	14	18	15	4	22	5	0	10	47	227	27	543	31	680	26	41	20	37	5	29	236
63	12.53	2.61	2.14	5.04	6.96	0.01	0.11	0.00	0.06	14	18	15	4	24	5	0	10	46	224	28	576	32	667	25	49	20	35	4	30	237

1995 VM70 SURFACE SAMPLES (MAIN GRID)

sample	% < 212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	19.82	2.50	1.97	5.17	8.71	0.01	0.09	0.00	0.06	13	19	18	4	31	4	0	10	41	202	29	479	32	648	20	31	18	35	4	23	230
2	19.91	2.07	1.72	5.17	11.94	0.01	0.06	0.00	0.06	13	23	17	3	39	3	0	11	35	185	22	417	35	579	10	25	14	26	4	19	236
3	19.61	1.85	1.73	5.54	13.95	0.01	0.05	0.00	0.06	13	25	18	3	45	2	0	12	32	188	18	383	35	551	5	26	13	24	4	17	225
4	15.31	1.88	1.71	4.98	11.68	0.01	0.07	0.00	0.06	13	23	16	3	39	3	0	11	35	180	16	441	35	562	10	34	13	25	4	21	232
5	12.95	2.09	1.81	4.69	9.70	0.01	0.08	0.00	0.06	14	21	15	3	33	3	0	10	37	185	18	504	33	599	22	18	15	27	5	24	245
6	12.65	2.15	1.92	4.72	10.37	0.01	0.09	0.00	0.06	14	22	16	3	32	3	0	11	36	188	21	493	33	582	15	17	16	28	4	24	240
7	13.95	2.40	2.29	4.29	11.53	0.01	0.11	0.00	0.07	16	24	18	4	35	4	0	11	36	193	28	526	36	542	14	44	21	30	5	27	242
8	20.52	2.26	1.64	5.17	9.65	0.01	0.05	0.00	0.06	12	20	15	3	28	3	0	10	38	180	21	424	32	592	16	42	15	27	4	20	237
9	14.88	2.47	2.12	5.08	6.73	0.01	0.12	0.00	0.25	13	18	16	4	26	5	0	9	41	223	25	567	31	692	25	24	21	42	5	27	239
10	15.85	2.17	1.93	5.38	10.75	0.02	0.09	0.00	0.06	14	22	17	3	37	3	0	11	39	208	19	512	34	639	15	31	15	28	4	23	232
11	14.64	2.26	2.09	5.41	8.87	0.01	0.10	0.00	0.06	14	21	17	4	32	4	0	11	42	221	19	554	33	681	20	31	16	31	5	25	234
12	12.28	1.99	1.73	4.25	6.34	0.01	0.09	0.00	0.06	13	17	13	3	24	4	0	9	39	182	17	555	29	600	21	27	14	27	3	26	221
13	12.83	2.14	1.80	4.29	8.18	0.01	0.09	0.00	0.05	14	19	14	3	27	4	0	10	40	183	19	560	31	599	18	34	15	27	4	27	222
14	13.87	2.37	2.26	4.79	11.11	0.01	0.12	0.00	0.07	15	23	18	4	33	3	0	11	36	207	24	521	36	576	15	35	19	29	5	27	248
15	18.25	2.43	1.80	5.10	7.41	0.01	0.09	0.00	0.06	13	18	14	3	24	4	0	10	43	207	22	558	31	677	23	33	16	31	4	24	235
16	14.45	2.62	2.21	5.04	4.26	0.01	0.16	0.00	0.06	13	15	15	4	17	5	0	8	47	241	23	668	29	771	31	36	19	38	4	29	236
17	19.80	2.36	2.00	4.83	4.89	0.01	0.12	0.00	0.05	13	15	14	4	19	4	0	9	45	221	22	643	29	714	28	32	17	34	4	28	241
18	11.31	2.24	1.92	4.70	4.59	0.01	0.10	0.00	0.05	13	15	14	3	18	5	0	8	45	207	19	643	28	687	26	30	15	31	4	29	231
19	11.38	2.39	2.15	4.75	3.49	0.01	0.12	0.00	0.05	13	14	14	4	15	5	0	8	46	223	20	670	26	718	29	40	17	32	4	31	226
20	12.67	2.21	1.90	4.09	4.30	0.01	0.10	0.00	0.05	13	15	13	3	16	5	0	8	42	194	20	618	28	633	27	37	16	29	4	30	226
21	11.95	2.24	2.11	4.43	9.22	0.01	0.10	0.00	0.06	14	21	15	4	27	4	0	11	36	200	22	505	33	572	18	29	18	28	5	26	233
22	20.74	2.40	1.82	4.99	6.08	0.01	0.10	0.00	0.06	12	16	12	4	20	4	0	9	45	219	23	587	31	711	25	32	16	32	4	22	242
23	13.23	2.74	2.27	5.03	3.67	0.01	0.13	0.00	0.05	13	14	14	5	15	5	0	8	50	252	23	741	27	804	33	35	19	37	4	30	234
24	13.29	2.55	2.33	4.79	2.30	0.01	0.13	0.00	0.05	13	12	14	4	11	5	0	8	49	243	23	746	24	776	33	37	19	38	4	32	220
25	13.62	2.52	2.30	4.25	2.56	0.01	0.09	0.00	0.04	14	13	13	4	12	5	0	8	44	217	23	698	25	667	32	33	19	34	4	32	224
26	10.62	2.63	2.41	4.82	2.22	0.01	0.13	0.00	0.05	13	12	14	4	11	5	0	8	49	248	24	716	25	782	35	32	20	37	4	32	222
27	12.78	2.53	2.23	4.49	3.11	0.01	0.14	0.00	0.05	13	13	14	4	13	5	0	8	48	230	22	706	26	733	32	27	19	36	4	33	220
28	14.11	2.54	2.31	4.72	8.00	0.01	0.13	0.00	0.06	15	20	16	4	26	4	0	10	41	224	38	576	32	652	23	29	20	35	5	29	244
29	22.68	2.57	1.85	5.90	10.08	0.01	0.09	0.00	0.14	13	21	14	4	31	3	0	12	47	230	29	589	34	722	18	32	17	34	4	20	236
30	18.16	2.53	1.96	5.01	6.84	0.01	0.12	0.00	0.06	13	18	14	4	22	4	0	9	48	232	24	647	31	718	25	39	17	34	4	25	244
31	14.64	2.60	2.34	4.57	2.96	0.01	0.17	0.00	0.06	16	15	15	3	13	7	0	9	48	224	30	753	27	698	37	27	22	40	5	34	233
32	11.83	2.28	2.08	4.48	2.20	0.01	0.11	0.00	0.04	12	11	12	3	10	5	0	8	46	219	22	701	24	717	32	32	18	33	4	30	208
33	12.88	2.77	2.30	4.69	4.14	0.01	0.14	0.00	0.05	14	15	15	4	15	6	0	8	51	248	26	664	28	767	30	38	23	38	4	31	245
34	17.03	2.19	1.52	4.10	7.80	0.01	0.09	0.00	0.05	13	19	12	3	24	4	0	9	48	183	20	524	30	634	18	34	16	31	3	25	233
35	14.68	2.38	1.97	4.34	7.04	0.01	0.11	0.00	0.06	14	18	14	3	23	4	0	9	42	203	23	550	30	631	23	26	19	32	4	28	223
36	24.69	2.46	1.76	5.55	8.16	0.01	0.08	0.00	0.37	13	19	13	3	30	5	0	10	46	225	28	619	32	698	23	42	20	41	4	22	239
37	16.38	2.39	1.71	4.74	7.57	0.01	0.10	0.00	0.07	13	19	13	3	24	4	0	8	47	214	24	619	31	686	22	27	18	33	4	23	233
38	13.16	2.55	2.19	4.15	4.24	0.01	0.15	0.00	0.06	15	16	14	4	17	6	0	6	43	205	27	673	28	630	32	35	23	38	4	32	231
39	15.15	2.28	1.77	3.45	4.31	0.01	0.09	0.00	0.05	14	15	11	3	16	5	0	6	41	179	23	681	27	573	29	32	18	35	3	30	213
40	10.99	2.45	2.03	3.49	1.67	0.01	0.10	0.00	0.04	14	12	10	4	9	6	0	6	50	215	22	726	21	691	33	27	22	33	4	36	203
41	11.06	2.48	1.96	4.55	5.73	0.01	0.12	0.00	0.06	14	17	14	4	19	5	0	10	50	224	23	591	30	705	26	37	19	37	5	29	233
42	13.38	2.34	1.76	4.25	8.15	0.01	0.10	0.00	0.06	13	19	14	3	25	4	0	9	43	195	22	487	31	611	19	41	18	32	4	26	234
43	22.47	2.74	1.96	5.87	7.55	0.01	0.09	0.00	0.06	13	18	14	4	25	4	0	10	50	247	29	652	32	764	25	36	18	35	4	24	248
44	17.96	2.38	1.75	4.37	4.49	0.01	0.09	0.00	0.05	13	15	11	3	17	5	0	8	47	211	24	674	27	678	29	36	17	33	4	26	237
45	13.16	2.49	2.00	3.83	4.60	0.01	0.14	0.00	0.06	14	16	12	4	17	5	0	8	45	212	24	690	29	640	31	35	21	39	4	32	237
46	12.48	2.46	1.98	3.82	3.10	0.01	0.13	0.00	0.05	14	14	12	3	13	6	0	7	47	214	23	722	25	660	34	31	20	39	4	35	221

1995 VM70 SURFACE SAMPLES (MAIN GRID)

47	11.52	2.40	1.88	3.99	4.38	0.01	0.09	0.00	0.05	14	15	12	3	15	5	0	8	47	211	23	638	27	662	28	38	19	34	4	31	232
48	10.71	2.77	2.25	4.70	5.40	0.01	0.14	0.00	0.06	14	17	15	4	19	5	0	9	50	247	27	607	29	736	29	44	22	40	4	31	240
49	10.78	2.47	1.95	4.28	6.97	0.01	0.11	0.00	0.06	14	18	14	3	22	5	0	9	45	210	27	559	30	640	24	44	20	35	4	30	234
50	20.72	2.34	1.73	4.82	5.15	0.01	0.08	0.00	0.05	11	15	11	3	18	4	0	8	45	215	25	590	29	670	26	57	17	32	4	22	226
51	14.60	2.53	1.99	4.55	5.48	0.01	0.12	0.00	0.06	13	16	12	4	18	5	0	9	45	233	25	609	29	685	28	43	20	37	4	26	227
52	11.56	2.76	2.14	4.37	6.83	0.01	0.14	0.00	0.06	14	18	14	4	23	5	0	10	49	243	28	609	31	707	27	40	22	41	4	29	247
53	12.00	2.47	1.88	3.85	5.54	0.01	0.12	0.00	0.06	13	17	12	4	19	5	0	8	47	215	28	596	28	656	27	36	20	38	4	30	236
54	12.81	2.78	2.17	4.76	5.72	0.01	0.12	0.00	0.06	14	17	15	4	19	5	0	10	53	251	28	621	30	762	28	37	22	39	4	30	251
55	12.49	2.70	2.07	4.95	8.61	0.01	0.13	0.00	0.07	14	20	15	4	25	4	0	10	50	243	29	510	33	729	21	38	20	41	4	26	240
56	13.84	2.34	1.73	4.49	9.14	0.01	0.11	0.00	0.06	13	20	14	3	26	4	0	9	44	201	23	452	32	614	17	37	18	33	4	23	237
57	19.71	2.67	2.03	5.25	6.36	0.01	0.10	0.00	0.06	13	17	13	4	21	4	0	9	49	245	30	648	31	743	28	37	19	37	4	26	237
58	11.60	2.39	1.93	3.98	4.03	0.01	0.14	0.00	0.06	13	15	11	3	15	5	0	9	43	215	27	606	27	650	33	46	21	39	4	29	221
59	12.85	2.51	1.99	3.71	5.29	0.01	0.11	0.00	0.05	14	16	13	4	18	5	0	9	45	218	25	581	29	647	29	42	22	37	4	30	233
60	11.39	2.36	1.77	3.62	4.38	0.01	0.08	0.00	0.05	15	16	11	4	16	7	0	9	48	206	27	616	28	642	28	42	18	34	5	31	221
61	11.75	2.39	1.91	3.99	3.93	0.01	0.10	0.00	0.05	13	15	12	4	15	5	0	8	48	216	26	607	26	670	28	40	19	35	4	31	228
62	14.58	2.64	2.10	4.71	6.69	0.01	0.10	0.00	0.07	14	18	15	4	22	5	0	10	47	227	27	543	31	680	26	41	20	37	5	29	236
63	12.53	2.61	2.14	5.04	6.96	0.01	0.11	0.00	0.06	14	18	15	4	24	5	0	10	46	224	28	576	32	667	25	49	20	35	4	30	237

1995 VM70 SURFACE SAMPLES (SOUTH TRANSECTS)

SOUTH TRANSECTS

sample	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	22.98	2.04	2.04	5.95	5.98	0.01	0.09	0.00	0.06	13	16	13	4	22	4	0	10	50	252	31	721	31	776	29	32	18	35	4	26	246
2	21.62	2.26	2.26	6.59	8.12	0.01	0.07	0.00	0.06	13	19	16	4	28	4	0	11	47	266	27	659	33	734	28	52	19	30	5	22	250
3	25.33	2.45	2.45	6.92	8.65	0.01	0.06	0.00	0.10	12	19	19	5	34	4	0	11	45	258	31	620	34	686	23	48	21	32	5	19	252
4	23.47	3.11	3.11	6.40	6.46	0.01	0.07	0.00	0.06	13	17	29	6	29	4	0	10	35	188	43	503	33	522	26	41	29	41	6	16	262
5	25.99	2.70	2.70	7.38	7.35	0.01	0.06	0.00	0.06	11	17	21	5	32	3	0	11	42	262	31	544	34	686	25	61	23	32	5	17	258
6														No Sample																
7	22.70	2.03	2.03	6.04	8.11	0.01	0.08	0.00	0.06	13	19	14	4	26	4	0	11	49	253	31	673	33	776	24	53	18	33	4	25	252
8	23.40	2.08	2.08	5.87	9.09	0.01	0.07	0.00	0.06	12	19	15	4	30	3	0	11	40	235	27	556	34	632	18	47	19	29	4	20	245
9	31.33	3.38	3.38	6.42	8.23	0.01	0.05	0.00	0.07	15	21	36	7	34	5	0	13	33	153	47	441	37	454	23	47	32	45	7	15	266
10	28.70	3.24	3.24	6.04	7.83	0.01	0.06	0.00	0.06	14	19	32	7	33	4	0	11	34	163	44	531	35	443	24	49	31	43	6	16	251
11	29.07	3.07	3.07	7.24	8.28	0.01	0.12	0.00	0.06	12	19	27	6	36	3	0	11	39	239	36	525	35	596	24	54	28	37	6	15	264
12	20.32	2.70	2.70	6.33	4.92	0.01	0.09	0.00	0.06	11	15	20	5	23	4	0	10	42	237	31	591	31	647	32	48	25	38	5	21	254
13	28.56	1.83	1.83	5.98	12.64	0.01	0.07	0.00	0.11	12	23	14	4	34	2	0	11	41	230	23	468	36	652	11	50	16	29	4	14	234
14	27.97	2.20	2.20	6.02	10.76	0.01	0.07	0.00	0.06	14	22	17	5	29	3	0	11	42	239	27	539	36	645	18	32	19	30	5	18	248
15	30.47	2.88	2.88	6.19	8.27	0.01	0.05	0.00	0.06	13	19	29	6	34	3	0	10	34	170	39	462	34	485	23	50	26	39	6	16	257
16	32.89	3.37	3.37	6.21	7.18	0.01	0.06	0.00	0.06	13	18	32	7	31	4	0	10	33	170	45	530	34	442	25	46	33	44	6	16	272
17	23.52	3.47	3.47	6.92	6.20	0.01	0.12	0.00	0.09	12	17	31	7	32	4	0	10	35	206	45	543	34	513	28	55	36	45	7	15	265
18	22.04	3.02	3.02	7.36	6.93	0.01	0.06	0.00	0.07	12	17	24	6	29	3	0	10	44	270	35	581	34	680	27	53	26	36	6	19	259

Samples collected from a 6 x 3 sample grid. Numbering starts from top left and progresses down the long south axis.

1995 VM70 SURFACE SAMPLES (EAST TRANSECTS)

EAST TRANSECTS

sample	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bl	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	13.34	2.33	2.33	3.79	2.03	0.01	0.09	0.00	0.04	14	12	12	5	10	6	0	7	46	240	28	639	24	704	34	48	22	36	4	35	220
2	12.74	2.00	2.00	3.43	5.94	0.01	0.16	0.00	0.08	14	18	11	3	23	5	0	7	39	208	28	571	29	591	35	46	23	43	4	32	231
3	13.34	2.49	2.49	4.21	4.17	0.01	0.17	0.00	0.05	14	15	14	5	17	6	0	8	45	253	29	596	29	695	37	52	24	44	5	36	235
4	13.86	2.18	2.18	4.25	9.72	0.01	0.09	0.00	0.06	15	22	14	5	28	5	0	10	39	225	28	477	34	600	23	43	23	40	5	31	244
5	11.66	2.26	2.26	4.29	4.82	0.01	0.09	0.00	0.05	13	16	13	5	19	5	0	8	43	233	27	569	29	653	36	47	22	42	4	34	237
6	12.79	2.31	2.31	4.52	5.67	0.01	0.09	0.00	0.05	13	17	14	5	20	5	0	9	47	249	29	634	30	686	33	42	23	41	5	35	254
7	19.17	2.19	2.19	4.96	7.16	0.01	0.10	0.00	0.06	13	18	14	5	23	4	0	9	51	253	32	635	31	733	35	54	21	45	5	32	245
8	14.82	2.44	2.44	4.77	3.45	0.01	0.11	0.00	0.05	13	14	15	5	14	5	0	8	56	274	39	730	27	808	37	44	24	44	5	32	244
9	25.55	2.04	2.04	5.06	7.60	0.01	0.08	0.00	0.07	13	19	14	4	24	5	0	11	53	249	50	601	32	733	29	42	20	41	5	25	236
10	12.92	1.66	1.66	3.15	2.58	0.01	0.07	0.00	0.04	13	12	9	3	11	5	0	7	44	185	22	614	23	583	30	42	18	30	3	32	207
11	14.75	2.19	2.19	3.88	1.98	0.01	0.11	0.00	0.04	13	12	12	4	10	6	0	7	48	232	27	640	23	691	34	50	23	38	4	36	222
12	12.25	1.93	1.93	3.55	1.83	0.01	0.12	0.00	0.04	13	11	10	3	11	6	0	6	45	203	24	636	22	628	36	42	22	39	3	35	214
13	12.26	1.95	1.95	3.90	5.21	0.01	0.08	0.00	0.05	13	16	12	3	19	5	0	8	40	200	27	526	28	573	32	51	22	40	4	33	244
14	15.12	1.82	1.82	3.80	6.01	0.01	0.08	0.00	0.06	13	17	12	3	20	4	0	8	39	194	28	532	29	549	37	49	22	39	4	32	219
15	13.90	1.73	1.73	3.55	8.00	0.01	0.09	0.00	0.05	13	19	12	3	19	3	0	9	41	210	22	575	31	521	20	45	22	34	4	28	238
16	18.27	1.72	1.72	3.73	5.04	0.01	0.08	0.00	0.05	13	15	11	3	17	4	0	7	44	192	22	612	27	563	30	56	19	37	4	31	229
17	17.48	1.68	1.68	3.95	4.20	0.01	0.08	0.00	0.04	12	14	12	3	16	5	0	7	48	193	24	624	26	609	30	40	18	36	3	29	220
18	19.60	1.84	1.84	4.59	6.05	0.01	0.08	0.00	0.05	13	17	14	4	22	5	0	8	51	213	28	593	30	661	28	50	20	40	4	28	236
19	13.07	1.95	1.95	3.90	2.44	0.01	0.09	0.00	0.04	13	12	11	4	11	5	0	6	48	216	26	657	24	677	31	50	20	35	4	34	220
20	12.57	2.12	2.12	3.91	2.47	0.01	0.07	0.00	0.04	13	12	12	4	11	6	0	6	45	226	25	549	24	681	31	47	21	34	4	31	217
21	12.45	1.97	1.97	4.02	3.46	0.01	0.07	0.00	0.05	13	14	12	3	14	5	0	6	44	207	27	563	26	632	30	38	21	32	4	31	240
22	12.62	0.07	0.07	0.13	0.13	0.00	-0.01	0.00	0.00	1	0	-3	0	0	-1	0	3	1	6	-1	19	1	22	1	13	1	0	-1	1	21
23	11.94	2.26	2.26	4.56	3.05	0.01	0.08	0.00	0.06	12	13	14	4	14	5	0	7	44	231	28	575	26	678	33	51	23	38	4	31	222
24	15.84	2.09	2.09	4.15	3.54	0.01	0.10	0.00	0.11	13	14	13	3	16	6	0	7	45	223	32	575	26	664	31	48	24	45	4	33	235
25	16.02	1.63	1.63	4.29	9.05	0.01	0.07	0.00	0.05	14	20	15	3	22	4	0	9	43	182	22	478	32	585	18	47	19	32	4	26	243
26	16.35	2.04	2.04	4.84	5.19	0.01	0.08	0.00	0.05	13	16	16	5	19	5	0	8	55	232	27	593	29	736	30	55	21	41	4	28	250
27	12.77	2.10	2.10	4.00	2.27	0.01	0.10	0.00	0.04	13	12	13	4	11	6	0	6	47	214	28	680	23	649	34	47	21	37	4	32	221

Samples collected from a 9 x 3 sample grid. Numbering starts from bottom left corner and progresses along the long horizontal axis.

1995 VM70 SURFACE SAMPLES (WEST TRANSECTS)

WEST TRANSECTS

sample	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	21.76	1.48	1.48	1.48	5.39	16.60	0.01	0.02	0.00	0.06	14	28	19	2	51	1	0	12	29	169	13	321	39	473	-2	45	10	17	4	13	220
2	19.67	1.92	1.92	6.08	13.61	0.01	0.01	0.05	0.00	0.06	14	26	20	3	42	3	0	13	34	204	18	369	38	561	8	49	13	22	6	16	235
3	20.46	2.22	2.22	6.97	14.66	0.01	0.01	0.05	0.00	0.07	13	26	22	4	43	2	0	13	34	232	17	348	40	592	7	56	15	22	5	17	228
4	20.74	1.09	1.09	3.56	13.17	0.01	0.01	0.02	0.00	0.05	12	23	12	2	33	1	0	10	22	119	11	257	34	363	0	41	9	14	3	14	205
5	23.04	1.74	1.74	4.25	11.99	0.01	0.01	0.00	0.05	0.05	11	22	14	3	28	1	0	10	25	170	12	257	35	460	5	43	13	18	4	13	225
6	24.37	1.83	1.83	3.64	14.38	0.01	0.01	0.06	0.00	0.05	13	25	17	3	31	1	0	11	27	172	12	277	36	492	0	43	14	20	4	16	212
7	19.09	2.05	2.05	4.17	12.25	0.01	0.01	0.07	0.00	0.06	14	23	17	4	27	3	0	9	32	213	23	332	35	583	11	49	20	27	4	20	228
8	20.15	2.19	2.19	4.27	11.31	0.01	0.01	0.08	0.00	0.05	14	22	17	5	25	3	0	10	33	224	23	354	34	617	14	48	21	28	5	21	236
9	11.71	1.68	1.68	3.57	11.99	0.01	0.01	0.07	0.00	0.05	14	23	13	4	28	3	0	10	30	183	18	278	35	539	11	42	20	29	4	20	218
10	18.91	1.73	1.73	5.39	14.54	0.01	0.01	0.06	0.00	0.06	15	26	18	3	43	3	0	12	37	197	16	402	38	587	8	53	15	28	4	20	228
11	14.40	1.84	1.84	5.65	14.20	0.01	0.01	0.07	0.00	0.07	14	25	19	3	42	2	0	12	35	196	18	375	38	569	7	48	15	25	4	17	227
12	21.78	2.01	2.01	6.08	14.14	0.01	0.01	0.05	0.00	0.06	15	27	21	3	41	3	0	14	33	196	21	356	40	534	9	46	16	24	6	16	240
13	20.07	2.06	2.06	5.26	15.26	0.01	0.01	0.06	0.00	0.06	15	27	19	4	39	2	0	13	32	186	20	377	39	539	5	48	16	23	5	18	228
14	19.90	2.29	2.29	5.60	14.90	0.01	0.01	0.06	0.00	0.06	14	27	21	4	39	2	0	12	37	213	21	383	39	621	6	60	17	24	5	17	240
15	20.59	1.59	1.59	3.49	16.27	0.01	0.01	0.06	0.00	0.07	16	29	16	3	36	3	0	12	32	155	17	384	39	504	0	45	15	22	4	21	223
16	23.91	1.90	1.90	3.67	14.14	0.01	0.01	0.05	0.00	0.06	13	25	16	4	27	2	0	12	28	184	18	273	36	505	3	43	17	20	4	15	234
17	21.43	1.94	1.94	3.95	12.67	0.01	0.01	0.07	0.00	0.06	14	24	17	4	29	3	0	11	34	203	23	367	36	580	11	40	19	25	4	23	245
18	24.61	1.94	1.94	3.98	14.35	0.01	0.01	0.08	0.00	0.06	15	27	15	5	31	3	0	12	32	206	20	285	37	562	8	49	21	28	4	21	233
19	18.29	1.85	1.85	4.71	11.17	0.01	0.01	0.08	0.00	0.06	14	23	16	3	34	3	0	10	36	190	21	467	34	584	13	53	16	27	4	23	240
20	17.35	1.65	1.65	4.72	12.79	0.01	0.01	0.07	0.00	0.06	14	24	16	3	38	3	0	11	35	171	19	413	35	541	9	53	15	24	4	20	223
21	19.37	1.67	1.67	4.43	14.38	0.01	0.01	0.07	0.00	0.06	15	26	17	3	39	2	0	12	34	165	16	414	37	518	6	48	14	23	4	20	229
22	20.83	1.92	1.92	4.65	15.44	0.01	0.01	0.05	0.00	0.07	16	29	18	3	37	4	0	15	32	180	19	356	41	527	5	56	15	23	6	17	229
23	25.20	1.76	1.76	3.79	18.85	0.01	0.01	0.04	0.00	0.06	16	32	17	3	39	2	0	14	29	165	16	304	40	498	-6	52	14	19	4	17	211
24	24.18	1.70	1.70	3.70	15.61	0.01	0.01	0.07	0.00	0.06	15	28	16	3	34	2	0	12	31	161	18	349	38	511	2	46	14	22	4	19	220
25	24.42	1.31	1.31	3.03	18.14	0.01	0.01	0.03	0.00	0.06	15	31	15	3	34	2	0	14	27	131	15	279	38	420	-6	42	12	17	3	16	211
26	22.29	1.85	1.85	3.73	14.91	0.01	0.01	0.06	0.00	0.06	14	27	17	4	30	2	0	14	28	187	20	268	38	506	4	49	18	23	4	18	228
27	26.54	1.60	1.60	3.36	18.23	0.01	0.01	0.05	0.00	0.06	16	31	15	4	34	2	0	13	24	167	15	221	38	438	-2	54	16	21	4	17	212

Samples collected from a 9 x 3 sample grid. Numbering starts from bottom right corner and progresses along the long horizontal axis.

VM70 SOIL PITS

SOIL PIT 1

depth	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	16.20	1.75	1.81	5.50	14.46	0.01	0.06	0.00	0.06	13	25	19	3	46	2	0	11	31	192	16	375	36	555	1	52	13	23	4	17	221
10-15cm	16.00	1.87	1.78	5.21	14.14	0.01	0.05	0.00	0.06	13	25	18	3	42	2	0	10	32	193	17	399	34	577	0	59	14	21	4	17	208

SOIL PIT 2

depth	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	12.37	2.49	2.44	4.79	2.39	0.01	0.15	0.00	0.05	13	12	14	4	11	5	0	6	47	244	26	730	24	795	32	63	20	37	4	31	228
10-15cm	11.19	2.27	2.17	4.40	2.49	0.01	0.08	0.00	0.04	12	12	13	4	11	5	0	6	45	221	21	706	23	743	28	53	17	30	4	30	227
20-25cm	13.47	2.53	2.42	4.83	2.57	0.01	0.09	0.00	0.04	13	12	15	5	11	5	0	6	49	246	28	763	24	814	31	55	19	33	4	32	225
30-35cm	11.51	2.45	2.33	4.49	2.32	0.01	0.06	0.00	0.04	12	12	14	4	10	5	0	6	48	240	24	751	22	789	30	54	18	30	4	30	228

SOIL PIT 3

depth	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	9.50	2.44	1.96	3.85	3.48	0.01	0.13	0.00	0.05	13	14	12	4	14	5	0	6	47	220	28	691	25	664	35	56	20	40	4	33	229
10-15cm	13.37	2.48	1.94	3.94	3.89	0.01	0.09	0.00	0.05	13	14	13	4	15	5	0	7	47	223	28	668	27	667	30	48	18	36	4	32	229
20-25cm	12.24	2.35	1.64	4.13	7.16	0.01	0.06	0.00	0.05	13	18	12	4	23	5	0	8	50	203	25	573	31	652	22	49	16	36	4	26	240
30-35cm	10.30	2.51	1.76	4.16	6.64	0.01	0.07	0.00	0.05	13	18	13	5	22	5	0	9	49	217	25	588	30	666	24	48	17	36	4	27	238

SOIL PIT 4

depth	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	12.36	2.59	2.24	3.72	2.74	0.01	0.09	0.00	0.04	14	13	12	5	11	6	0	6	47	228	26	664	24	725	30	51	21	35	4	34	220
10-15cm	11.91	2.78	2.40	4.06	4.55	0.01	0.08	0.00	0.05	13	16	14	5	16	6	0	7	46	251	27	588	27	746	27	58	21	35	4	31	234
20-25cm	15.51	2.28	1.74	4.08	10.95	0.01	0.04	0.00	0.05	12	22	12	5	33	4	0	9	40	223	24	350	31	645	8	47	17	33	4	18	230

SOIL PIT 5

depth	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
0-5cm	12.79	2.39	2.06	3.71	6.61	0.01	0.08	0.00	0.05	14	17	13	4	21	4	0	7	37	205	24	505	28	599	27	54	21	39	4	29	228
10-15cm	13.33	2.25	1.88	3.73	9.82	0.01	0.06	0.00	0.05	14	21	13	4	24	5	0	9	35	198	29	421	30	576	12	54	21	29	4	25	232
20-25cm	21.60	1.68	1.32	4.25	17.83	0.01	0.02	0.00	0.06	13	28	12	3	36	1	0	12	27	158	20	209	36	484	-10	56	16	21	3	10	204

SEQUENTIAL EXTRACTION RESULTS FOR 1995 VM70 SOIL PIT SAMPLES

Exchangeable cation																														
Soil Pit	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0-5cm	0.00	0.02	0.00	0.62	-0.02	-0.01	0.00	0.04	-2	6	0	0	0	3	0	60	5	4	0	6	33	8	33	91	6	1	3	3	282
1	10-15cm	0.00	0.02	0.00	0.6	-0.02	-0.02	0.00	0.04	-2	6	0	0	0	3	0	61	5	4	0	2	33	7	34	99	6	1	3	3	300
2	0-5cm	0.00	0.02	0.00	0.72	-0.02	0.01	0.00	0.04	-2	7	0	0	0	4	0	61	5	5	0	13	35	8	35	103	6	2	3	4	310
2	10-15cm	0.00	0.02	0.00	0.69	-0.02	-0.02	0.00	0.04	-2	7	0	0	0	3	0	61	5	4	0	3	34	9	34	92	6	1	3	4	299
2	20-25cm	0.00	0.02	0.00	0.72	-0.02	-0.02	0.00	0.04	-2	7	0	0	0	4	0	60	5	5	0	4	35	8	34	101	6	1	3	5	307
2	30-35cm	0.00	0.02	0.00	0.73	-0.02	-0.02	0.00	0.04	-2	7	0	0	0	4	0	61	5	4	0	3	34	9	33	101	6	1	3	6	307
3	0-5cm	0.00	0.02	0.00	0.75	-0.01	0.02	0.00	0.04	-1	7	0	0	0	4	0	60	5	5	1	9	36	8	34	94	6	2	3	4	309
3	10-15cm	0.00	0.02	0.00	0.73	-0.01	-0.01	0.00	0.04	-2	7	0	0	0	4	0	60	5	4	0	2	35	8	33	94	6	2	3	4	307
3	20-25cm	0.00	0.02	0.00	0.71	-0.01	-0.01	0.00	0.04	-2	7	0	0	0	4	0	60	5	4	0	1	34	8	33	87	6	2	3	3	290
3	30-35cm	0.00	0.02	0.00	0.72	-0.02	-0.02	0.00	0.04	-2	7	0	0	0	4	0	61	5	4	0	1	35	8	34	83	6	1	3	3	307

Carbonate Bound																													
Soil Pit	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	0-5cm	0.01	0.00	1.05	8.66	7.22	0.06	0.00	0.04	10	20	4	0	25	1	20	3	4	0	82	38	10	0	32	1	2	1	6	288
1	10-15cm	0.00	0.00	1.03	8.25	7.01	0.06	0.00	0.04	10	19	4	0	22	1	20	3	3	0	68	37	9	1	10	1	2	1	6	304
2	0-5cm	0.01	0.00	1.26	0.61	6.93	0.08	0.00	0.02	3	4	1	0	2	1	18	1	0	0	42	15	10	8	27	0	2	1	5	169
2	10-15cm	0.01	0.00	1.11	0.71	6.86	0.08	0.00	0.02	3	4	1	0	2	1	17	1	0	0	24	15	9	9	19	0	1	1	6	168
2	20-25cm	0.01	0.00	1.17	0.76	6.89	0.08	0.00	0.02	3	4	1	0	3	1	17	1	0	0	28	16	10	8	21	0	1	1	6	179
2	30-35cm	0.01	0.00	1.19	0.68	7.08	0.10	0.00	0.02	2	4	3	0	2	1	18	1	0	0	23	15	9	8	27	0	1	1	6	184
3	0-5cm	0.01	0.00	0.88	1.22	7.12	0.04	0.00	0.02	4	6	3	0	4	1	18	2	0	0	44	19	9	10	38	0	2	1	6	198
3	10-15cm	0.01	0.00	1.00	1.68	7.23	0.04	0.00	0.03	4	8	3	0	5	1	18	1	0	0	29	23	9	8	30	0	2	1	6	234
3	20-25cm	0.01	0.00	1.04	3.66	7.15	0.05	0.00	0.03	6	12	3	0	10	1	19	2	1	0	41	29	10	7	14	1	2	1	6	270
3	30-35cm	0.01	0.00	0.98	3.27	7.02	0.05	0.00	0.03	6	11	3	0	9	1	18	2	1	0	35	28	9	7	32	1	1	1	6	263

Fulvic fraction																														
Soil Pit	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0-5cm	0.00	0.00	0.00	0.09	0.58	-0.04	0.00	0.00	2	1	0	0	0	0	0	45	0	0	0	0	2	1	2	28	1	1	0	0	13
1	10-15cm	0.00	0.00	0.00	0.06	0.50	-0.04	0.00	0.00	1	1	0	0	0	0	0	45	0	0	0	0	1	0	2	-1	1	0	0	0	10
2	0-5cm	0.01	0.00	0.01	0.01	0.77	-0.04	0.00	0.00	1	0	0	0	0	0	0	45	0	1	1	3	1	3	2	15	1	1	0	0	-2
2	10-15cm	0.04	0.02	0.03	0.01	0.66	-0.04	0.00	0.00	2	1	0	0	0	0	0	45	1	2	1	8	1	9	3	-1	2	1	0	0	9
2	20-25cm	0.04	0.02	0.03	0.01	0.78	-0.04	0.00	0.00	2	1	0	0	0	0	0	46	0	2	1	7	1	9	3	24	2	1	0	0	4
2	30-35cm	0.09	0.05	0.07	0.02	0.68	-0.04	0.00	0.00	2	1	1	0	0	0	1	44	1	4	2	13	1	19	4	18	2	2	0	1	7
3	0-5cm	0.01	0.01	0.01	0.01	0.40	-0.04	0.00	0.00	2	1	0	0	0	0	0	46	1	1	1	4	0	4	3	8	1	1	0	0	6
3	10-15cm	0.05	0.02	0.03	0.02	0.37	-0.04	0.00	0.00	2	1	0	0	0	0	0	45	1	2	1	8	1	7	3	15	2	1	0	0	6
3	20-25cm	0.04	0.02	0.02	0.02	0.30	-0.04	0.00	0.00	2	1	0	0	0	0	0	45	0	1	1	5	1	5	3	17	2	1	0	0	1
3	30-35cm	0.04	0.02	0.02	0.02	0.42	-0.04	0.00	0.00	2	1	0	0	0	0	0	46	0	1	1	5	1	5	3	13	2	3	0	1	6

SEQUENTIAL EXTRACTION RESULTS FOR 1995 VM70 SOIL PIT SAMPLES

Humic fraction																														
Soil Pit	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0-5cm	0.01	0.00	0.01	0.00	0.52	-0.01	0.00	0.66	-1	0	0	0	0	0	0	61	0	0	0	-1	0	0	1	0	11	0	0	0	-2
1	10-15cm	0.01	0.00	0.02	0.00	0.52	-0.01	0.00	0.66	-1	0	0	0	0	0	0	61	0	0	-1	0	0	2	-1	7	0	0	0	4	
2	0-5cm	0.03	0.02	0.06	0.00	0.53	0.00	0.00	0.66	-1	0	0	0	0	0	0	60	1	5	0	3	0	10	-1	3	0	0	0	3	
2	10-15cm	0.22	0.16	0.37	0.00	0.60	0.00	0.00	0.67	0	0	1	0	0	0	0	60	2	26	0	14	2	69	2	-5	1	3	0	24	
2	20-25cm	0.19	0.12	0.33	0.00	0.59	0.00	0.00	0.66	0	0	1	0	0	0	0	60	2	22	0	12	1	60	2	12	1	2	0	19	
2	30-35cm	0.63	0.59	0.97	0.01	0.82	0.01	0.00	0.89	0	0	3	1	0	0	0	60	6	68	2	35	5	186	8	23	4	8	1	56	
3	0-5cm	0.06	0.05	0.06	0.00	0.53	0.00	0.00	0.66	1	0	1	0	0	0	0	61	1	8	0	3	0	15	1	-6	0	1	0	6	
3	10-15cm	0.25	0.17	0.34	0.00	0.57	0.00	0.00	0.66	0	0	1	0	0	0	0	60	3	25	0	13	1	68	3	-1	1	3	0	16	
3	20-25cm	0.18	0.11	0.26	0.00	0.54	0.00	0.00	0.64	0	0	1	0	0	0	0	60	2	17	0	8	2	52	2	10	1	2	0	17	
3	30-35cm	0.22	0.15	0.31	0.00	0.59	0.00	0.00	0.68	0	0	1	0	0	0	0	61	2	21	0	11	1	63	2	22	1	5	0	21	

Secondary Manganese Oxide																														
Soil Pit	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0-5cm	0.00	0.00	0.04	0.47	0.06	0.00	0.00	0.01	2	3	1	0	2	0	0	17	1	-1	0	54	8	2	2	10	0	1	0	2	63
1	10-15cm	0.00	0.00	0.03	0.38	0.06	0.00	0.00	0.01	1	2	0	0	1	0	0	17	2	-1	0	83	7	3	2	5	0	1	0	2	52
2	0-5cm	0.00	0.00	0.04	0.03	0.26	0.00	0.00	0.00	0	0	0	0	0	0	0	16	1	0	0	85	1	3	0	3	0	0	0	2	-3
2	10-15cm	0.00	0.00	0.03	0.03	0.27	0.00	0.00	0.00	0	0	0	0	0	0	0	16	1	-1	0	139	1	3	0	16	0	0	0	2	0
2	20-25cm	0.00	0.00	0.04	0.03	0.27	0.00	0.00	0.00	0	0	0	0	0	0	0	16	1	-1	0	135	1	3	0	5	0	0	0	2	3
2	30-35cm	0.00	0.00	0.03	0.03	0.24	0.00	0.00	0.00	0	0	0	0	0	0	0	16	2	-1	0	162	1	5	0	14	0	1	0	2	-2
3	0-5cm	0.00	0.00	0.03	0.05	0.25	0.00	0.00	0.00	0	1	0	0	0	0	0	17	1	0	0	102	1	2	1	-3	0	1	0	2	8
3	10-15cm	0.00	0.00	0.03	0.06	0.22	0.00	0.00	0.00	0	1	0	0	0	0	0	17	1	-1	0	136	2	3	1	10	0	1	0	2	7
3	20-25cm	0.00	0.00	0.03	0.11	0.19	0.00	0.00	0.00	0	1	0	0	0	0	0	18	1	-1	0	127	3	2	1	25	0	1	0	2	20
3	30-35cm	0.00	0.00	0.02	0.11	0.20	0.00	0.00	0.00	0	1	0	0	0	0	0	17	2	-1	0	138	2	3	0	21	0	1	0	2	14

Secondary Iron Oxides																														
Soil Pit	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As	
1	0-5cm	0.10	0.09	0.06	0.00	0.00	0.00	0.00	0.01	0	0	0	0	0	0	0	16	4	3	3	36	1	25	1	7	1	3	0	0	6
1	10-15cm	0.07	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	15	3	1	2	26	1	18	0	16	1	1	0	0	3
2	0-5cm	0.10	0.06	0.07	0.00	0.02	0.00	0.00	0.00	0	0	0	0	0	0	1	15	4	1	3	156	1	39	2	16	2	4	0	2	9
2	10-15cm	0.09	0.06	0.06	0.00	0.02	0.00	0.00	0.00	0	0	0	0	0	0	1	15	7	1	3	168	0	44	1	14	2	3	0	1	6
2	20-25cm	0.09	0.06	0.06	0.00	0.02	0.00	0.00	0.00	0	0	0	0	0	0	1	16	7	1	4	154	0	42	1	14	2	2	0	1	9
2	30-35cm	0.12	0.09	0.08	0.00	0.02	0.00	0.00	0.00	0	0	0	0	0	0	1	16	11	3	5	223	1	70	1	13	3	3	0	1	19
3	0-5cm	0.12	0.07	0.05	0.00	0.02	0.00	0.00	0.01	1	0	0	0	0	0	1	16	4	2	4	160	1	41	3	7	3	3	0	1	16
3	10-15cm	0.13	0.09	0.06	0.00	0.02	0.00	0.00	0.01	1	0	0	1	0	0	1	16	8	3	6	176	1	52	2	0	3	3	0	1	9
3	20-25cm	0.13	0.08	0.05	0.00	0.01	0.00	0.00	0.01	0	0	0	1	0	0	1	15	9	2	5	123	1	46	2	9	4	3	0	1	9
3	30-35cm	0.15	0.10	0.06	0.00	0.01	0.00	0.00	0.01	0	0	0	1	0	0	1	15	9	3	6	140	0	54	2	4	4	2	0	1	3

SEQUENTIAL EXTRACTION RESULTS FOR 1995 VM70 SOIL PIT SAMPLES

Residual (pseudo-total)																															
Soil Pkt	Depth	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As		
1	0-5cm	1.89	2.55	6.04	0.46	0.00	0.04	0.01	0.04	4	4	17	4	3	1	20	29	260	13	170	23	646	27	41	14	25	6	5	224		
1	10-15cm	2.07	2.58	5.54	0.41	0.00	0.05	0.01	0.03	4	4	16	5	2	2	20	31	265	14	197	23	650	26	58	15	23	6	5	205		
2	0-5cm	2.65	3.12	4.61	0.14	0.01	0.10	0.00	0.03	7	5	15	6	2	3	20	38	287	17	312	20	721	32	53	19	35	6	12	178		
2	10-15cm	2.48	2.94	4.48	0.13	0.01	0.08	0.01	0.03	8	4	14	5	1	3	20	35	276	16	292	18	690	30	48	19	30	6	11	169		
2	20-25cm	2.79	3.31	4.97	0.14	0.01	0.09	0.01	0.03	8	5	16	6	2	3	20	39	308	22	339	22	756	32	43	21	34	7	13	178		
2	30-35cm	2.53	3.01	4.68	0.14	0.01	0.08	0.01	0.03	8	5	15	5	2	3	19	33	288	15	246	19	690	30	41	19	30	6	10	186		
3	0-5cm	1.75	1.78	2.77	0.15	0.01	0.05	0.00	0.03	6	4	9	4	1	3	18	30	180	13	205	15	479	28	37	13	27	4	10	136		
3	10-15cm	1.59	1.61	2.67	0.16	0.01	0.04	0.00	0.02	6	4	8	3	1	3	18	28	172	12	190	15	457	23	41	12	23	4	10	133		
3	20-25cm	1.61	1.54	2.96	0.21	0.01	0.04	0.00	0.02	5	4	8	3	1	2	18	30	174	12	167	15	486	21	41	11	24	3	7	143		
3	30-35cm	2.65	2.68	4.17	0.29	0.01	0.08	0.01	0.03	7	5	13	6	2	3	19	37	281	16	214	21	663	30	45	17	36	6	10	203		

CN11 SURFACE SAMPLES

MAIN GRID

Sample	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Ba	As
1	5.02	3.24	2.86	1.52	12.77	0.01	0.41	0.00	0.10	35	35	28	5	126	9	-13	44	17	55	34	677	18	113	18	20	31	60	204	40
2	7.15	3.27	2.86	1.59	13.10	0.01	0.40	0.00	0.10	35	35	30	5	130	9	-13	44	17	55	34	669	17	116	18	21	31	65	189	36
3	6.82	3.25	2.98	1.60	13.02	0.01	0.44	0.00	0.12	35	35	32	5	138	9	-13	45	17	52	35	656	18	109	17	24	30	67	167	35
4	5.79	3.57	3.12	1.60	13.44	0.01	0.40	0.00	0.10	35	35	33	6	135	9	-13	44	17	53	35	630	18	104	17	20	33	66	151	35
5	7.39	3.29	2.88	1.50	13.65	0.01	0.37	0.00	0.10	34	35	32	5	136	8	-13	44	16	48	34	641	18	94	13	21	32	63	144	35
6	8.70	3.32	2.88	1.49	13.49	0.01	0.45	0.00	0.11	35	35	28	5	136	9	-13	43	17	53	34	659	18	109	17	19	30	62	214	32
7	7.78	3.43	3.03	1.60	14.22	0.01	0.43	0.00	0.11	36	37	31	6	142	9	-13	46	18	56	35	661	19	116	18	23	32	66	205	39
8	6.93	2.99	2.66	1.49	14.38	0.01	0.39	0.00	0.11	34	37	29	5	144	8	-13	45	16	49	33	633	18	110	13	26	30	62	187	25
9	8.45	2.91	2.57	1.44	14.54	0.01	0.39	0.00	0.11	34	37	28	5	140	8	-13	44	16	46	32	641	19	102	11	20	29	61	155	25
10	7.02	3.24	2.78	1.43	13.92	0.01	0.39	0.00	0.11	34	36	30	5	144	9	-13	44	16	46	33	647	18	92	12	19	31	62	147	35
11	5.12	3.09	2.77	1.43	12.85	0.01	0.48	0.00	0.11	34	35	28	5	129	9	-13	45	16	49	36	683	17	103	16	22	29	63	215	41
12	7.82	3.22	2.85	1.47	13.97	0.01	0.38	0.00	0.10	34	36	30	5	136	8	-13	44	16	50	33	626	18	101	14	21	31	61	200	29
13	7.28	3.18	2.85	1.48	13.96	0.01	0.41	0.00	0.11	34	36	30	5	140	8	-13	45	16	49	34	632	18	100	17	20	29	63	214	31
14	7.97	2.86	2.47	1.36	16.50	0.01	0.39	0.00	0.11	34	49	26	5	163	8	-13	45	16	46	32	627	19	104	7	17	28	58	188	11
15	10.68	2.70	2.36	1.31	15.27	0.01	0.35	0.00	0.10	34	61	27	5	163	9	-13	46	15	41	29	677	18	93	8	21	27	58	148	12
16	10.09	3.24	2.78	1.38	12.93	0.01	0.42	0.00	0.10	37	37	27	5	135	10	-13	45	17	47	34	711	19	95	16	17	32	63	279	39
17	7.24	3.08	2.63	1.37	15.05	0.01	0.39	0.00	0.11	34	37	27	5	146	9	-13	45	16	48	34	633	19	100	12	21	29	59	231	24
18	7.62	2.53	2.16	1.16	15.95	0.01	0.31	0.00	0.10	31	36	23	4	156	7	-13	45	14	40	28	536	18	86	4	22	26	49	197	11
19	8.57	2.19	1.83	1.11	18.89	0.01	0.27	0.00	0.10	31	39	23	4	175	7	-13	46	13	34	25	501	19	81	-6	20	23	45	197	-15
20	7.55	2.66	2.39	1.25	16.20	0.01	0.33	0.00	0.10	31	36	28	4	164	7	-13	46	14	38	30	496	18	79	1	18	26	52	168	7
21	7.84	3.21	2.69	1.29	13.70	0.01	0.38	0.00	0.09	36	36	26	5	156	9	-13	45	15	44	34	663	18	86	13	24	30	59	295	30
22	6.59	2.84	2.44	1.25	14.71	0.01	0.37	0.00	0.10	34	37	25	5	150	9	-13	44	15	44	31	632	18	91	9	20	28	54	243	21
23	9.52	2.53	2.10	1.16	19.14	0.01	0.30	0.00	0.10	32	40	25	4	174	7	-13	46	14	38	29	498	19	81	-3	17	26	47	226	-9
24	8.52	2.18	1.79	1.04	22.52	0.01	0.24	0.00	0.09	31	43	24	4	195	6	-13	47	12	30	26	420	20	63	-14	19	22	40	217	-31
25																													

Samples collected from a 5 x 5 sample grid. Numbering starts in bottom left corner and progresses horizontally.

TRANSECTS

Sample	% <212 um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	Ti2O	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Ba	As
1	7.58	3.40	3.06	1.51	12.83	0.01	0.34	0.00	0.10	35	35	35	6	152	9	-13	44	16	47	36	705	19	87	15	24	30	65	136	41
2	6.16	3.16	2.93	1.49	12.33	0.01	0.31	0.00	0.10	35	34	34	5	147	9	-13	46	16	45	36	748	18	91	15	24	30	66	144	38
3	6.54	3.39	3.16	1.54	11.12	0.01	0.33	0.00	0.10	35	33	35	6	137	9	-13	45	16	48	37	712	18	91	18	23	33	69	145	51
4	6.68	2.77	2.52	1.45	11.35	0.01	0.26	0.00	0.09	34	32	34	5	132	9	-13	44	16	40	29	722	17	87	14	21	27	65	142	42
5	6.21	2.60	2.41	1.33	12.50	0.01	0.22	0.00	0.08	32	33	33	5	131	8	-13	44	15	38	28	674	17	79	9	21	26	61	131	29
6	6.35	3.22	3.01	1.39	12.96	0.01	0.28	0.00	0.09	33	34	34	5	135	8	-13	44	15	44	37	675	18	80	11	21	29	64	132	32
7	7.34	3.35	3.06	1.39	13.36	0.01	0.27	0.00	0.09	34	35	34	6	139	8	-13	45	15	47	36	675	18	85	11	19	31	64	136	32
8	6.41	3.42	3.08	1.42	13.58	0.01	0.34	0.00	0.10	35	36	33	6	143	9	-13	44	16	51	35	718	18	96	12	23	31	65	142	33
9	4.86	3.32	2.90	1.28	13.67	0.01	0.38	0.00	0.10	38	38	29	5	133	11	-13	46	18	56	33	764	18	121	14	24	30	63	140	33
10	7.12	3.00	2.49	1.00	12.48	0.01	0.35	0.00	0.10	38	37	21	5	110	12	-13	45	18	58	27	704	17	131	14	16	30	53	118	30
11	7.79	3.46	3.09	1.54	11.79	0.01	0.39	0.00	0.10	35	34	34	6	134	9	-13	43	16	49	38	747	18	94	17	21	31	66	141	48
12	6.69	3.21	2.91	1.49	12.06	0.01	0.34	0.00	0.10	34	34	34	5	138	9	-13	44	16	45	38	741	18	90	14	26	31	65	141	38
13	6.35	3.56	3.20	1.56	11.21	0.01	0.36	0.00	0.10	35	33	36	6	122	9	-13	44	17	49	39	747	18	92	18	23	34	68	143	49
14	6.74	3.48	3.18	1.53	11.38	0.01	0.34	0.00	0.10	35	33	35	6	125	9	-13	44	16	48	39	715	17	90	18	21	33	68	143	46
15	6.49	3.05	2.86	1.40	12.17	0.01	0.28	0.00	0.09	33	34	33	5	130	9	-13	44	16	43	35	708	17	84	13	23	29	64	138	36
16	5.76	3.42	3.13	1.46	13.18	0.01	0.30	0.00	0.10	35	35	35	6	140	9	-13	45	16	48	37	713	18	88	13	27	32	67	142	35
17	6.80	3.49	3.14	1.44	13.05	0.01	0.30	0.00	0.09	35	35	34	6	138	9	-13	44	16	49	36	701	18	89	14	26	33	65	137	43
18	6.09	3.32	2.99	1.41	12.84	0.01	0.33	0.00	0.10	34	35	33	5	135	9	-13	45	16	49	35	702	18	95	13	22	32	64	141	40
19	7.53	3.87	3.22	1.32	13.82	0.01	0.44	0.00	0.11	41	39	29	6	130	11	-13	46	20	66	33	821	19	138	17	20	37	65	143	38
20	6.76	3.77	3.15	1.17	13.52	0.01	0.38	0.00	0.09	41	39	25	6	111	11	-13	45	20	68	31	765	19	149	17	18	33	59	128	40

Samples collected from a 10 x 2 sample transect. Numbering starts at bottom left and progresses along the long horizontal axis.

VM87 SURFACE SAMPLES

Sample	% <212um	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	Ce	La	Li	Sc	Sr	Y	Ag	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	V	Zn	Cd	Ba	As
1	6.62	4.32	5.16	3.80	3.43	0.01	0.21	0.00	0.07	37	28	24	11	17	9	-115	100	49	253	41	1029	22	504	66	7	58	55	-3	39	28
2	5.60	5.02	5.85	3.57	3.67	0.02	0.18	0.00	0.07	34	28	28	12	17	10	-114	101	45	283	44	937	23	474	59	4	64	50	-3	36	24
3	7.28	5.03	5.81	3.73	3.20	0.01	0.22	0.00	0.07	36	27	27	12	17	10	-115	99	49	280	44	1018	23	493	66	6	63	55	-3	39	28
4	8.95	4.56	5.33	3.64	3.53	0.01	0.19	0.00	0.07	36	29	25	11	17	10	-115	99	47	257	42	989	22	481	63	7	59	52	-3	38	25
5	8.12	4.69	5.45	3.70	4.12	0.01	0.20	0.00	0.07	36	29	26	12	18	9	-115	100	46	263	43	960	24	480	63	10	61	53	-3	38	20
6	7.98	5.03	5.72	3.62	3.45	0.01	0.23	0.00	0.08	36	28	27	12	16	10	-115	99	45	275	43	951	23	476	67	7	63	54	-3	38	26
7	6.59	4.63	5.40	3.47	2.89	0.01	0.22	0.00	0.08	36	26	25	11	15	10	-115	100	45	257	44	961	21	465	63	8	61	54	-3	39	27
8	8.68	5.09	5.77	3.78	4.12	0.01	0.23	0.01	0.08	36	29	28	13	18	9	-115	100	48	286	42	999	24	491	65	4	64	53	-3	37	19
9	9.08	4.91	5.80	3.78	3.29	0.01	0.20	0.00	0.07	39	28	27	12	18	10	-113	101	51	281	43	1097	23	513	67	5	62	54	-3	40	26
10	6.32	4.18	5.11	3.45	2.75	0.01	0.16	0.00	0.07	40	26	26	12	16	10	-114	101	50	243	40	1094	21	485	62	5	57	51	-3	40	26
11	8.78	4.71	5.66	3.55	2.66	0.01	0.19	0.00	0.07	40	26	27	12	15	10	-114	101	51	269	42	1093	22	497	69	6	60	54	-3	41	31
12	8.43	4.96	5.83	3.61	2.59	0.01	0.21	0.00	0.07	39	26	27	12	15	10	-113	102	51	274	42	1088	21	502	71	9	65	55	-3	41	25
13	9.21	4.88	5.82	3.58	2.61	0.01	0.19	0.00	0.07	40	26	27	12	15	11	-113	102	51	278	42	1105	22	503	70	5	58	55	-3	42	28
14	8.08	4.59	5.50	3.50	2.64	0.01	0.18	0.00	0.07	40	27	25	11	15	10	-113	102	49	259	41	1073	21	489	66	6	58	54	-3	41	27
15	6.25	4.92	5.66	3.78	5.41	0.02	0.20	0.01	0.07	36	32	28	12	20	9	-114	103	46	283	41	932	26	494	62	3	62	51	-3	37	21
16	8.61	4.51	5.39	3.69	4.15	0.01	0.17	0.00	0.07	39	29	26	11	18	10	-114	102	50	264	40	1056	23	496	62	8	60	50	-3	38	31
17	8.29	4.00	4.90	3.46	2.90	0.01	0.14	0.00	0.06	40	26	23	10	16	10	-114	102	52	236	39	1125	20	488	62	6	56	49	-3	39	27
18	7.72	4.63	5.55	3.55	2.67	0.01	0.18	0.00	0.07	41	26	25	11	16	11	-113	102	52	265	42	1121	22	500	71	6	62	53	-3	41	28
19	7.83	4.60	5.56	3.44	2.16	0.01	0.18	0.00	0.07	42	25	25	11	14	11	-113	102	53	261	41	1172	20	497	68	3	61	54	-3	42	22
20	7.55	4.03	4.85	3.21	1.93	0.01	0.15	0.00	0.06	41	24	22	10	14	11	-113	102	51	227	40	1144	19	471	62	9	55	51	-3	42	29
21	9.13	5.46	6.90	3.26	1.90	0.01	0.15	0.00	0.07	39	24	27	14	14	12	-13	77	50	304	48	1108	19	459	62	44	72	52	-5	42	61
22	8.16	4.60	5.15	3.54	8.73	0.02	0.19	0.01	0.08	36	38	27	12	23	8	-114	102	41	263	38	806	27	452	52	4	58	46	-3	34	4
23	9.18	4.72	5.63	3.75	3.98	0.01	0.18	0.01	0.07	38	29	27	12	18	10	-114	102	50	276	42	1039	24	503	66	2	63	51	-3	38	29
24	7.49	4.44	5.24	3.66	3.51	0.01	0.17	0.00	0.07	39	28	25	11	18	10	-113	102	50	260	40	1067	23	495	66	8	61	50	-3	38	28
25	8.24	4.78	5.68	3.66	3.03	0.01	0.19	0.00	0.07	41	27	26	12	16	10	-113	102	52	271	42	1129	22	504	71	3	63	53	-3	41	30
26	8.81	4.72	5.66	3.46	2.13	0.01	0.20	0.00	0.07	42	26	25	12	15	11	-113	103	53	264	42	1166	21	497	70	3	63	55	-3	43	29
27	9.71	4.87	5.83	3.45	1.89	0.01	0.20	0.00	0.06	43	25	26	12	15	11	-113	102	50	239	43	1182	21	498	69	6	65	56	-4	44	31
28	7.93	4.27	5.19	3.26	1.83	0.01	0.17	0.00	0.06	40	24	23	10	15	11	-113	102	50	269	43	1106	19	473	63	9	59	52	-3	41	30
29	7.96	4.25	4.95	3.52	7.11	0.02	0.16	0.00	0.07	36	35	26	11	22	9	-114	103	42	248	39	837	25	456	51	6	56	46	-2	34	13
30	8.62	4.46	5.26	3.67	6.32	0.01	0.17	0.00	0.07	37	34	26	11	21	9	-113	103	46	263	39	918	26	479	57	6	58	48	-3	36	15
31	7.13	3.48	4.25	3.36	5.20	0.01	0.11	0.00	0.06	37	31	22	8	21	9	-114	103	46	209	35	981	21	447	52	6	52	43	-2	35	18
32	8.13	4.47	5.36	3.80	4.51	0.02	0.18	0.00	0.08	38	31	26	11	19	10	-113	102	48	261	41	1025	24	494	65	9	60	51	-3	38	23
33	7.90	4.26	5.14	3.56	3.31	0.01	0.16	0.00	0.07	40	28	24	11	17	10	-113	102	51	247	40	1139	22	489	66	7	59	51	-3	40	26
34	10.12	4.41	5.38	3.40	2.10	0.01	0.17	0.00	0.06	43	25	24	11	15	11	-113	101	54	250	40	1217	21	489	66	5	60	53	-3	43	30
35	7.68	5.15	6.05	3.51	2.15	0.01	0.22	0.00	0.07	42	26	28	13	16	11	-113	102	51	281	44	1143	22	499	72	0	67	58	-4	43	30
36	9.37	4.30	4.93	3.60	7.11	0.01	0.15	0.00	0.07	30	31	25	11	23	9	-14	77	40	241	38	813	20	448	36	27	55	45	-3	58	39
37	9.47	4.23	5.05	3.70	5.56	0.01	0.14	0.00	0.07	32	28	24	10	22	9	-14	77	44	242	38	925	19	468	41	26	56	46	-4	62	50
38	9.49	4.59	5.37	3.70	4.78	0.01	0.16	0.00	0.07	31	27	25	12	21	9	-14	77	43	257	39	913	19	468	47	28	61	48	-4	62	49
39	8.16	3.88	4.61	3.62	5.13	0.01	0.12	0.00	0.07	32	28	22	9	21	9	-14	76	43	221	39	946	19	459	43	33	56	46	-3	61	45
40	7.14	4.07	3.73	3.73	4.38	0.01	0.13	0.00	0.08	33	26	22	10	19	10	-14	76	46	230	40	1040	19	480	47	29	57	48	-3	63	48
41	6.93	4.13	4.92	3.41	2.92	0.01	0.14	0.00	0.07	33	23	21	10	16	9	-14	77	46	231	38	1064	17	459	49	32	55	47	-4	63	52
42	8.85	4.69	5.59	3.71	2.55	0.01	0.17	0.00	0.07	38	23	24	12	17	11	-14	78	53	259	43	1236	18	509	55	29	61	54	-4	72	57
43	6.53	4.81	5.30	3.87	7.07	0.01	0.21	0.00	0.08	29	31	28	12	26	9	-14	78	38	260	41	795	21	451	41	33	57	50	-4	58	39
44	9.34	5.14	5.78	3.86	4.85	0.01	0.20	0.00	0.07	31	28	28	13	22	9	-14	78	43	280	42	894	20	485	49	33	60	52	-4	64	55
45	6.35	4.57	5.38	3.71	4.73	0.01	0.16	0.00	0.07	33	27	25	11	21	9	-14	78	45	257	40	971	20	468	48	30	58	49	-4	62	55
46	7.98	4.38	5.19	3.74	3.80	0.01	0.14	0.00	0.07	34	26	23	11	18	10	-14	78	48	247	42	1063	19	491	50	28	60	50	-3	66	52
47	12.25	5.10	5.94	3.95	3.43	0.01	0.19	0.00	0.08	35	25	27	13	18	10	-14	78	50	283	43	1099	19	514	58	29	63	54	-4	67	61
48	7.84	4.59	5.42	3.73	2.87	0.01	0.16	0.00	0.07	34	24	24	11	16	10	-14	78	48	257	42	1080	18	499	53	53	52	52	-4	66	52
49	7.44	5.03	5.87	3.90	2.86	0.01	0.18	0.00	0.08	36	24	26	13	17	10	-14	78	52	278	44	1226	18	522	57	34	65	55	-4	70	59

Samples collected from a 7 x 7 sample grid. Numbering starts from the bottom left corner and progresses along the horizontal axis.

