The petrology and structure of the tertiary volcanic rocks of west-central Skye, N. W. Scotland

Williamson, Ian T.

THE PETROLOGY AND STRUCTURE OF THE TERTIARY VOLCANIC ROCKS OF WEST-CENTRAL SKYE, N.W. SCOTLAND

Ian T. Williamson B.Sc. (Edinburgh)

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ABSTRACT

An area of approximately 125 square kilometres of Lower Tertiary volcanic and associated intrusive igneous rocks in the Minginish district of west-central Skye was investigated.

Detailed mapping of the lava field revealed that it was possible to divide the volcanic sequence into a series of units or groups; each characterised by associations of lava types and separated from one another by locally developed pyroclastic and sedimentary rocks including fluvial conglomerates. The nature, provenance and regional implications of the presence of various clasts within the conglomerates is discussed. Penecontemporaneous, subaerially weathered flow tops and fossil lateritic soils were also recognised and investigated. An overall volcanic stratigraphy is established and structural aspects are considered.

Whole-rock and primary mineral chemical data indicate that the majority of lavas belong to mildly alkaline to transitional alkaline (basalt-hawaiite-mugearite-benmoreite-trachyte) suites but that rare tholeiites and true transitional basalts are also present. Comparisons with other Hebridean suites points to important regional variations. The wide spectrum and locally almost random distribution of lava types encountered in these suites and the presence of tholeiites late in the Skye suite implies a rather complex petrogenesis. This is reasoned to have involved various

criteria, the most important of which were probably differing degrees of progressive partial and batch melting of a predominantly garnet lherzolite upper mantle, varying ascent rates, polybaric crystal fractionation, re-equilibration of high-pressure phase to relatively low-pressure ones in an intricate series of upper crustal magma reservoirs, crustal contamination and possibly also batch mixing. The structure and petrology of the minor intrusions and immediately adjacent plutonic rocks is also considered and an overall igneous sequence postulated.

The volcanic sequence was variously affected by zeolite facies metamorphism resulting in the wide-spread systematic deposition of zeolite and associated mineral assemblages in vesicles and veins; a large-scale hydrothermal circulatory system having been established in the area subsequent to burial. Superimposed upon this is a thermal-metasomatic, contact aureole developed around the Cuillin Hills Intrusive Complex. In this aureole, a narrow, irregular zone of high-grade basaltic hornfels is succeeded outwards by zones characterised by the appearance of distinctive mineral assemblages at the expense of primary minerals and in the amygdales. The metamorphism is not considered to have been one of progressive change; each zone therefore developing independently. Consideration of the geochemical data for the meta-volcanics indicates that some degree of mobilisation of certain elements normally considered relatively unaffected under such conditions, characterises the aureole.

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TABLE OF CONTENTS

		Page
Abstract		i
Acknowledgements		iii
Table of Contents		v
List of Plates		xiii
List of Figures		xvii
List of Tables		xxi
Chapter 1.	Introduction	1
1.1.	Location and scope of study	1
1.2.	History of Research	1
1.3.	Physiogeography	12
1.4.	Superficial Deposits and Economic Geology	13
1.4.i)	Boulder Clay and Glacial Sands	13
1.4.ii)	Glacial Erratics	14
1.4.iii)	Raised Beaches	14
1.4.iv)	Beach Sands	15
1.4.v)	Peat	15
1.4.vi)	River Gravels	16
1.4.vii)	Alluvium	16
1.4.viii)	Fresh Water	16
Chapter 2.	Pre-Tertiary Sedimentary Rocks	18
Chapter 3.	Tertiary Volcaniclastics and other sediments	21
3.1.	Pyroclastic Rocks within or connected with vents	21
3.2.	Pyroclastic Rocks not associated with or outwith vents	24
3.3.	Conglomerates and sandstones	29

			Page
	3.3.i)	Occurrence	29
	3.3.ii)	Interpretation and Discussion	37
	3.4.	Lacustrine mudstones and laminated ashes	43
	3.5.	The Stratigraphy of the Tertiary Sediments	46
Chapter	4.	Tertiary Intrusive Igneous Rocks	48
	4.1.	Basic and Intermediate Dykes	48
	4.2.	Inclined sheets and Cone-sheets	53
	4.2.i)	Inclined sheets	53
	4.2.ii)	Cone Sheets	55
	4.3.	The Gabbros	56
	4.3.i)	The Outer Gabbros	56
	4.3.ii)	The Form of the Gabbro-Lava contact in west-central Skye	57
	4.3.iii)	The Gabbro plug of Loch Brittle	60
	4.4.	The Ultrabasics	61
	4.4.i)	The Peridotite Boss of An Sguman	61
	4.4.ii)	Ultrabasic Dykes and Sills	62
	4.5.	The Acidic Intrusions of Glen Brittle and Late-stage veins	63
	4.5.i)	The Felsites of Glen Brittle	63
	4.5.ii)	The Acid Dyke of East Loch Brittle	64
	4.5.iii)	Late-stage veins	64
	4.6.	Intrusion Breccias	65
	4.7.	Intrusive History	66
Chapter	5.	The Structural Aspects of the Volcanic Field	68
	5.1.	The Indination of the Volcanics	68
	5.2.	The Fault Systems	71
	5.3.	Structure of the Tertiary Dyke Swarm	74

			Page
Chapter	6.	<u>The Tertiary Lavas</u>	75
	6.1.	Structural Aspects of Individual Flows	75
	6.1.i)	Dimensions of Flows	75
	6.1.ii)	Structures Association with the Upper and Lower Surfaces of Flows	83
	6.1.ii)A	Amygdaloidal Structures	85
	6.1.ii)B	Lateritic Soils and the reddening of exposed upper surfaces	89
	6.1.iii)	Flow Structures	91
	6.1.iv)	Jointing within Individual Lavas	94
	6.1.iv)A	Columnar and Block Jointing	94
	6.1.iv)B	Other Jointing Systems	99
	6.2.	The Stratigraphy of the Tertiary Lavas	103
	6.2.i)	The Meacnaish Group	113
	6.2.ii)	The Bualintur Group	114
	6.2.iii)	The Cruachan Group	115
	6.2.iv)	The Tusdale Group	116
	6.2.v)	The Arnaval Group	117
	6.2.vi)	The Loch Dubh Group	121
	6.2.vii)	The Talisker Group	122
	6.3.	The Secondary Mineralisation associated with the Volcanics	122
	6.3.i)	Introduction	122
	6.3.ii)	Occurrence	123
	6.3.iii)	Order of Deposition of Amygdale Minerals	129
	6.3.iv)	The Timing and Origins of Zeolitisation	131
	6.3.v)	Applications of the Zeolites and Zeolitic Zones	133
Chapter	7.	<u>The Petrography of the Tertiary Volcanics and Associated Rocks</u>	137
	7.1.	Petrography of the Lavas	137
	7.1.i)	Basalts	137

Page

7.1.i)A Olivine and Spinel Porphyritic Basalts 139

7.1.i)B Olivine Porphyritic Basalts 145

7.1.i)C Olivine + Plagioclase Porphyritic Basalts 148

7.1.i)D Clinopyroxene Porphyritic Basalts 153

7.1.i)E Olivine + Plagioclase + Clino- pyroxene Porphyritic Basalts 155

7.1.i)F Plagioclase Macroporphyritic Basalts 160

7.1.i)G Aphyric Basalts 164

7.1.i)H Olivine + Plagioclase Porphyritic Olivine Tholeiite of Talisker 165

7.1.ii) Hawaiites 177

7.1.ii)A Olivine + Plagioclase + Magnetite Microporphyritic Hawaiites 178

7.1.ii)B Olivine + Plagioclase Micro- porphyritic Hawaiites 183

7.1.ii)C Coarse-grained and Transitional Hawaiites 184

7.1.ii)D Aphyric Hawaiites 187

7.1.ii)E Plagioclase Macroporphyritic Hawaiites 188

7.1.ii)F The Composite Hawaiite of Dun Ard an t-Sabhail 196

7.1.iii) Mugearites 203

7.1.iii)A Olivine + Plagioclase + Magnetite Microporphyritic Mugearites 205

7.1.iii)B Coarse-grained Mugearites 211

7.1.iii)C Olivine + Magnetite Micro- porphyritic 212

7.1.iii)D Aphyric Mugearites 214

7.1.iii)E Plagioclase Macroporphyritic Mugearites 214

7.1.iv) Benmoreites 215

7.1.v) Trachytes 216

			Page
	7.2.	Petrography of the Intrusive Igneous Rocks	228
	7.2.i)	Dykes	229
	7.2.i)A	Ultrabasic and Picritic Dykes	229
	7.2.i)B	Basaltic Dykes	236
	7.2.i)C	Intermediate Dykes	239
	7.2.i)D	Acid Intermediate Dykes	241
	7.2.ii)	Inclined Basic Sheets	244
	7.2.iii)	Large Basic-Intermediate Sills	245
	7.2.iv)	Felsites and Granophyres	249
	7.2.v)	Intrusion Breccias, Marginal Gabbros and Peridotites	252
	7.3.	The Petrography of the Tertiary Sediments and Pyroclastics associated with the Volcanic Series.	261
	7.3.i)	Pebbles in the Conglomerates and Associated Sandstones	261
	7.3.ii)	Tuffaceous Interlava horizons	272
	7.3.iii)	Boles and fine-grained Sediments	276
Chapter	8.	The Mineralogy of the Tertiary Lavas	280
	8.1.	Olivines	280
	8.1.i)	Basaltic Olivines	282
	8.1.ii)	Intermediate Lava Olivines	284
	8.1.iii)	Minor Element Variation within the Olivine Series	288
	8.1.iii)A	Al_2O_3	288
	8.1.iii)B	TiO_2	289
	8.1.iii)C	Na_2O	290
	8.1.iii)D	MnO	290
	8.1.iii)E	NiO	291
	8.1.iii)F	CaO	294
	8.2.	Pyroxenes	296
	8.2.i)	Major Element Variation	297

			Page
	8.2.i)A	Basalts	297
	8.2.i)B	Intermediates	300
	8.2.ii)	Minor Element Variation	301
	8.2.ii)A	TiO_2	305
	8.2.ii)B	Al_2O_3	307
	8.2.ii)C	Na_2O	309
	8.2.ii)D	MnO	310
	8.2.ii)E	Cr_2O_3 and NiO	312
	8.2.iii)	Orthopyroxenes	313
	8.3.	Feldspars	315
	8.3.i)	Major Element Variation	316
	8.3.ii)	Minor Element Variation	322
	8.4.	Iron-Titanium and Chromium Oxides	322
	8.4.i)	Chrome-Spinels	325
	8.4.ii)	Titaniferous Magnetites	329
	8.4.iii)	Ilmenites	332
	8.4.iv)	Hercynite Spinel	333
	8.5.	Biotites and Amphiboles	335
	8.6.	Accessory Minerals	337
Chapter	9.	Geochemistry of the Tertiary Volcanics and Associated Rocks	339
	9.1.	Introduction	339
	9.1.i)	Sampling	341
	9.1.ii)	Sample preparation and analysis	342
	9.2.	Classification	348
	9.3.	Chemical Variation and Petrogenesis of the Lavas and Intrusions	351
	9.3.i)	The Alkalic Suite	352
	9.3.ii)	The Sub-Alkalic Suite	403
	9.3.iii)	The Transitional Suite	406
	9.3.iv)	The Tholeiitic Suite	413
	9.3.iv)A	The Low-alkali Olivine Tholeiites	413

Page

	9.3.iv)B	The Gabbros	424
	9.3.iv)C	Intermediates	425
	9.3.iv)D	The Ultrabasics	426
	9.3.iv)E	The Acid Rocks	427
	9.3.iv)F	Petrogenesis of the Tholeiitic Suite	429
	9.3.iv)G	Formation of the Talisker Group	431
	9.4.	The Igneous Sequence in West-Central Skye	437
	9.5.	Chemical Variation and Origins of Amygdaloidal Zones and Boles	441
	9.5.i)	Amygdaloidal Zones and the effects of widespread zeolitisation	441
	9.5.ii)	Boles and interlava related sediments	447
	9.5.ii)A	Boles: Chemistry and Formation	447
	9.5.ii)B	Boles as fossil soils: A comparison with present day processes	449
	9.5.ii)C	Interflow sediments distinct from the red boles	450
Chapter	10.	The Contact Aureole of the Cuillin Hills Intrusive Complex	452
	10.1.	Introduction	452
	10.2.	The Petrography and general characteristics of the lavas involved in the contact aureole	454
	10.2.i)	The Outer Zones	455
	10.2.ii)	The Middle Zone	458
	10.2.iii)	The Inner Zones	460
	10.2.iv)	Summary and Metamorphic Facies	472
	10.3.	The Geochemistry of the Metamorphosed Lavas	474

		Page
References		483
Appendix 1.	Major and Trace Element Analysis	496
Appendix 2.	C.I.P.W. Normative data	497
Appendix 3.	Mineral analyses by microprobe	498
Maps	(inside back cover)	

Page

LIST OF PLATES

1-A	Coarse agglomerate/lava breccia at Glen Brittle beach	25
1-B	Sgurr an Duine cliffs showing	25
2.	Intraformational conglomerate at Geodh'a'Ghamhna	33
3.	Lenticular body of sandstone in conglomerates	33
4.	Bedded sandstone intercalations in conglomerates	34
5.	Minor coals within the upper sandstone units of the Geodh'a'Ghamhna sediments	34
6.	Fallen mass of lava in the upper sandstone unit of the Allt Mor sediments	35
7-A	Interlava sediments at Ben Scaalan	36
7-B	" " " " "	36
8.	Laminated sediments at Beinn nan Cuithean	45
9.	Globular ash at Beinn nan Cuithean	45
10.	Xenolithic ultrabasic dyke at An Leac	52
11.	Xenolithic basaltic dyke at Fiskavaig	52
12.	Inclined sheet traversing the lavas of Sgurr nan Boc	54
13.	Inclined sheets traversing the sea-cliffs at Stac a'Mheadais	54
14.	Coastal view at Sgurr nan Fiadh	70
15.	The Allt Mor breccia	70
16.	Lava lenses at Sgurr nan Boc	76
17.	Intrusive sheet in highly amygdaloidal lavas at Sgurr nan Boc	76
18.	The Sgurr nan Boc cliffs from the south of the Allt Mor ravine	79
19.	North cliffs of Talisker Bay at Rubha Cruinn	80
20.	Preshal More from Talisker Bay	80
21.	Panorama of Preshal More and Preshal Beg from Ben Scaalan	82
22-A	Flow units in lavas at Talisker Bay	86
22-B	Pipe vesicles in lavas at Talisker Bay	86
23.	Brecciated lava flow base near Carbost	87
24.	Contact of the low-alkali tholeiite at Preshal Beg and underlying breccia	87
25.	Small scale folding in the mugearite at Macfarlane's Rocks	93
26.	Trough structure in mugearite	93
27.	Columnar jointing on Preshal Beg	96
28.	Panoramic view of Preshal More from Sleadale	97
29-A	Fissile structure or horizontal jointing in mugearite	102
29-B	" " " " " "	102
30.	Talisker Bay and Preshal More from Rubha Cruinn	119
31.	Dun Ard an t-Sabhail from the south-west	119

Page

32. Photomicrograph of olivine + spinel porphyritic basalt 141
33. Photomicrograph of spinels outside olivines 142
34-A Photomicrograph of large skeletal olivine with chrome-spinels 143
34-B Photomicrograph of skeletal or corroded chrome-spinels 143
35. Photomicrograph of zoned olivines in olivine porphyritic basalt 146
36-A Photomicrograph of poikilitic olivine porphyritic basalts 146
36-B " " " " 146
37. Photomicrograph of olivine + plagioclase porphyritic basalt 150
38. Photomicrograph of olivine + plagioclase porphyritic basalt 150
39. Photomicrograph of doleritic olivine basalt 151
40. Photomicrograph of doleritic olivine basalt 151
41. Photomicrograph of Transitional Basalt with clinopyroxene microphenocrysts 156
42. Photomicrograph of olivine basalt with pseudo-microporphyritic clinopyroxenes 156
43. Photomicrograph of olivine + plagioclase + clinopyroxene porphyritic basalt 158
44. Photomicrograph of olivine + plagioclase + clinopyroxene porphyritic basalt 158
45. Photomicrograph of plagioclase macroporphyritic basalt 162
46. Photomicrograph of plagioclase macroporphyritic basalt with olivine 162
47. Photomicrograph of the basaltic breccia beneath Preshal Beg olivine tholeiite 168
48. Photomicrograph of the chilled base to Preshal Beg olivine tholeiite 168
49. Photomicrograph of the Preshal More olivine tholeiite showing banded structure 173
50. Photomicrograph of large poikilitic clino-pyroxenes in the Preshal Beg olivine tholeiite 173
51. Photomicrograph of interstitial opaque phase in the Preshal More olivine tholeiite 175
52. Photomicrograph of fine-grained olivine + plagioclase + titaniferous magnetite porphyritic hawaiite 180
53. Photomicrograph of a Loch Dubh-type hawaiite 180
54. Photomicrograph of 2 directional flow banding in a hawaiite 182
55. Photomicrograph of an olivine + plagioclase porphyritic hawaiite 182

Page

56. Photomicrograph of an olivine + plagioclase porphyritic hawaiite of Loch Dubh type 185
57. Photomocrograph of coarse basaltic-hawaiite 185
58. Photomicrograph of a Loch Dubh-type plagioclase macroporphyritic hawaiite 191
59. Photomicrograph of a plagioclase macroporphyritic hawaiite 194
60. Photomicrograph of basaltic hornblend in plagioclase macroporphyritic hawaiite 194
61. Photomicrograph of the Dun Ard an t'Sabhail composite hawaiite-upper unit 198
62. Spinels exposed on the weathered surface of the Dun Ard an t'Sabhail composite hawaiite 198
63. Photomicrograph of intergrowths in the Dun Ard an t-Sabhail composite hawaiite 202
64. Photomicrograph of the Dun Ard an t-Sabhail composite hawaiite-lower unit 202
65. Photomicrograph of olivine + plagioclase + titaniferous magnetite porphyritic mugearite 206
66. Photomicrograph of fine-grained mugearite with stellate plagioclase 206
67. Photomicrograph of fine-grained mugearite with oscillating zoned plagioclase 208
68. Photomicrograph of a coarse-grained mugearite 208
69-A Photomicrograph of the aphanitic benmoreite of Portnalong 217
69-B " " " " " " 217
70. Photomicrograph of the Sleadale intermediate or sub-alkalic trachyte 220
71. Photomicrograph of clinopyroxene microphenocryst in the Sleadale trachyte 222
72. Photomicrograph of well-developed apatite microphenocrysts in the Sleadale trachyte 222
73. Photomicrograph of the Alkali trachyte of Cnoc Scarall with amphibole? 226
74. Photomicrograph of the Alkali trachyte of Snoc Scarall with anorthoclase ·226
75. Photomicrograph of the dunite-wehrlite dyke at An Leac 231
76. Photomicrograph of an allivalitic-gabbroic xenolith 231
77. Photomicrograph of the feldspathic peridotite of Carn Mor 234
78. Photomicrograph of the olivine + spinel porphyritic picritic dyke of An Sguman 234
79. Photomicrograph of acidic dyke in meta-lavas of Loch Brittle 243
80. Photomicrograph of typical low-alkali tholeiite inclined sheet 243

Page

81. Photomicrograph of the Creagan Dubh tholeiitic sill 247
82. Photomicrograph of the andesitic Bualintur sill 247
83. Photomicrograph of Glen Brittle felsite sheet at Leachd Thuilm 251
84. Photomicrograph of acid-veining at An Sguman 251
85. Photomicrograph of the intrusion breccia at An Sguman 253
86. Photomicrograph of the Outer Ring Eucrite/Gabbro 256
87. Photomicrograph of orthopyroxene-bearing variant to the contact gabbros 256
88. Photomicrograph of leucocratic, pegmatitic layers in the Loch Brittle gabbro plug 259
89. Photomicrograph of the feldspathic peridotite of An Sguman 259
90. Photomicrograph of felsite cobble in conglomerate 263
91. Photomicrograph of feldspar porphyritic granophyre cobble in conglomerate 263
92. Photomicrograph of fine-grained granophyre pebble/ cobble in conglomerate 265
93. Photomicrograph of banded siltstone cobble in conglomerate 265
94. Photomicrograph of epidotic arkose cobble in conglomerate 269
95. Photomicrograph of plagioclase macroporphyritic basalt cobble in clonglomerate 269
96. Photomicrograph of the banded tuff of An Leac and altered lava 274
97. Photomicrograph of well-developed bole 274
98. Photomicrograph of the laminated sediments of Ben Scaalan 275
99. Photomicrograph of meta-lava with reacting olivines 463
100. Photomicrograph of meta-lava with clouding of groundmass feldspars and vein 463
101. Photomicrograph of meta-lava with amygdale 465
102. Photomicrograph of high-grade granular hornfels 468
103. Photomicrograph of high-grade granular hornfels with relict amygdales 468

Page

LIST OF FIGURES

1-A	Location map of the west of Scotland with position of thesis area and Central Intrusive Complexes.	2
1-B	Selected localities map in west-central Skye.	3
2.	Map showing location of pyroclastic and sedimentary intercalations in the lava pile.	22
3.	Map showing the broad Geology of the Inner Hebrides region and conglomerate localities.	42
4.	Map showing location of dykes and other intrusions in west-central Skye.	49
5.	Cross sections across the western margins of the Central Intrusive Complex.	59
6.	Lava flow structures.	84
7.	Cross sections of Preshal More and Preshal Beg.	100
8.	Stratigraphy of the Meacnaish lava group.	104
9.	Stratigraphy of the Bualintur lava group.	105
10.	Stratigraphy of the Cruachan lava group.	106
11.	Stratigraphy of the Tusdale lava group.	107
12.	Stratigraphy of the Arnaval lava group.	108
13.	Stratigraphy of the Talisker lava group.	109
14.	Stratigraphy of the Loch Dubh lava group.	110

Page

15. Map showing the division of the Skye lava field into the various lava groups. 111

16. Cross sections (diagrammatic) across the lava field in northern and south-west Skye. 112

17. Map showing distribution of zeolite localities. 125

18. Sampling points and structural divisions of the low-alkali tholeiite of Talisker. 170

19. Cross sections across the Cnoc Scarall region. 224

20. Element variations in olivines against Forsterite content. 286

21. The olivines of the alkali trachyte in terms of Fayalite-Forsterite-Tephroite end members. 292

22. Sub-calcic pyroxene quadrilateral. 298

23. Element variations in clinopyroxenes against host rock Differentiation Index. 302

24. Element variations in clinopyroxenes as expressed in the structural formula against silica. 304

25. Feldspar analyses in terms of the Albite-Orthoclase-Anorthite system. 317

26. Chrome-spinels and others from Skye plotted in the system Al-Fe-Cr. 326

27. Spinels and titaniferous magnetites plotted in the system Cr-Fe-Ti-Al. 328

28. Reaction trends of titaniferous magnetites and their variation with differentiation in the system $FeO-Fe_2O_3-TiO_2$. 330

29. Plot of major and trace element variation in the lavas and intrusions of west-central Skye versus the Thornton-Tuttle Differentiation Index. 354

Page

30. Major element variation plotted against iron/magnesium ratio for the lavas. 365

31. Ternary AFM plot. 367

32. Normative feldspar compositions in terms of Albite-Orthoclase-Anorthite. 368

33. Total alkalis versus silica plot for lava and intrusion samples from west-central Skye. 369

34. Basaltic lavas from west-central Skye plotted in terms of Olivine-Clinopyroxene-Nepheline-Quartz. 371

35. Selected lavas and minor intrusions projected into the ternary system Di-Fo-An. 372

36. Total alkalis versus iron/magnesium ratio for the west-central Skye lavas and intrusions. 373

37. Selected trace element concentrations in the lavas plotted against Zr or P_2O_5 contents. 381

38. Log-Log plot for the lavas and intrusions of west-central Skye. Cr _vs_ Ni. 384

39. Plot of Ti versus Zr for the basaltic lavas and minor intrusions. 407

40. Plot of TiO_2 versus iron/magnesium ratio showing the various suites present. 409

41. Major element variation between and within the low-alkali tholeiite outliers of Preshal More and Preshal Beg with height in the flow. 419

42. Trace element variation between and within the low-alkali tholeiite outliers of Preshal More and Preshal Beg with height in the flow. 420

Page

43. 'Average' major and trace element variation within the low-alkali tholeiite plotted against height within the flow. 421

44. Concentration ratio plot of Ti/Y against Zr/Y for selected basalt lavas. 423

45. Acid veining and trachyte lavas plotted in the system Quartz-Albite-Orthoclase. 428

46. Schematic outline of the petrogenesis of the Skye lavas. 433

47. Generalised igneous sequence as observed in west-central Skye. 434

48. Diagrammatic representation of events in the formation of the Talisker Group. 435

49. Map of the Cuillin Hills Intrusive Complex aureole showing zonal arrangement. 453

50. Total alkalis versus silica for the metamorphosed lavas adjacent to the Intrusive Complex. 475

51-A. Silica versus Zr plot for the metamorphosed lavas. 478

51-B. Silica versus Nb plot for the metamorphosed lavas. 478

52. Plot of Zr against Ti for the lavas of the aureole. 479

53. P_2O_5 plotted against TiO_2 showing metamorphosed lavas and other Hebridean trends. 480

Page

LIST OF TABLES

1. The lava groups of northern and west-central Skye — 8
2. Measured section through the intergroup sediments at Geodh'a'Ghamhna — 32
3. Intrusive history of western and central Skye — 67
4. Zeolites and secondary minerals — 124
5. Zeolite and secondary mineral localities in west-central Skye — 126
6. Clay mineral-zeolite intergrowths recorded at Talisker — 130
7. Olivine micorprobe analyses — 281
8. H_2O (total) FeO and CO_2 analyses of selected specimens — 344
9. Analytical precision on selected specimens — 347
10. Representative basaltic major and trace element analyses — 376
11. Comparison of calculated olivine compositions and observed compositions — 390
12. Comparative analyses of flows, amygdaloids and boles — 443

CHAPTER 1

INTRODUCTION

1.1 Location and scope of study

The area studied in this thesis covers some 125 square kilometres of the Geological Survey 1" Sheet number 70 (Minginish) (Fig.1) and comprises various Tertiary volcanic rocks, intercalated sediments and minor intrusions not surveyed in detail since the time of Harker at the turn of the last century, although similar sequences to the North were resurveyed by the Geological Survey in subsequent years. Pre-Tertiary sedimentary rocks and the margins of the outer gabbros of the Central Complex were also encountered during the course of the project and form an integral part of it. The primary mapping was done at a scale of 1:10,560 on Ordnance Survey base maps supplemented for much of the area by approximately 1:25,000 vertical aerial photographs of varying quality. The final maps have been produced at a scale of 1:25,000 for convenience and are appended at the back of this thesis and the grid references used throughout refer to them.

1.2 History of Research

The Tertiary Igneous rocks of Skye, in particular the volcanic rocks, possess a history of research into their structure, mineralogy and chemistry going back over

FIGURE 1-A

Map of the north-western sea-board of Scotland indicating the position of the various Central Intrusive Complexes and the area dealt with in the thesis. (see legend on figure 1-B)

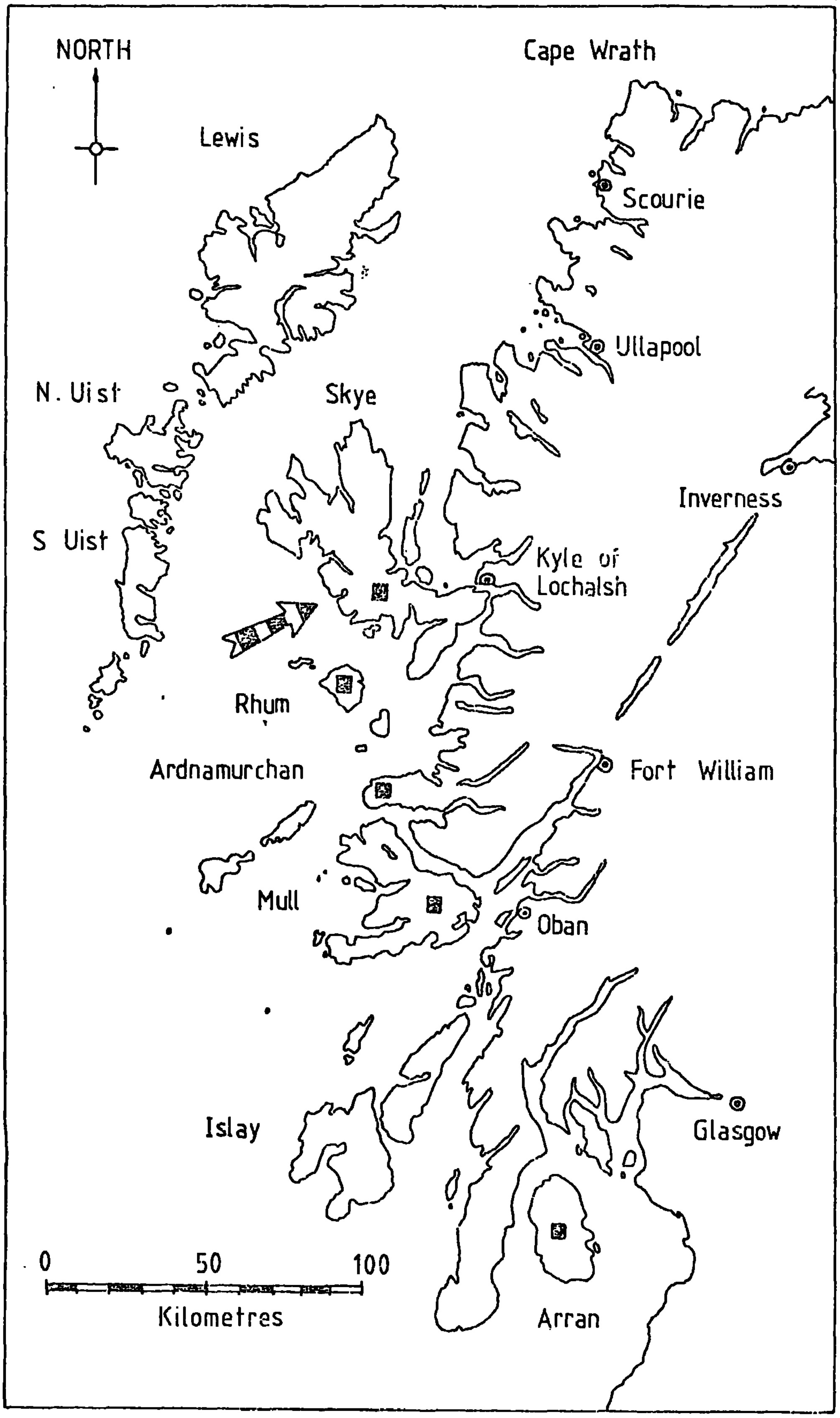

NORTH
Cape Wrath
Lewis
Scourie
Ullapool
N. Uist
Skye
Inverness
S Uist
Kyle of
Lochalsh
Rhum
Ardnamurchan
Fort William
Mull
Oban
Islay
Glasgow
0
50
100
Kilometres
Arran

Figure 1-A

FIGURE 1-B

Map of west-central Skye showing selected localities which are frequently mentioned in the text.

(arrow symbol)	The area covered by the Thesis
■	Central Intrusive Complexes
◎	Villages, towns etc.
●	Important place names

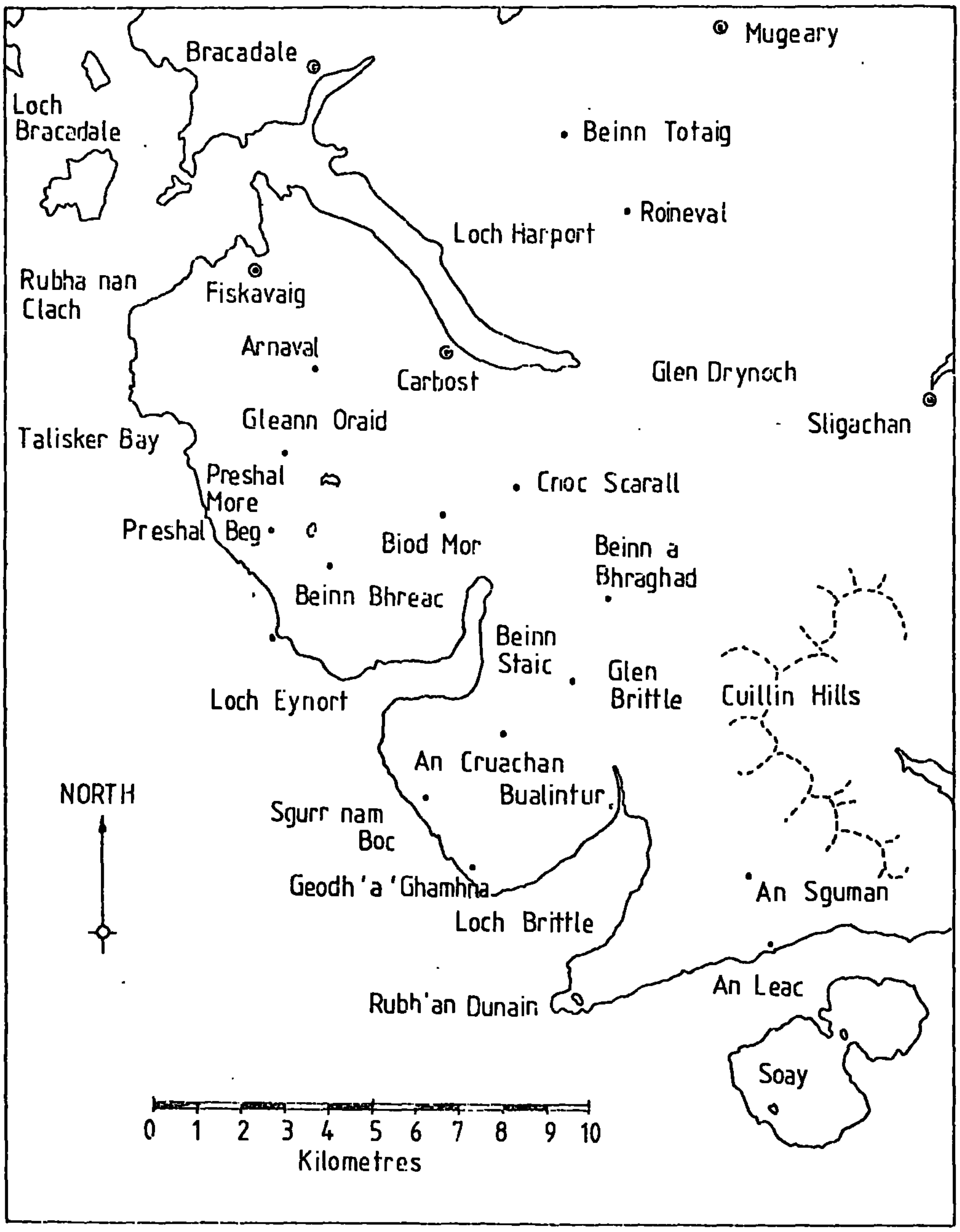

Mugeary
Bracadale
Loch
Bracadale
Beinn Totaig
Roineval
Loch Harport
Rubha nan
Clach
Fiskavaig
Arnaval
Carbost
Glen Drynoch
Sligachan
Talisker Bay
Gleann Oraid
Preshal
More
Preshal
Beg
Croc Scarall
Biod Mor
Beinn a
Bhraghad
Beinn Bhreac
Beinn
Staic
Glen
Brittle
Cuillin Hills
Loch Eynort
An Cruachan
NORTH
Sgurr nam
Boc
Bualintur
Geodh 'a 'Ghamhna
Loch Brittle
An Sguman
Rubh'an Dunain
An Leac
Soay
0 1 2 3 4 5 6 7 8 9 10
Kilometres

Figure 1-B

one hundred and fifty years.

Of the early accounts, the observations of John Macculloch during the first quarter of the nineteenth century are probably of most importance and interest. Macculloch, who recognised the igneous origins of the lavas and observed that they overlie the Mesozoic strata of Skye, was the first distinguished geologist to visit that area of West-Central Skye dealt with in this thesis. He was impressed by the seclusion and tranquility of the valley at Talisker, describing it as "....a most singular and unexpected spot, a green emerald in a sea of almost universal brown...." (1824, p.461-462), and by the columnar faces of the hill Brish Meal (Preshal More). He noted the presence of variously coloured clay horizons (now known to be the products of contemporaneous weathering of lavas and tuffs) intercalated with the lavas of the precipitous coastal cliffs, but attempted no interpretation of the rocks or structures of the area.

Between the years 1850-1900, important contributions to various aspects of the geology of Skye were made by Zirkel (1870), Judd (1874,1889) and Heddle (1856 etc.), but it is to Sir Archibald Geikie and his immediate successors that the early study of the Skye lavas perhaps owes most. Geikie's researches were mainly concerned with the structure of the Hebridean lava plateaux and after a prolonged study, concluded that the lavas were erupted along major fissures, thus fundamentally disagreeing with the view advocated by Judd (1874) that they were erupted at the central vents of large Tertiary volcanoes. Although he initially considered the lavas as being no younger than Jurassic (1861) he later revised his opinions in favour of a Tertiary age. He correctly deduced the relative ages of the lavas and the gabbros and granites of the central complex, and in his capacity as Director of the United Kingdom Geological Survey in 1895, instituted the detailed mapping of much of Skye, principally by A. Harker and C.T. Clough.

Apart from Harker's misinterpretation of many of the thicker and more massive lavas as sills and the fact that he considered it impossible to systematically distinguish the various lava-types in the field although a considerable compositional range was recognised, the two resulting Memoirs (1904a, 1904b) remain invaluable works of reference and are dealt with in more detail in the succeeding chapters.

The work of Harker and his colleagues in Skye was the first attempt at the intensive and systematic mapping of a British Tertiary igneous centre and consequently set new standards in igneous petrology, laying down guidelines which were to be followed by the later surveys of Mull by Bailey et al. (1924) and Ardnamurchan by Richey and Thomas (1930). Such were the complexities of the ring structures discovered in these centres that the apparent simplicity of Harker's overall igneous sequence in Skye became questionable; the Geological Survey undertaking primary re-surveys of the Northern part of the island.

Apart from Kennedy's interpretation of Harker's "Roineval type of Composite Double Sills" as composite lavas (1931) interest in the lavas waned and not until the early 1950's was serious research and interest revived. However, during this time much work was done by E.M. Patterson and G.P.L. Walker on various aspects of the Antrim lava field in Northern Ireland. Wager (1956) discussed the role of crystal fractionation in producing the lavas of the Hebridean Tertiary Igneous Province, comparing them with those of Hawaii and elsewhere, and geochemical data was presented by Nockolds and Allen (1956). Muir and Tilley (1961) first reassessed the chemistry and status of the mugearites and trachytes in the light of Walker's reappraisal of the type Mugearite from Skye (1952), before critically re-examining the Hebridean Plateau Magma Type of the Mull Memoir (1924) responsible for the more basic lavas (1962). In Strathaird, South-east of the Cuillins, the thermal metamorphism and petrology of the lavas near the intrusions was part of a Ph.D. study by Almond (1960), the metamorphism being dealt with fully in a later paper (1964).

The results of the re-surveying of Northern Skye, begun in the 1930's were finally published in 1966. F.W. Anderson and K.C. Dunham as co-authors of the Memoir were concerned to present evidence showing that those rocks identified by Harker as sills intruding the lavas (1904a), were no more than the hard, compact flow-centres emphasised from their amygdaloidal borders by subsequent erosion. In the field they distinguished the lavas as basalt, mugearite, trachyte and their porphyritic equivalents dividing the succession into five stratigraphic groupings (Table 1). These were based upon the occurrences of several locally interstratified sedimentary horizons and overlapped oneanother to some degree. Although the exact sequence was unknown, the Osdale and Bracadale Groups were thought probably the youngest. Palagonitic tuffs and breccias containing porphyritic sideromelane glass bombs and pillow lavas of tholeiitic affinities were discovered to preceed the main alkaline lava phase and it was considered probable that a more tholeiitic magma was generally available when volcanic activity began in Skye. Major fissures, linked to local near surface reservoirs, possibly interconnected and situated around a developing central volcano in the Cuillin area, were argued to be the eruptive sites best suited to explain the near random spatial and temporal distribution of the lavas.

TABLE 1

The proposed lava groupings of northern and west-central Skye based on the work of Anderson and Dunham (1966) and this thesis, with approximate thicknesses. The stratigraphy of those from west-central Skye is illustrated in figures 8-14 and their distribution and relationships in figures 15 and 16 respectively.

NORTHERN SKYE

Group Name	Approx. Thickness	Description
5. Osdale	490m	Alternating basalt and mugearite flows
4. Bracadale	125m	Alternating mugearite and trachyte flows
3. Beinn Totaig	610m	Alternating basalt and mugearite flows. A porphyritic basalt at the top of the group
2. Ramascaig	760m	Alternating porphyritic and non-porphyritic basalts with a mugearite flow over the top of the group
1. Beinn Edra	305m	Non-porphyritic basalts with a few porphyritic flows and a mugearite (hawaiite) at the top

WEST-CENTRAL SKYE

Group Name	Approx. Thickness	Description
7. Talisker	140m	Low-alkali, high-calcium olivine tholeiites
6. Loch Dubh	80m	Feldspar porphyritic hawaiites. Contemporaneous with 5.
5. Arnaval	440m	Mugearitic and hawaiite flows overlying a type 4 sequence (middle zones). Trachyte/benmoreite at the top of the group.
4. Tusdale	435m	Olivine ± plagioclase porphyritic basalts with a few olivine ± spinel types towards the base. Hawaiites at approximately mid-group.
3. Cruachan	400m	Complex grouping of alkali-olivine basalts - both aphyric and porphyritic Hawaiites cap the group and Transitional Basalts occur near the base.
2. Bualintur	250m	Alternating cycles of olivine basalts and a series of hawaiites. A big-feldspar basalt and mugearite occur at the top of the group.
1. Meacnaish	400m	Early differentiates succeeded by alkali olivine basalts capped by a series of big-feldspar basalts. In part, probably contemporaneous with 2.

In all, the past twenty years have witnessed a vast increase in the amount of research undertaken in the Tertiary Hebridean Igneous Province, much of it relevant to Skye. A good review of the work and literature concerning the chronology, composition, structure and tectonics of the Tertiary igneous sequence on Skye is given by Bell (1976) and so will not be dealt with in any detail here. It is perhaps sufficient to say that a hitherto unsuspected complexity, approaching that of Mull, is revealed.

As a separate entity, the lavas received comparatively little attention after the Geological Survey Memoir on Northern Skye (1966). When Thompson et al. (1972) published new major element chemical data, the only previously published work concentrating solely upon the lavas was by Thompson (1967). In this short communication he interpreted some of Harker's rhyolites in the Fionn Choire area, bordering the Cuillins to the North-west as quartz-contaminated trachytes, although in fairness, Harker had himself recognised that they were considerably altered and replaced by secondary quartz "....leaving the true nature of the rocks.....a question of obscurity." (1904 , p.61). Thompson et al. (1972) as well as presenting new chemical data, divided the lavas into members of the alkali-basalt-hawaiite-mugearite-trachyte suite and stated that most of the lavas mapped by the Geological Survey (1966, 1" sheet 80) as mugearites were in fact hawaiites. They found that hypersthene- and nepheline-normative basaltic rocks were equally abundant and the fact that the more leucocratic lavas tended not to belong to a single lineage as previously thought, led them to suspect that all the hypersthene in the norm was not necessarily the product of hydrothermal and weathering processes as was the view of Tilley and Muir (1962). Instead, two divergent trends were envisaged. These were a silica-rich, iron-poor trend from basalt to trachyte and a relatively silica-poor, iron-rich trend from basalts towards benmoreites, resulting from the low pressure thermal divide near the critical plane of silica undersaturation splitting a continuous spectrum of basaltic compositions as they rose from equilibrium with a high pressure regime to lower pressures in upper crustal magma reservoirs. They also reported the occurrence of sparse alkali-poor, calcium-rich olivine tholeiites, inter-bedded with the predominantly alkalic lavas which they termed the Skye Main Lava Series. A revised petrogenetic model for the evolution of the Skye lavas, in the light of anhydrous experimental studies within their melting ranges at pressures up to 30kb was presented by Thompson (1974a) and Esson et al. (1975) published details of the chemistry and one atmosphere melting experiments of the low-alkali tholeiites, concluding that they were probably some of the youngest lavas on Skye and probably associated with the early stages of a central volcano superimposed upon the plateau lavas of South-west Skye.

The spatial geochemistry and petrology of the Skye dyke swarm, which includes many with low-alkali tholeiite and related compositions has recently been studied by Mattey et al. (1977), while detailed investigations of the composite lava flows of Northern Skye and one near Talisker in west-central Skye, are included as part of a Ph.D. study by Boyd (1974).

Palaeomagnetic studies of the lavas of Northern Skye by Wilson et al. (1972) showed that, as in earlier British Tertiary studies, all the lavas are reversely magnetised and have shallow reversed inclinations characteristic of the Hebridean Tertiary Igneous Province as a whole. All of the Geological Survey's five proposed stratigraphic groupings (Table 1) were found to have "....characteristic distributions of directions of magnetism...." indicating their emplacement at different times and supporting their validity.

Recent Geological and Geophysical investigations by the Institute of Geological Sciences in the Sea of the Hebrides (Binns et al. 1973) has shown that the lavas of the Minginish district of West-central Skye appear to extend South-westwards in the form of a broad submarine ridge (The Canna Ridge) possibly overlying a deep trough filled with Mesozoic and earlier sediments which may extend northwards beneath the volcanics of Northern Skye. The importance of this ridge will be discussed in a later chapter.

1.3 Physiogeography

In marked contrast to the bare, jagged peaks of the Cuillins, the topography developed by the volcanics is somewhat subdued. The layered nature of the essentially flat-lying lavas imparts a characteristic terraced appearance which is partially dependent upon rock-type. As the Cuillins are approached in the vicinity of Glen Brittle, the hills are more rolling and less-well exposed with the weathering processes not readily distinguishing between the thermally metamorphosed massive centres of the lavas and their amygdaloidal zones. Harker (1904 , page 439) also notes the change in weathering characteristics towards the Central Complex. The maximum elevation is 452 metres on Beinn a'Bhraghad, although many of the inland hills are over 350 metres high. The coastline is an almost continuous Northwest-Southeast trending, probably fault controlled, seacliff rising in places to over 200 metres and broken only by sea lochs and minor bays. Due to a shorter period of exposure to the elements, terracing is not marked in these sections and boulder-strewn beaches testify to continuous and rigorous erosion at the present time.

Although not as resistant to weathering and glacial erosion as the gabbros and ultrabasics of the Cuillins, the lavas do occasionally show direct evidence of glacial action especially as low-profile roches moutonees and diffuse striae. These structures indicate a general north-westerly ice flow diverted westwards and south-westwards down the local glens by high ground such as the Cuillins, Beinn Bhreac and the An Cruachan - Beinn a'Bhraghad and Stockval-Arnaval ridges. The outliers of Preshal More and Preshal Beg appear glacially sculpted and their outlines may be due to the convergence of north and westerly flowing valley glaciers from Sleadale and Gleann Oraid. Full details of Quaternary events in Skye are given by Anderson and Dunham (1966 , Chapter XII).

1.4 Superficial Deposits and Economic Geology

1.4i) Boulder Clay and Glacial Sands

Boulder clay is present in many areas but is generally thin and only patchily developed and often grades laterally into a brownish-red sandy drift with scattered boulders of gabbro, granite and basalt. At Kearra, along one of the tributaries of the River Eynort, north-west of Biod Mor (c.360283), 1 metre of boulder clay is overlain by brownish sand with boulders which grades to the east into laminated and well-sorted sands. Similar sands are met with at Merkadale (c.385312).

1.4ii) Glacial Erratics

Surprisingly few glacial erratics of any rock foreign to the volcanic tract are found. Towards the Cuillins, a few gabbroic blocks are evident but are not plentiful until the very margins of the intrusions. Erratics of Torridonian sandstone, recorded near Dunvegan (Anderson and Dunham 1966) are almost completely absent in west-central Skye. This is in very marked contrast to the abundance of such erratics on the Island of Canna to the south-west, which probably originate from Rhum. At Glen Brittle, large erratics of red sandstone and indurated conglomerate are found on the beach along with minor siltstones and plutonic rocks.

1.4iii) Raised Beaches

Two levels of raised beach deposits are recognised. At Fiskavaig Bay, Talisker Bay, Merkadale and Upper Loch Eynort, a low terrace of rounded boulders and sand is found at an elevation of 6-10 metres, while at the head of Loch Brittle, an equivalent terrace, including some wind-blown sand and a higher, more restricted terrace at a level of about 15-20 metres, is seen. Low lying platforms of eroded lavas at Creagan Dubh (348243) and Macfarlane's Rocks (c.302314) may represent ancient wave-cut platforms.

1.4iv) Beach Sands

The present day beach deposits are composed of debris from the direct weathering of the lavas and as such are dark green to black in colour due to the proportion of glassy lava, olivines and pyroxenes. All the major bays are of this deposit which is commonly overlain by some local shell material giving a false impression of white beaches from a distance. At Glen Brittle, the beach contains fragments of gabbro, granite and sandstone as well as the local volcanics. Wind-blown, cross bedded sand with some bivalve shells and plant remains is exposed near the small suspension bridge over the River Brittle at Bualintur, but is not widespread.

1.4v) Peat

Hill and valley peat is extensively developed and frequently worked for fuel. The reserves of this material, in common with the rest of the island, are vast; the present day workings being confined to the roadsides and never going deeper than about 2 metres. As a consequence of the distribution of peat, most of the land is poorly drained and infertile.

1.4vi) <u>River Gravels</u>

Except for small patches of gravel in Glen Eynort, the only river gravels recorded are associated with the widespread alluvium of Glen Brittle. The gravels in the River Brittle consist of sand and boulders derived from the gabbroic rocks being eroded and transported from the corries to the east, and occasional erratic granites and basalts are found. At present they are used as a base for new Forestry Commission roads in various parts of the Glen Brittle forest along with weathered basalt from numerous roadside cuttings in Gleann Oraid, Glen Eynort and Upper Glen Brittle itself.

1.4vii) <u>Alluvium</u>

Freshwater alluvial deposits of silts and clays are confined to the narrow strips adjacent to streams and in the beds of dried-up lochans. Presently filled lochans have mixtures of gravelly deposits and dark carbonaceous clay, derived from the surrounding lavas and moorland vegetation.

1.4viii) <u>Fresh Water</u>

Fresh water in the form of small lochans and innumerable streams is abundant and most of the domestic supply comes direct from the hillsides into settling tanks or small dams as at Fiskavaig. The water is acidic and strongly coloured after heavy rainfall due to a high percentage of included organic matter from the peat. Apart from domenstic supply, the abundance of freshwater has also resulted in the growth of the small Talisker Whisky Distillery at Carbost which is the only distillery on the island and apart from crofting and the Forestry Commission is the chief employer of labour in the area.

CHAPTER 2

PRE-TERTIARY SEDIMENTARY ROCKS

The Tertiary Igneous rocks of Skye rest upon and intrude a selection of Torridonian, Cambro-Ordovician and Mesozoic strata and although outwith the scope of the present investigation, a summary of the occurrence of these country rocks as they crop out along the Northern shores of Soay Sound is given below.

Beneath the earliest lavas to the East of the An Leac promintory (443170) pink and frequently false-bedded arkosic grits of Torridonian age crop out, being succeeded westwards with slight unconformity by coarse and fine conglomerates and thin, lenticular, reddish sandstones assigned to the Permo-Trias (Clough et al., 1904). These conglomerates, about 10 metres thick, contain subangular and rounded pebbles predominantly of Cambrian quartzites, limestones and dolomites up to 20 centimetres long, set in a calcareous sandstone matrix. Further to the East, the percentage of Torridonian increases until almost the whole of the rock is composed of arkosic pebbles as along the coast below Cnoc Leathan (440169-450172).

At, and to the west of the mouth of the Allt na Meacnaish (438170), Rhaetic passage beds (Clough et al., 1904) of calcareous yellow sandstones and multi-coloured shales sometimes containing thin lignites and fragments of wood, occur between the Permo-Trias conglomerates and the limestone-shale alternations of the lower Lias. 500 metres west-south-westwards near the sea cave (432168) the Liassic age of the upper sediments is proved by the presence of horizons of impure limestones, concretionary sandstones and calcareous shales containing bands of Gryphaea arcuata, a few belemnites and scattered crinoid ossicles. Conformably overlying these sediments at the same locality are 15 metres of westwardly dipping glauconitic sandstones and cherts of Cretaceous age. The sub-Tertiary unconformity throughout this coastal sequence has a gentle westerly dip.

The only other reported occurrence of allegedly non-Tertiary rocks from the area are those brought up as cores during the construction of the pier at Carbost. Clough et al. (1904) state that the borings were only some 2 metres in depth but did enter sandstones, presumably of Jurassic age, indicating the Mesozoic-Tertiary unconformity near the surface. Mapping of the lavas in and around the Carbost area has failed to pick up the faults required to bring the unconformity to such a level and in general appears to indicate that the lavas are structurally high up in the local sequence and consequently considerable doubt is thrown on the Jurassic age of the sediments recovered. The sediments may well be part of a local

Tertiary river-system much the same as those proved in the area of Glen Brittle.

CHAPTER 3

TERTIARY VOLCANICLASTICS AND OTHER SEDIMENTS

Within the lava succession of West-central Skye relatively few intercalations of volcanic agglomerate or sediments are preserved, a feature also observed by Geikie (1897) and Harker (1904). In Northern Skye the base of the lava pile is characterised by the widespread occurrence of pyroclastic rocks including palagonite tuffs (Anderson and Dunham, 1966) but no source vent is exposed. Such accumulations of volcaniclastic rocks and sediments when found within the lava sequence do furnish evidence that the otherwise quiet effusion of lava was at times accompanied by explosive activity and comparatively long periods of quiescence within localised areas (Fig.2).

These deposits may be subdivided into four main categories as follows:

1. Pyroclastic rocks within vents.
2. Pyroclastic rocks possessing no visible connections with obvious vents.
3. River-channel conglomerates and sandstones.
4. Lacustrine mudstones and laminated ashes.

3.1 Pyroclastic Rocks within or connected with vents

Three small vents are recognised within the area mapped. The first, cutting through a succession of Torridonian and Mesozoic strata 800 metres west of the

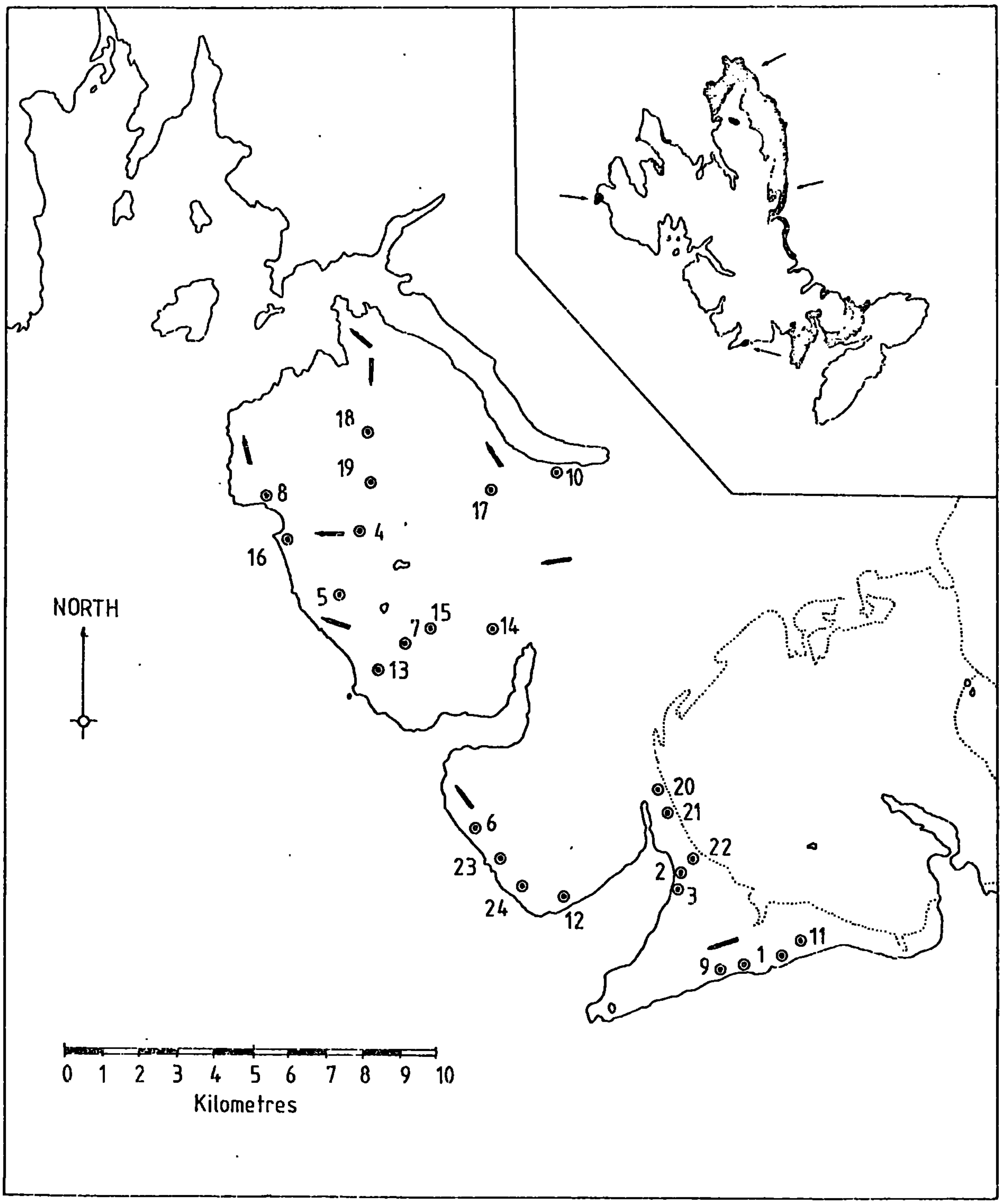
FIGURE 2

Location of volcaniclastics and sediments intercalated with the lavas of west-central Skye showing directions of inclination of fault blocks and major faults.

Insert: Map of Skye showing the present distribution of Mesozoic sediments beneath the lavas showing their basin structure which is reflected in the overall inclination of the lava field.

Volcaniclastic and sediment localities

1.	Vent and bedded agglomerates within basal ash at An Leac
2+3.	Agglomerates/lava breccias on Loch Brittle
4.	Agglomerate and bedded tuffs of Preshal More
5.	Coarse agglomerate and basal breccia of Preshal Beg
6.	Agglomerate of Sgurr an Duine and Sgurr nan Boc
7.	Agglomerate of Beinn Bhreac summit
8.	Agglomerate and shaley boles of north Talisker Bay
9.	Agglomerate of Stachd on Soay Sound
10.	Thin agglomerate at Carbost
11.	Banded crystal-lithic tuff at An Leac-Cnoc Leathan
12.	Thin tuffs and localised agglomerate of An Crocan
13.	Laminated sediments and lignite of Ben Scaalan
14.	Lignite of Biod Mor
15.	Thin ashy sediments of Beinn na Cuinneig
16.	Thin mudstones and globular ash of Beinn nan Cuithean
17.	Sediments of Carbost Burn
18+19.	Thin sediments on the slopes of Arnaval
20+21 +22	Intraformational conglomerates of Glen Brittle
23.	Intraformational conglomerates of the Allt mor ravine
24.	Intraformational conglomerates, sandstones and coals of Geodh'a'Ghamhna


18
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11
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0 1 2 3 4 5 6 7 8 9 10
Kilometres

Figure 2

promintory of An Leac on the north shore of Soay Sound (431168), was mapped by the Geological Survey and shown to be earlier than the first lavas in the region as they appear to pass unbroken over it. Some 30 metres in diameter with sub-vertical walls it is filled by broken and angular debris from the strata through which it passes but contains no igneous fragments. Also it does not contain any basement gneissose fragments and it appears therefore that the explosive activity which produced it was confined to high crustal levels with the Lewisian basement at considerable depth. It was interpreted by Clough and Harker (1904 , pp.33-34) as a volcanic 'blow-hole' due to the volatile release from magma at depth, the fragments being merely blocks of the wall rocks which have fallen into the vent.

The other two occurrences are not previously reported and supply evidence that small vents are probably quite common among the lavas although not exposed due to large areas of peat and moorland. They pierce through the lavas exposed on the shore to the south-east of Glen Brittle beach (414199, 413196), a little less than 1 kilometre from the margins of the Cuillin gabbros which are responsible for the thermal metamorphism of the agglomerates and lavas in the vicinity. Both vents have brecciated sub-vertical contacts and arcuate outlines. The more southerly vent is some 40 metres across containing a poorly sorted assemblage of angular to sub-angular fragments of olivine porphyritic, plagioclase macroporphyritic and aphyric basalt, veined by a light orange-brown weathering, conspicuously olivine porphyritic basalt, while the more northerly vent, about 25 metres in diameter, although generally coarser in aspect appears to be composed of monogenetic basaltic fragments in a lithic matrix (Plate 1).

3.2 Pyroclastic rocks not associated with or outwith vents

Several minor accumulations of bedded pyroclastic rocks not in continuity within any vent and one which may be linked with the small vent west of An Leac, occur throughout the region.

Associated with and to the east of the vent at An Leac, a horizontal bed of agglomerate of variable thickness and restricted lateral extent overlies limestones,cherts and sandstones of Liassic and Cretaceous age (1904 , 1904) and as well as sedimentary fragments, contains some amygdaloidal basalt blocks set in a tuffaceous matrix (433168).

Hetergeneous bedded agglomerates of unknown origin occur as a capping to the hill of Beinn Bhreac (334269), sporadically along the cliffs west of Glen Brittle towards Sguir an Duine (362208, 359213, 356215) and on the slopes of the twin hills of Preshal More (c. 334300) and Preshal

PLATE 1-A

Coarse agglomerate and lava-breccia at Glen Brittle beach intruded by an inclined basic sheet, 1 metre wide and striking radial to the Central Intrusive Complex. The hills in the background are Beinn Staic and Beinn a'Bhraghad mostly formed by lavas of the Cruachan Group.

PLATE 1-B

The precipitous sea-cliffs at Sgurr an Duine showing the sub-horizontal contact between light-weathering amygdaloidal lavas (L) and darker, blanketing agglomerate (A): the contact towards the right is formed by a steep fault. Below is the sea-stack and natural arch of Stac an Tuill with the islands of An Dubh-Sgeir and Stac a'Mheadais in the distance to the north.


A
L

Beg (c. 330280) near Talisker. In each case, the deposit comprises solely fragments of the underlying lava sequences up to 1 metre in diameter but usually less than 25 centimetres in diameter, set in a green tuffaceous matrix which towards the top frequently takes on a reddish-ferriginous aspect.

At Sguir an Duine (356215) south of Loch Eynort the obvious 'mantling' nature of the agglomerate against the lavas is observed. The approximate shape is lenticular, possessing a maximum preserved thickness of some 20 metres with a faulted contact in the south-facing sea-cliffs. The agglomerate is distinctly draped over the cliff top to the north (357216). A small patch of agglomerate at the same horizon as that of Sguir an Duine occurs on the slopes of Sgurr nam Boc (361208) 800 metres to the south-east (Plate 1B).

The conical summit of Beinn Bhreac (height 450 metres) is formed from a deeply weathered, considerably iron-stained fragmental agglomerate composed of rounded, up to 20 centimetres diameter, aphyric and porphyritic lava fragments and decomposed laterite. It is about 300 metres in extent and a maximum of 10 metres thick with a small fault to the west down-throwing it against the hawaiitic and mugearitic lavas of the summit plateau.

The heterogeneous nature of these disconnected beds of agglomerate is shown best on Preshal Beg and Preshal More. At the former locality the main body of the agglomerate encircling the hill is composed primarily of angular to sub-rounded lava fragments, red crystal tuffs and indurated bole less than 25 centimetres in diameter, but often containing large, well-rounded blocks up to a metre or more in diameter, set in a matrix of fine-grained basic ashy tuff. Zeolitisation is conspicuous in the upper metre of this deposit. Bedding is crudely present as indicated by thin, sub-horizontal horizons of grey or green tuff and ash, often in part reddened by exposure to the atmosphere.

Harker (1904 , p.25) unequivocally states that no such deposit is found on Preshal More, 2 kilometres to the north, but in fact the north-eastern margin of the hill exhibits a thin, discontinuous wedge of coarse agglomerate identical in most aspects to that of Preshal Beg, being associated with and overlain by partly water-lain and partly air-fall, laminated tuffs. The sorting is considerably better than on Preshal Beg and the presence of carbonaceous matter in the finely laminated grey ashes may indicate the presence of a body of standing water into which the overlying lava flowed. Because of the generally coarser nature of the agglomerate on Preshal Beg, it is considered that it was closer to the source vent than was Preshal More and the size of the fragments indicating the close proximity of the actual vent. The lava and agglomerate of Preshal Beg lies upon a heterogeneous surface of trachytes, hawaiites and alkali-olivine basalts whereas at Preshal More, the trachyte is missing except as fragments in the agglomerate and lavas of mugearitic affinities are common. A substantially long period of quiescence is indicated prior to the resurgence of explosive activity and it is important in a consideration of the overlying lava and its petrogenesis.

Scattered exposures of agglomerate or tuff are found as small lenses at Talisker Bay (305308), Stachd on Soay Sound (421167) and Carbost shore (388313) but are comparatively minor. They nevertheless show that explosive volcanism was a frequent accompaniment to the eruptions of the lavas.

Many of the thicker lateritic soils show textures indicating an origin as tuffs or air-borne volcanic ashes and are found throughout the region, and are surprisingly common. An example from the slopes of Cnoc Leathan (441171) 300 metres north-east of An Leac shows a fluxion textured matrix of basaltic glass with shattered microphenocrysts of plagioclase and tuff carrying roughly equal percentages of lithic and crystal fragments. A thin and less well developed occurrence is found in association with the small bed of localised agglomerate in the cliffs at An Crocan (379189), west of Glen Brittle.

3.3 Conglomerates and Sandstones

3.3i Occurrence

Lenticular and channel-like bodies of conglomerate and sandstone interpreted as having been deposited by river systems, crop out among, and are therefore contemporaneous with the lavas at various localities within the Inner Hebrides (Harker 1904 , 1908, Geikie 1896 ,1897) (fig.3).

In west-central Skye, several such bodies are observed interstratified with the lavas near Glen Brittle and along the sea cliffs between Loch Brittle and Loch Eynort (Fig.2).

Along the margin of the Cuillin outer-gabbros, and extending in a line for 1.5 kilometres south-east of Glen Brittle House, three small outcrops of conglomerate and sandstone are found. The most southerly of the three, 1 kilometre south-east of Loch an Fhir-bhallaich between Coire Lagan and Coire na Banachdich (422204), exhibits a fine 10-12 metres section of indurated conglomerates and intercalated grey and green sandstones and siltstones cut by several minor intrusions. The pebbles in the lower of the two largest beds are mostly feldspathic grits and rare quartz-porphyritic felsites set in a matrix not dissimilar to that of the interbedded sediments and composed of subangular quartz and feldspar grains in a clay-rich matrix. Accessories include biotite, epidote and sphene while chloritic and serpentinous alteration is common. Many of the sediments themselves show graded bedding and small-scale slump structures. The upper conglomerate, only five metres from the gabbros, appears highly metamorphosed and incorporates pebbles of sandstone up to 4 centimetres in diameter, rare granophyre and basalt in a considerably more melanocratic, clay-rich matrix, which may conceivably be partly tuffaceous.

At Allt a Mhuillin, 800 metres to the north-west and 425 metres east of Glen Brittle Cottage and in the Allt Coire na Banachdich, 600 metres further north-west and 300 metres east of Glen Brittle House (416209, 414214) similar sequences of sediments are found. In both cases they are again truncated obliquely by the outer gabbros and show at least two beds of highly metamorphosed conglomerates separated by horizontally-bedded units which in some instances may be partly volcaniclastic in origin although the majority appears to be a rather fine-grained, immature arkosic rock. Poor exposure and invasion by minor intrusions close to the lava-gabbro contact make it difficult to determine the overall shape and relationship of these rocks. However, they do appear to be lense-shaped bodies with truncated tops.

Interlava conglomerates, outwith the main zone of alteration imposed on the country rocks by the intrusions of the Cuillin Complex, are found at two locations along the sea-cliffs between Loch Brittle and Loch Eynort.

At Geodh'a'Ghamhna (369197) in the cliff 500 metres east of Rubha Thearna Sgurr, at a level relatively low in the overall lava succession, the best exposures of these sediments in west-central Skye are encountered. An excellent succession is exposed on the south side of the small stream (Table 2). The north side of the stream is slightly down-faulted and reveals a substantially thinner wedge of conglomerates and buff-coloured sandstone lenses. The interleaved sandstones show some degree of false-bedding, ripple-like surfaces and poorly defined plant remains. One of the lower beds of sandstone is noted to continue north-westwards for about 100 metres (Plates 2-6). The sandstones themselves contain a high percentage of granophyric rock fragments and may be classified as granophyric feldspathic litharenites (Folk, 1974) but are not the tuffs supposed by Harker (1904 , pp.25-26).

In the ravine of the Allt Mor, 900 metres to the north-west, three separate conglomerates and associated sandstones are exposed interfingering with the lavas. Although heavily faulted and intruded by minor intrusions, the lower conglomerates are basically similar to those of

TABLE 2

Section in the cliffs at Geodh'a'Ghamhna. This is one of several localities in west-central Skye where sandstones and conglomerates are intercalated in the lava sequence. These have considerable palaeo-environmental implications for the Inner Hebrides region during the Lower Tertiary.

14.	Thin alkali-olivine basalts with scoriaceous tops totalling	7m
13.	Massive basaltic lava with pillow-structures towards the base	5m
12.	Thin white ash	0.03m
11.	Coal	0.05m
10.	Sandstone with obscure plant remains occurring as diffuse carbonaceous streaks and rootlets - possibly a seat-earth	0.2m
9.	Coal	0.01-0.05m
8.	Conglomerate with well-packed, rounded pebbles and cobbles of granophyre, quartzite, porphyritic felsite and red arkose, having a maximum diameter of 10-15cms in a pale sandy matrix	3.2m
7.	Sandstone with micaceous partings	0.2m
6.	Coal	0.02m
5.	Sandstone with plant remains	1.8m
4.	Conglomerate with a more 'sandy' matrix than Bed 2 and a smaller proportion of acid igneous rocks to arenaceous sediments among the pebbles than Bed 8. Rare pebbles of amygdaloidal and feldspar macrophyritic basalt. Clast size up to 30cms but averaging 10-15cms. Thin lenses of a white sandstone up to 5cms thick are present in the lower part	2.3m
3.	Sandstone with a fine-grained, sharply defined, laminated base	1.1m
2.	Massive conglomerate with densely packed and crudely imbricated clasts of red arkoses up to 30cm in diameter and green siltstones with a sandstone wedge thickening to the north	2.75m
1.	Highly amygdaloidal basaltic lavas forming the top of the cliff at about 125m above sea-level	10m

PLATE 2

A lenticular body of conglomerate and sandstone intercalated between the lavas of the Bualintur and Cruachan groups at Geodh'a'Ghamhna, and intruded by a thick columnar 'andesitic' sill which forms a rough dome at this locality.

PLATE 3

A small lensoid erosional channel infilled with immature sandstone cut into the intraformational conglomerates at Geodh'a'Ghamhna.

PLATE 4

The erosional top to one of the conglomerate beds, overlain by laminated and well-sorted sandstones exhibiting some false-bedding and possible small-scale ripple marks, at Geodh'a'Ghamhna.

PLATE 5

Detail of the uppermost conglomerate horizon at Geodh'a' Ghamhna showing the development of minor sandstones and thin coals (C). The conglomerate shows clasts of light-weathering granophyre and felsite and darker sandstones and siltstones in roughly equal abundance and only minor imbrication. The upper coal is succeeded upwards by a thin ash. The base of the overlying basaltic lava is considerably brecciated and exhibits some pillow-like structures.


c
c

PLATE 6

A large fallen mass of compact lava (L) within the red sandstones (S) forming the uppermost sedimentary horizon within the deeply incised ravine of the Allt Mor. The bedding below the boulder is noticeably disturbed. The sequence is overlain by a crudely columnar amygdaloidal basalt.


S
L
S

PLATE 7-A and 7-B

Two views of the sedimentary horizon between the Tusdale and Arnaval Groups as exposed on Ben Scaalan. In 7-A, an impure lignite (L) rests upon massive mudstones (M), while in 7-B, the lignite is reduced in thickness and orange and grey, bedded ashes and ironstones and laminated mudstones form the bulk of the exposure. The overlying flow is an olivine + plagioclase porphyritic basalt showing crude columnar jointing.


L
M

Geodh'a'Ghamhna containing abundant well-rounded pebbles of green and red grit and rare granophyre and basalt several centimetres in diameter. Towards the top of this deeply incised gorge, which is eroded along a major fault, the lowest conglomerate grades laterally into a coarse, reddish, arkosic sandstone and wedges-out below highly vesicular lavas. The uppermost sediment has an uneven base of pinkish, feldspathic sandstone into which large masses of lava have fallen, visibly disturbing the bedding (Plate 6). The proportion of amygdaloidal basalt fragments increases upwards but is never predominant over arkose. The deposit, some 12 metres thick, is extremely poorly sorted and immature and is overlain by highly amygdaloidal, often sparsely porphyritic olivine basalts which are the lateral continuations of the lower sequences observed in the coastal cliffs.

3.3ii Interpretation and Discussion

The overall shape and associations of lithology of these sedimentary bodies is consistent with deposition in a fluviatile environment, but the apparent scarcity of pebbles or even broken, degraded fragments of the lavas, which the streams were obviously eroding and the abundance of acidic igneous and arenaceous rocks, is worthy of further comment.

The differences in abundance of these rock types as pebbles is probably linked to their weathering style as well as to the action of the stream itself and the nature of the surrounding topography. With regard to their weathering characteristics, basalts differ from granitic rocks in several important respects. The minerals in basalt and related rock-types crystallise at temperatures about 300°C higher than those in granite and in a relatively anhydrous environment. The calcic and mafic phases in basalt will therefore decompose more easily (Goldich 1938, Blatt *et al*. 1972). In addition, basalts are generally more microcrystalline than granites and may contain substantial interstitial glass which will accelerate the decomposition process. These differences coupled with the fact that the average basalt contains about 12% total iron compared to only 4% in granite, leads to fairly rapid oxidation and the development, especially in humid climates, of soft, iron-titanium rich laterites and associated clay-soils on the basalts. That such weathering processes accompanied the extrusion of the lavas of west-central Skye is shown by the almost ubiquitous boles. Such rocks are unlikely to be preserved in sediments deposited by fast-flowing, strongly-eroding streams, and decomposition products would quickly be winnowed out from the inter-conglomerate sands as appears to have happened in Skye. In terms of resistance to weathering, arkoses and other quartzose rocks found in abundance in all the conglomerates would behave even more rigidly than granites, possessing as they do, a higher felsic content. Although carrying large pebbles the eroding power of the streams may not have been always high, and the conglomerates mainly deposited during periods of flash-flooding, with the sandstones and coals belonging to quieter periods of sedimentation when the water level and current strength were low.

The presence of acid igneous pebbles in the conglomerates argues the existence of a series of early Tertiary acid intrusions exposed somewhere in the region and being contemporaneously eroded with the lavas. No such body has been shown to exist in Skye although a hypothesis (Walker 1975) that the lavas and basic intrusive complexes of the Hebrides were preceeded by a general up-doming of the country rocks by rising granitic plutons, has strong supporting evidence from Arran, Mull, Ardnamurchan and Rhum. In the latter, the western granophyres are visibly older than the lavas and the Central Complex (Black 1954, Dunham and Emeleus 1967). The possibility, however, that these foreign pebbles may be derived from the erosion of extraneous vent agglomerates (Harker 1904 , p.26) must not be overlooked, but still indicates a period of earlier acid magmatism in the region. It has been assumed that the acid rocks are indeed of Tertiary age, as in their petrography they are fairly similar to some of the later Tertiary Epigranites and felsites of the Red Hills Complexes. They also bear reasonably close resemblance to some of the acid igneous rocks described from Rhum by Hughes (1960) and Dunham (1968) but the question of their ultimate origins must remain open to discussion and further investigation.

The sedimentary pebbles are, in most instances identical to the Torridonian arkoses and micaceous silt-stones exposed in west-central Skye at present along the shores of Soay Sound and on the Island of Soay (Clough and Harker 1904, pp.4-7) but need not have been derived from such a local source as the Torridonian forms the country rock to substantial parts of Skye. Although the Permo-Trias through to Cretaceous strata underlying the Tertiary lavas are exposed along Soay Sound and elsewhere, no pebbles of quartzite, sandstone, limestone or chert definitely belonging to them are recorded. Presumably therefore, these and the other extensive developments of Mesozoic sediments e.g. in Strathaird, were totally buried during the volcanic period and did not contribute to the conglomerates. One reason for their non-contribution may be connected with their having been down-faulted east of the Camasunary-Skerryvore fault which was active at the time. This, if an erosional fault-scarp was developed, would provide an effective barrier to the westerly transport of sedimentary material. Another probable source of typical Torridonian arkoses, siltstones and grits is of course the Island of Rhum which lies only 12 kilometres south of west-central Skye. It and the Island of Canna where conglomerates are also locally interstratified with the lavas, both also lie west of the Camasunary-Skerryvore fault (figure 3). Periods of relative quiescence characterised by conglomerates and other sediments are therefore features of all three islands and the possibility exists that they are more or less pene-contemporaneous. This is especially true of Canna and west-central Skye which have been shown by Binns et al. (1973) to be linked by a ridge of volcanics under the Sea of the Hebrides - the Canna Ridge.

Topographically, the landscape at the time must have been considerably subdued, at least in the lava field which was apparently developing over a gently subsiding basin. The Torridonian? and acid igneous clasts must have been eroded from an upland area of considerable relief at the margines of this basin to account for the general characteristics of the conglomerates. The island of Rhum lies close to the margins of this basin and is here considered the most likely source of origin of the clasts. However, an early weakness along the line of the Camasunary-Skerryvore fault

FIGURE 3

Geological map of the Inner Hebrides showing both land and submarine outcrops (after Binns et al., 1973) and the locations of interlava conglomerates which are known to contain acid igneous and Torridonian sedimentary clasts. Those of Canna carry gneissose clasts in addition and the likely origin for all of these is perhaps on the island of Rhum.

M.T.	Moine Thrust
S.F.	Strathconnon Fault
C-S.F.	Camasunary-Skerryvore Fault
C.H.	Cuillin Hills Basic Igneous Complex
R.H.	Red Hills Acid Igneous Complexes
W.G.	Western Granophyre
R.C.	Rhum Central Complex
A.P.C.	Ardnamurchan Plutonic Centres
M.G.C.[C].	Morvern Granite Complex (Caledonian)

Locality 1.	Glen Osdale
Locality 2.	Geodh'a'Ghamhna and Allt Mor
Locality 3.	Glen Brittle
Locality 4.	Sanday-Canna

■	Tertiary conglomerates
	Lavas, sill complex and Tertiary minor intrusions
(stippled)	Tertiary Plutonic Centres and Caledonian granite
A	Mesozoic sediments
B	Late pre-Cambrian and Palaeozoic (Torridonian, Cambro-Ordovician Sediments and Moine Schists)
C	Lewisian Gneiss

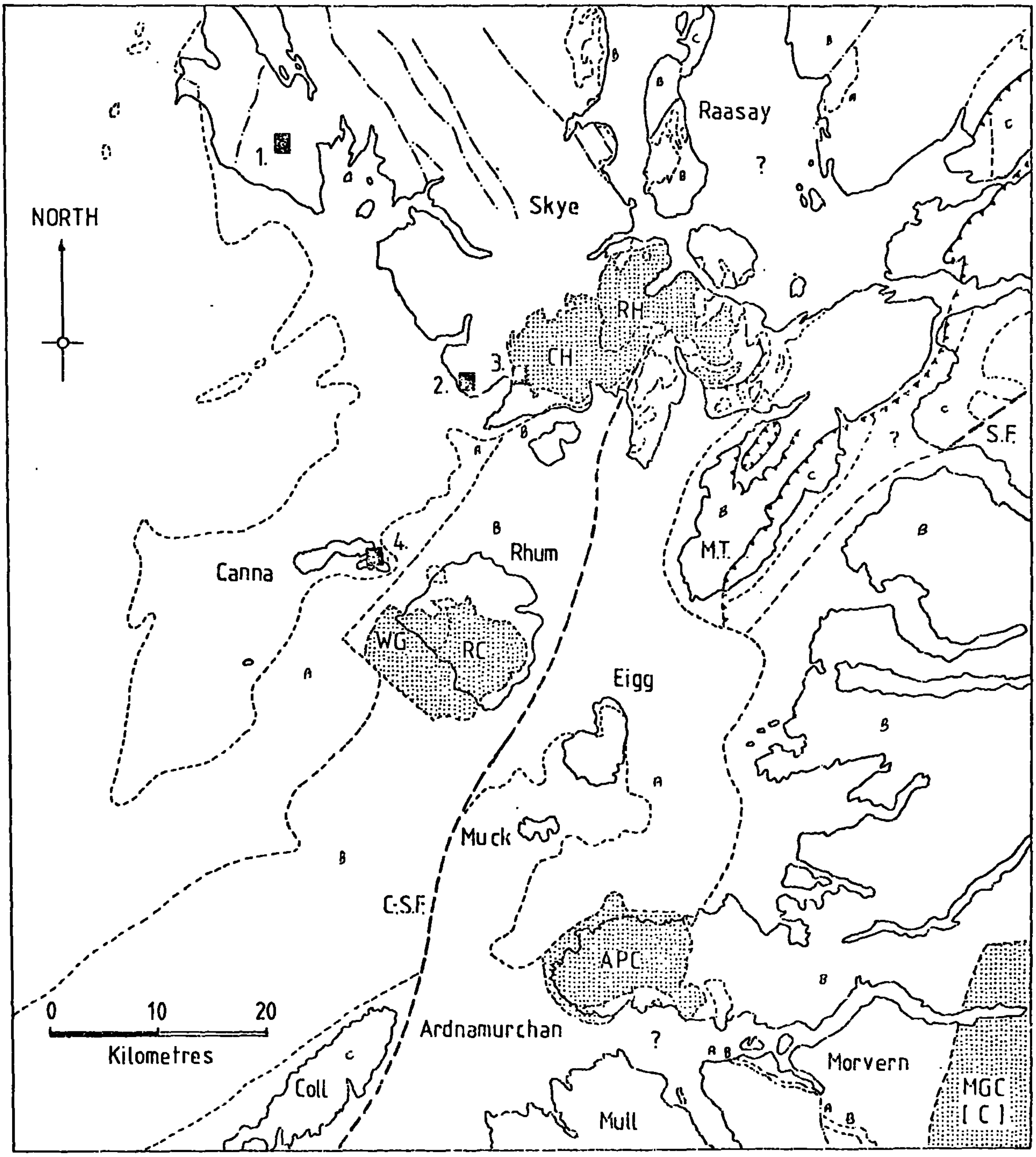
NORTH
Raasay
Skye
RH
CH
1.
2.
3.
4.
Canna
Rhum
WG
RC
Eigg
M.T.
S.F.
Muck
C.S.F.
APC
0
10
20
Kilometres
Ardnamurchan
Coll
Mull
Morvern
MGC
[C]

Figure 3

may have guided an early granitic pluton in Skye (Walker 1975), and the intrusions and breccias so produced, upon weathering could also explain the origins of the clasts in the conglomerates, subsequent cauldron subsidence and ring-faulting of this region possibly creating the space now occupied in part by the Cuillin Hills Intrusive Complex. The ultimate origins of these clasts can however only be speculated upon at present and until geochemical and mineralogical investigations are carried out on the granophyres and felsites for comparison with presently exposed Hebridean Tertiary acid rocks, will remain so. If however a series of pre-volcanic acid intrusions was responsible then their fate is unknown.

3.4 Lacustrine Mudstones and Laminated Ashes

In several localities often accompanying tuffaceous horizons, finely laminated orange-yellow and grey, highly ferriginous ashes and derived mudstones occur, their laminated nature, the presence of small loading structures and false bedding and the occasional carbonaceous streak probably indicative of a quiet water-lain environment. This environment is interpreted as being one of shallow, gently flowing streams with ponds or lakes on the weathered lava surface into which ash and volcanic dust, as well as the weathering products of the lavas were carried and laid down as muds and silts.

The largest occurrence of such sediments is found at Ben Scaalan (335260) 1.4 kilometres west of the summit of Beinn Bhreac and displays some 15 metres of intercalated mudstones and ashes and thin olivine-porphyritic lavas overlain by a couple of metres of orange mudstone and indurated ironstone with rare carbonaceous material, capped by a rather impure lignite (Plate 7). The deposit has no more than 50 metres lateral extent.

Lignite is also found on the south-west flank of Biod Mor (369269) but is very thin and localised while laminated mudstones appear near Beinn na Cuinneig (353269) and in the sea-cliffs of Beinn nan Cuithean (316285) where they are associated with globular masses of ash and highly decomposed lava (Plates 8,9) which overlie the thick succession of alkali-olivine basalts but preceed a series of more differentiated lavas as at Scaalan.

Again intercalated with thin (1-2 metres) olivine porphyritic flows at about the same horizon as Beinn nan Cuithean, brown and purple shales occur as sparse accessories to many of the interflow laterites at Talisker Bay (312306),

PLATE 8

Orange-brown ashy mudstones showing convoluted, but essentially horizontal, close-set laminations exposed at Beinn nan Cuithean. These are similar to those of Plates 7-A and 7-B and possibly belong to the same general stratigraphic level. The hard ironstone horizons of Ben Scaalan are absent.

PLATE 9

Globular ash and severely altered lavas weathering into pillow-like masses with vesicular margins. These rest directly upon the sediments of Beinn nan Cuithean and suggest a small body of standing water, possibly a small lake as the depositional environment for the finer-grained mudstones. The scale is graduated every 2 centimetres.

and also at the waterfall near the school house on Carbost Burn (374310).

3.5 The Stratigraphy of the Tertiary Sediments

Anderson and Dunham (1966 , p.77) report inter-basaltic horizons of various types, generally identical to those mentioned above, as forming predominantly during quiescent interludes in the eruption of the major lava groups of Northern Skye (Table 1). The stratigraphic positioning of these interbasaltic sediments in the Minginish district of Skye is complex and correlation between horizons fraught with difficulties due to the localised occurrence of the deposits and the heavily faulted nature of much of the terrain. However, following the example of the Geological Survey, the sediments can here also be employed to subdivide the lava succession into a number of stratigraphically important but essentially petrologically insignificant groups or associations.

The conglomerates and agglomerates between Glen Brittle and Loch Eynort appear at relatively low levels within the lava-pile, some possibly belonging to the same period. They separate three differing groups of lavas which have been given the names of the Meacnaish, Bualintur and Cruachan groups (see Chapter 6.2) in order of extrusion and characterising these localities.

The ashes, mudstones and lignites of Ben Scaalan and

Biod Mor crop out at a level much higher than the conglomerates and are perhaps contemporaries of the sediments separating the Ramascaig and Osdale groups of North Skye. In west-central Skye the groups are somewhat similar to those of the northern part of the island but differ in detail and are given the names of the Tusdale and Arnaval groups respectively.

The major agglomerate and tuff accumulations of Preshal More and Preshal Beg are the stratigraphically highest deposits found and intervene between the remnants of what may have been a series of lavas akin to the Bracadale group of Northern Skye and the low-alkali tholeiite lava of the above mentioned two hills defining the Talisker lava group.

CHAPTER 4

TERTIARY INTRUSIVE IGNEOUS ROCKS

The Tertiary intrusive rocks form an integral part of the overall igneous sequence in west-central Skye. To establish the petrography and essential geochemistry of these intrusive igneous rocks associated with the lavas and sediments, several examples of dykes, inclined sheets and the major intrusive bodies along the margins of the Central Complex were sampled from the localities shown (Fig.4). Most were analysed along with the main lava successions for both major and trace elements. They are divided as follows:

1. Basic and Intermediate Dykes.
2. Inclined Sheets and Cone Sheets.
3. Gabbros.
4. Ultrabasics.
5. Acidic Intrusions of Glen Brittle and late stage veins.
6. Intrusion Breccias.

4.1 Basic and Intermediate Dykes

As with most of the Tertiary Intrusive Centres of North-west Britain, Skye possesses a dense dyke swarm having a general distinctly NW-SE trend. The best sections, displaying the vast number of dykes that make up the swarm

FIGURE 4

Map of west-central Skye showing the location of the intrusions sampled in this thesis and the axis of the Skye Regional Dyke Swarm and associated sub-swarms (after Speight 1972 and Mattey et al. 1977).

Key

●	1-20 Dykes Dy001-Dy020
◎	Localities with many dykes and/or inclined basic sheets
⊕	Gabbros
◒	Ultrabasic plug
◓	Acidic Veining
	Inclined sheets and orientation also major sills
	Pre-Tertiary sediments
C.H.	Cuillin Hills Central Intrusive Complex
W.R.H.	Western Red Hills Complex
S.n.C	Srath na Creitheach Centre

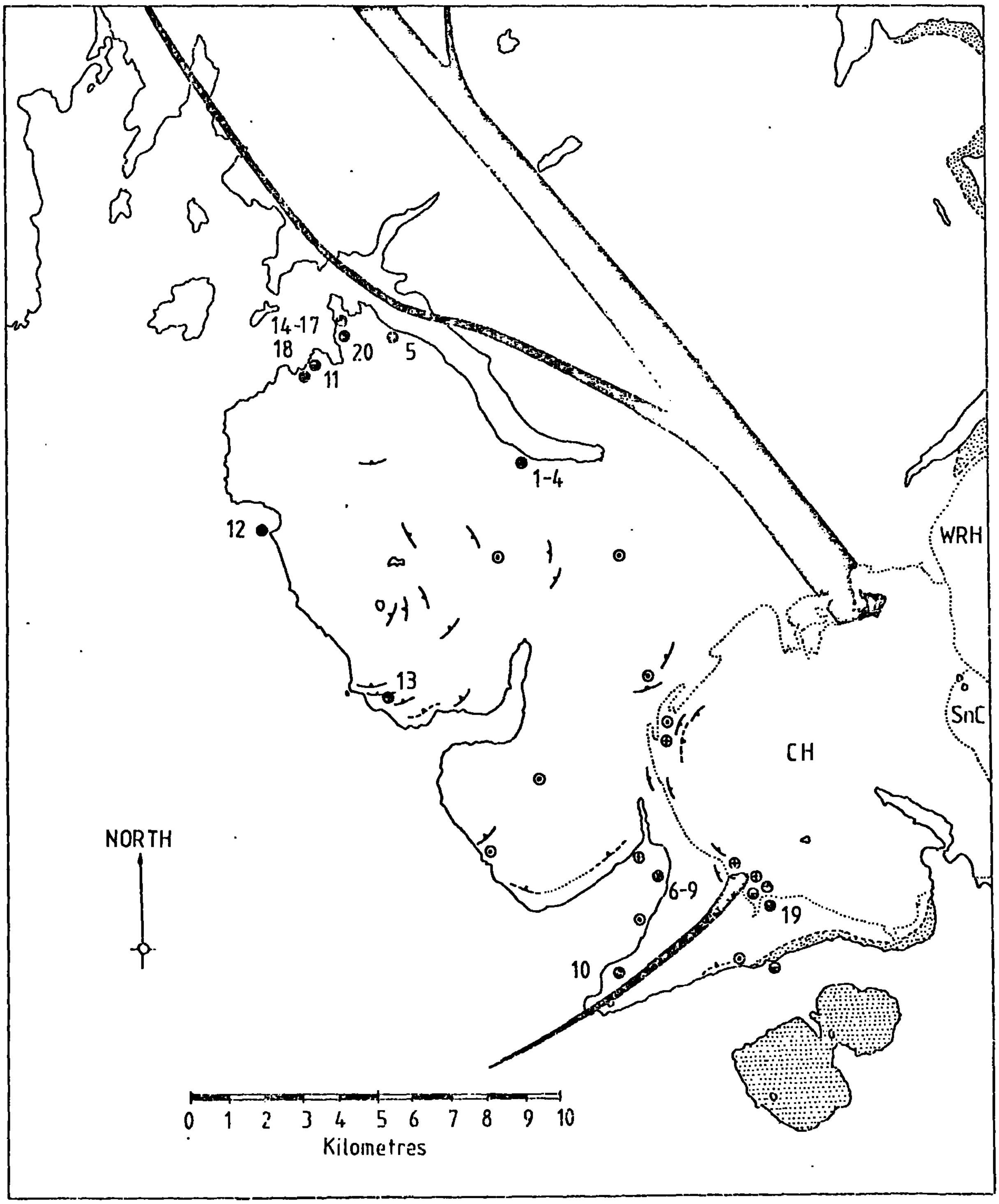
14-17
18
20
5
11
1-4
12
WRH
13
SnC
CH
NORTH
6-9
19
10
0 1 2 3 4 5 6 7 8 9 10
Kilometres

Figure 4

are therefore those oblique and ideally at right-angles, to the swarm trend. Consequently, the coastal section from the head of Loch Harport to Rubha nan Clach affords an excellent and well-exposed cross-section.

Some 35-40 dykes are recorded having an average thickness of 1.3 metres, average trend of $340^{o}/160^{o}$ and producing an overall crustal extension of approximately 1.5% but during the mapping of these intrusions it was obvious that a higher proportion was concentrated towards the Loch Harport end and conforming to a position much closer to the central axis of maximum dilation of the swarm which from the 1" Minginish Geological Map appears to run in a NW-SE line through the Drynoch area (Fig.4) (Mattey et al. 1977). Here Harker (1904) mapped vast numbers of dykes among which he recognised trachytic and compound types, a few of which are exposed in the Vikisgill Burn and the streams issuing from Moineach Mararaulin along the north-eastern borders of the area. Southwards from Loch Harport, many of the dykes seen along the coastal cliffs, which roughly parallel the fault and dyke trend, appear to acquire more westerly trends which only rarely become radial to the plutonic centres, as along the margins of the Cuillins at An Leac (441170) and north-eastwards from Rubha na Creige Moire (402178) (Plates 1 and 10, Fig.4). The majority of dykes encountered retain a broad

NW-SE trend right up to the margins of the Complex in Glen Brittle.

Morphologically, the dykes are frequently irregular in shape and thickness and may be undulating in their trends but mostly they appear to be remarkably rectilinear and of uniform dimensions depending upon the nature of the rocks through which they pass. Generally, the hades are to the north-east. In thickness they vary from a few centimetres to around 4 metres but nowhere is exposure good enough for them to be traced far, and inland, due to thick peat and moorland vegetation cover, dykes are only sporadically met with, their numbers nevertheless probably being high. On well-exposed inland cliffs such as on the north face of An Cruachan (385226) and Beinn a' Bhraghad (412253) numerous dykes traversing the lavas testify to their concealed numbers. Many of the thicker dykes have tachylitic margins and either vesicular or amygdaloidal centres often reflecting flow-lines. Two dykes carrying conspicuous xenoliths of gabbro are recorded. The first is a dunite cutting the early lavas at An Leac (441170) and the second at a considerable distance from the Cuillins near Sgurr nan Uan at Fiskavaig (325345) (Plates 10 and 11). Even the small numbers of dykes mapped tends to present evidence that the intrusion of the dykes was a polyphase process. The main evidence for this is the cross-cutting

PLATE 10

The xenolithic dunite-wehrlite-peridotite inclined sheet or dyke at An Leac emplaced within the basal lavas of the Meacnaish Group. The majority of xenoliths are gabbroic but allivalitic types are common. Note the rounded nature of many of the xenoliths.

PLATE 11

The xenolithic basaltic dyke at Fiskavaig Bay emplaced into the lavas of the Arnaval Group. In contrast to Plate 10, the essentially diffuse but angular nature of the wholly gabbroic, possibly cognate, xenoliths, is a notable feature.

relationships observed on the south-west facing slopes of Beinn a Bhraghad, along the shore south-west of Glen Brittle beach and towards the margins of the outer gabbros at An Sguman. These relationships involve both inclined sheets and the larger intrusions and the relative ages are summarised in 4.7.

4.2 Inclined Sheets and Cone-sheets

4.2i Inclined Sheets

Throughout many parts of the area, but increasingly towards the Beinn Bhreac (343267)-Stockval (350295) area between Gleann Oraid and Loch Eynort, inclined basaltic sheets are found intrusive into the lava succession (Fig.4).

In appearance they closely resemble the dyke rocks but are usually dull, orange-brown weathering, with minor cooling joints perpendicular to the contacts, generally only a metre or so thick, sparsely plagioclase porphyritic and inclined at various angles to the west and north-west although deflections of dip occur where they fail to penetrate more competent horizons, normally represented by the thicker intermediate lavas, as at Sgurr nan Boc (362207) (Plate 12). Mostly they are markedly transgressive towards the volcanics but may be more sill-like with only occasional transgressive leaps from one horizon to another. One of the more spectacular occurrences is at Stac a Mheadais (332254) where the relationships of at least six, light-

PLATE 12

An inclined basic sheet (S) transgressing the thin-bedded, highly amygdaloidal olivine porphyritic basaltic lavas (B) of Sgurr nan Boc. The sheet is visibly forced to assume a more sill-like attitude in contact with the overlying, more massive hawaiite lava (H). The latter also shows a characteristic 3-tier structure into lower and upper amygdaloidal zones with a more massive, crudely columnar central portion. The scale is given by the hammer near the base of the hawaiite and the displacement caused by the sheets intrusion shown by considering the position of the red-bole on the uppermost basalt.

PLATE 13

The sea-cliffs opposite Stac a'Mheadais exhibiting 4 to 5 thin, transgressive basic sheets (S) cutting the lavas towards the base of the Tusdale Group. The basal basalt and major red horizon can be seen forming the wave-cut platform and is overlain by a thick, columnar jointed mugearite (M), in turn overlain by a sequence of thin-bedded amygdaloidal olivine $\pm$ spinel $\pm$ plagioclase porphyritic basalts (B) capped by more massive basalts and an hawaiite forming the steep feature at the top of the cliff.


H
S
B


B
S
S
S
S
S
M

weathering sheets to the more melanocratic lavas and sub-vertical dykes are displayed (Plate 13). These sheets have uniform geochemical characteristics distinct from those of the lavas and are closely comparable to the Preshal More and Fairy Bridge magma type minor intrusions studied by Mattey et al. (1977). This aspect is dealt with more fully in Chapters 7 and 9.

4.2ii Cone Sheets

A second set of inclined basic sheets not related to the above-mentioned group are the Cone-sheets of the Central Complex. These are found throughout the Complex, comprising an almost complete set of minor intrusions dipping towards a common focus. More than one generation is recorded. (Bell, 1976).

Only a few are seen cutting the outer gabbros and the examples quoted occur cutting these gabbros in the Allt Coire Lagan near the lava-gabbro contact (431196). The best example (Sk760802) is 1.5-1.6 metres thick and has a dip of between 35° and 40° towards 065° but has a frequently irregular and chilled outline invading the gabbro as numerous minor basaltic tongues a few centimetres long. It, along with the other examples appears to be an olivine tholeiite or transitional olivine tholeiite.

4.3 The Gabbros

The marginal gabbros and outer ring-Eucrite of the Central Complex were both encountered during the mapping of parts of the lava-plutonic contact in, and south-west of Glen Brittle. The nature and chemistry of these intrusions has been dealt with by Hutchison (1964 , 1966 , 1968). Both types were investigated in the field and the specimens collected provide adequate background information as to the basic petrography and general geochemistry of that part of the Complex involved with the lavas in west-central Skye. A small gabbro plug two kilometres from the Complex was discovered in the weakly metamorphosed lavas south-east of Glen Brittle and its occurrence is reported here.

4.3i The Outer Gabbros

In shape, the principal units of the Central Complex are arcuate and form a funnel-shaped, layered intrusive mass cross-cutting the Outer Gabbros and Ring Eucrite. It is these latter gabbros that come into direct contact with the lavas of the western and south-western margins of the Cuillins. To the east of the area covered by this thesis, Weedon (1961) mapped the marginal gabbros as the Gars Bheinn gabbro and the Ring Eucrite. It is the Ring Eucrite which is noted to be in contact with the lavas at least as far west as Glen Brittle and it is characterised by a medium to coarse-grained rock sometimes of a pegmatitic nature and occasionally carrying highly metamorphosed xenoliths of the lavas as at the foot of Coire Lagan (432195). At this same locality and also close to the contact with the later ultrabasic mass of An Sguman, numerous dykes and sheets cut the gabbro which is frequently veined by irregular, thin, feldspathic veins. To the north, this coarse gabbro gives way to a doleritic rock but the junction is difficult to establish, being mostly gradational. The only other localities where the contacts with the lavas can be closely estimated are in the central and upper parts of Glen Brittle. Opposite the youth-hostel on the Allt a'Choire Ghreadaidh, the contact can be traced to within 2 metres and is chilled to a doleritic marginal rock. Here, the exceptionally coarse gabbro, which is very susceptible to weathering and is consequently much decomposed, sends flat or gently inclined tongues into the lavas (412226). Two kilometres further north, in the area of Leachd Thuilm the contact is considerably intricate with off-shoots of the gabbro and large detached masses of lavas (c.419242).

4.3ii <u>The Form of the Gabbro-Lava Contact in West-central Skye</u>

Weedon (1961) reports an inclined contact of 40^{o} or greater outwards or alternatively 40^{o} or less inwards as characteristic of the Ring Eucrite to the east and south of Gars Bheinn, based on considerations of exposure configurations, while similar considerations here applied to the ill-exposed marginal zone in most of west-central Skye suggest a 40^{o}-50^{o} outward dipping contact for much of Glen Brittle and either sub-vertical or steeply outward dipping contacts at An Sguman, and its immediate neighbourhood. In mid-Glen Brittle near Leachd Thuilm and some 2 kilometres west of Coire a Ghreadaidh, where detached lava masses are encountered at the margins of the gabbros, a low-inclined inwards and also outward dipping contact is common and a pseudo-lacolithic model not too dissimilar to that of Harker (1904) is easily envisaged in the field (Figs. 4 and 5). Unfortunately, exposure is poor in those areas of critical interest.

Small scale faulting is evident at a few localities but no anular folding of the country rocks is observed around this portion of the Central Complex in contrast to the anticlinal structure of the lavas immediately adjacent to the gabbros of the Blaven Range. In the area under discussion in this thesis, the lavas strike mostly parallel or near parallel to the contacts as in upper-Glen Brittle or are apparently sharply truncated as in the region of An Sguman.

In conclusion, apart from sill-like tongues of gabbro

FIGURE 5

Cross-sections across the margins of the Cuillin Hills Basic Intrusive Complex at Leach Thuilm (1), Glen Brittle Youth Hostel (2) and An Aguman (3).

Key

Tertiary lavas of the Meacnaish and Bualintur lava groups

Olivine + Plagioclase + Clinopyroxene porphyritic lava of An Sguman

Gabbros a-doleritic b-coarse grained c-porphyritic d-pegmatitic e-orthopyroxene bearing variant f-fine-grained tholeiitic sheets (e + f zenolithic)

Feldspathic peridotite

Intrusion breccia

Felsite

Feldspar macroporphyritic tholeiite

DY Dykes

CS Cone-sheets

f Faults

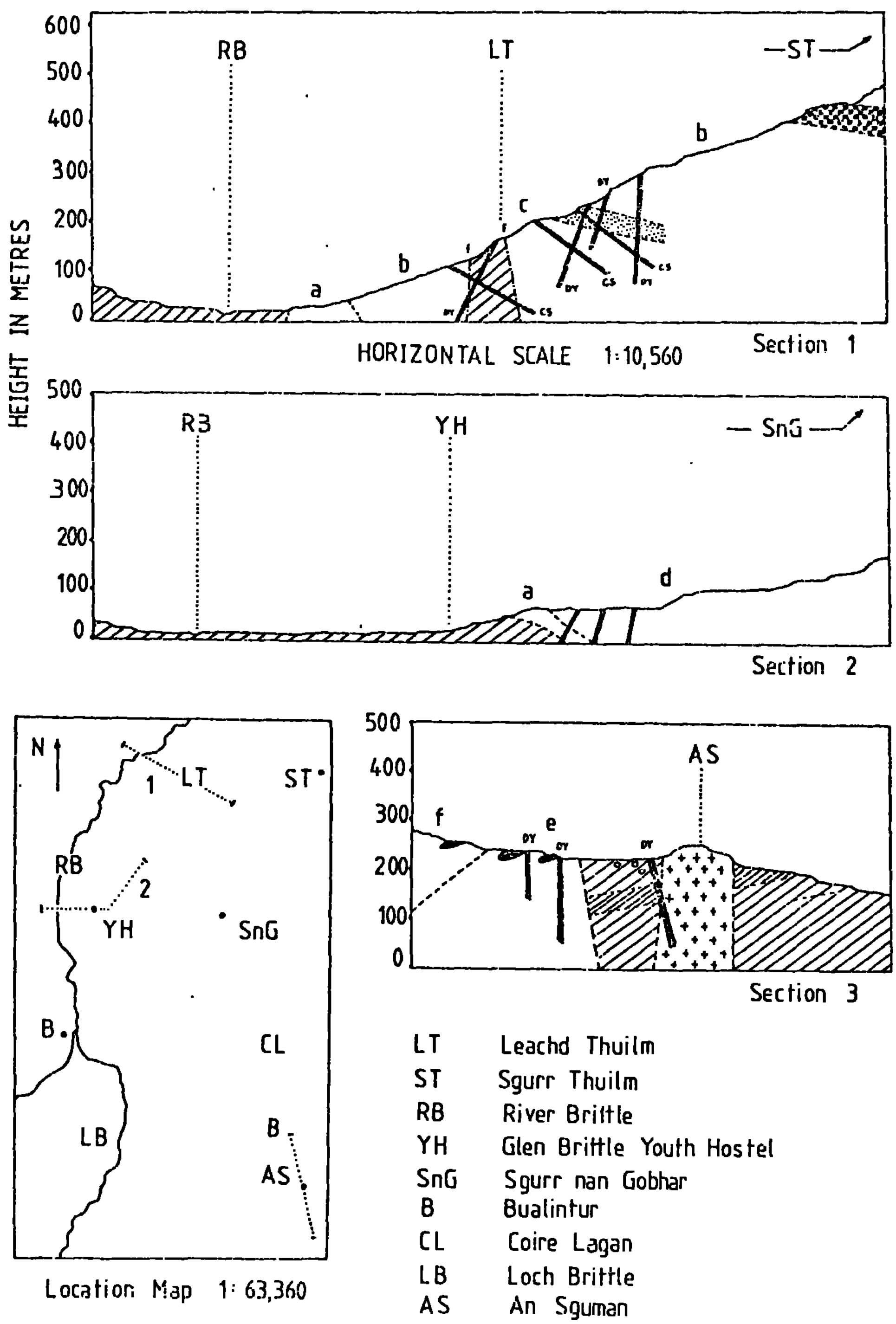
HEIGHT IN METRES
RB
LT
—ST—
HORIZONTAL SCALE 1:10,560
Section 1
R3
YH
— SnG —
Section 2
AS
Section 3
Location Map 1: 63,360
LT Leachd Thuilm
ST Sgurr Thuilm
RB River Brittle
YH Glen Brittle Youth Hostel
SnG Sgurr nan Gobhar
B Bualintur
CL Coire Lagan
LB Loch Brittle
AS An Sguman

Figure 5

in parts of Glen Brittle, the arcuate lava-gabbro contact in west-central Skye is for the most part outwardly inclined at angles varying from about 10° to 50°.

4.3iii <u>The Gabbro Plug of Loch Brittle</u>

A single, small and arcuate body of gabbro crops out within weakly thermally metamorphosed lavas 800 metres east of Sgurr Brittle on the north-west shore of Loch Brittle (c.397198). Its occurrence has not previously been mentioned and it is absent from Harker's detailed 1:10,560 scale map of Central Skye (1904).

Although only 70-80 metres wide, the internal variation in rock type and structure is interesting. The bulk of the intrusion comprises a rather dark, medium grained, reasonably dense gabbro which weathers with a brownish-orange hue. A finer-grained marginal facies is seen in contact with the lavas and is often heavily sheared parallel to the contact, perhaps indicating some post-emplacement movement along an arcuate fault. A remarkable feature is the presence of a number of highly feldspathic and hence much more leucocratic bands up to a metre thick and dipping in a general northerly direction at angles of 10°-15° but becoming progressively steeper towards the contact zone. These layers are petrographically and chemically distinct (See Chapters 7 and 9) from the host-gabbro but are not true cumulates attributable to <u>in situ</u>

crystal settling. They are deeply hydrothermally altered and friable with large pegmatitic patches and dendritic, frond-like growths of feldspar in some instances. The intrusion, whose seaward margin lies beneath Loch Brittle, also seems to possess a set of inclined joint planes dipping to the south-east. A couple of NW-SE trending dykes cut the intrusion.

The relatively close proximity of this plug to the small vents of south-east Glen Brittle beach might imply that similar plugs possibly underly the vents at depth, but in detail, although both are cut by the minor intrusions of the area, the alkalic lavas are thermally metamorphosed by the main gabbros while the gabbro which is of tholeiitic affinities similar to the main gabbros (Chapter 9) is probably contemporaneous with the main intrusive period in the area, and is relatively unmetamorphosed.

4.4 The Ultrabasics

The south-western margin of the Central Complex and the outlying lavas is characterised by the presence of ultrabasic intrusions of varying form and extent. A single boss-shaped body and dykes and sills are found.

4.4i The Peridotite Boss of An Sguman

An irregular, approximately 1 kilometre by 0.5 kilometre, steeply sided boss of feldspathic peridotite crops out at An Sguman (435188) cutting both marginal gabbros and the earlier lavas. The main body of the intrusion is formed from a yellowish, obviously olivine-rich rock which characteristically weathers reddish brown in sharp careous ridges and hollows. Variable feldspathic patches are encountered and give an impression in the field of some tenuous banding on a large scale but true layering is absent. In shape, the intrusion is somewhat irregular, possessing a number of dyke-like apophyses at the northern end in close proximity to the gabbros. Contacts with the gabbros and the lavas to the north are markedly transgressive, generally sheared, subvertical and often containing numerous cognate as well as accidental xenoliths.

4.4ii) Ultrabasic Dykes and Sills

The south-west margin of the Cuillin Hills is also characterised by a layered sill with dyke-like projections. It crops out east of the research area at Gars Bheinn and was studied in some detail by Weedon (1960). Various ultrabasic rocks from dunite to highly feldspathic peridotite are recorded.

Within five kilometres of An Sguman, within the lava succession, at least three minor ultrabasic intrusions are found. A 12 metres thick feldspathic peridotite dyke cuts weakly metamorphosed lavas at Carn Mor (393167) while the more altered lavas to the north-east at the mouth of the Allt Coire Lagan (412192) and the Allt na Buaile

Duibhe are cut by a 2 metre thick dyke of peridotite closely resembling the An Sguman rock and striking towards that locality. The last noted occurrence of ultrabasic rock is found a few metres to the east of An Leac and consists of an inclined and highly xenolithic, picritic to dunite sheet. The xenoliths in the lower parts of the sheet where it is in contact with the red sandstones of the Torridonian, consist of quartzite?, as well as basaltic and either layered or banded gabbro and allivalite.

A thick dyke to the West near Stachd (421166) may also be ultrabasic in character but was not sampled, and a thin radial dyke near the hornfels, near the small lochan north-east of An Sguman, is picritic in composition.

4.5 The Acidic Intrusions of Glen Brittle and Late-stage veins

Acidic intrusive rocks are rare in west-central Skye but a few examples, including the late-stage veins, originating within the outer gabbros, as they affect the inner-metalavas, are recorded.

4.5i) The Felsites of Glen Brittle

Several small masses of a dull, grey-pink coloured feldspar-biotite, fluxion textured felsite were reported by Harker (1904, p.55-62) enclosed within the marginal gabbros at Leachd Thuilm some 200 metres east of the roadbridge across the River Brittle and on the slopes of

Sgurr Thuilm to the north-east. Harker considered them earlier than the enveloping gabbros although the contacts were not exposed and because of this 'assumed' early age they were investigated during the present study as comparisons with the granophyre and porphyritic felsite pebbles of the interlava conglomerates. However, in thin section they are substantially different and no connection is implied. In the field they are intimately associated with the gabbros and detached masses of lava and well-developed hornfels. The mass near the roadbridge is intruded by several minor basaltic intrusions.

4.5ii) The Acid Dyke of East Loch Brittle

In the small bay immediately south of the small vent described in 3.1 (c.413195) a thin and very irregular porphyritic pitchstone cuts the lava succession. The dyke averages some 20 centimetres in thickness with a sinuous general trend to the east-west and a hade of 60° south. In handspecimen it is notably feldspar porphyritic, and bears a close similarity to a few of the felsite pebbles within the conglomerates.

4.5iii) Late Stage Veins

Along the margins of the outer gabbros, especially at An Sguman, thin granophyric veins and flats invade the gabbros and the metalavas. They are not confined to any particular trend and appear as irregular anastomosing strings, often in patches, and represent the latter stages of fractionation of the gabbros, or localised melts of the Torridonian which at this locality lies only some 250 metres below. The problem of their genesis is the problem of the origin of granites and is not dealt with in detail here, but being volumetrically insignificant it is possible that they originate from rheomorphosed Torridonian sediments, similar to some of the veins described as such near the gabbro contact in Strathaird, by Almond (1960).

4.6 Intrusion Breccias

Extremely rare, isolated patches of Intrusion Breccia are also associated with the lava-plutonic contacts at An Sguman. The metamorphosed basaltic lavas adjacent to the western contact of the An Sguman peridotite are brecciated and intimately intruded by a fine-grained olivine porphyritic variolitic basalt or intermediate rock. In the field, the rock resembles an agglomerate but the intrusive nature of the veining material is evident in thin section; the lava being hornfelsed and a chilled contact developed around many of the fragments. No other intrusion breccias appear to have accompanied the major intrusions in this region of Skye and this occurrence was probably a localised event consequent upon the emplacement of the peridotite.

4.7 Intrusive History

From the relatively few cross-cutting relationships observed, the intrusive igneous history of west-central Skye is seen to be complex and to occupy a considerable time span and was obviously a polyphase process with several intrusive episodes of dykes, sheets and plugs as well as the main event which produced the central complex. Table 3 attempts to set out the sequence as deduced from this limited study and from a consideration of the immediately bordering areas.

TABLE 3

The main intrusive events in west-central Skye as encountered in this study.

11	Doleritic and picritic dykes near the Cuillin margins
10	Intrusion breccias of An Sguman
9	Peridotite of An Sguman and Carn Mor
8	Cone Sheets
7	Acid, basic and intermediate dykes and sheets associated with Cuillin margins
6	Radial Tholeiite dykes
5	Ring Eucrite and Outer Gabbros
4	Inclined tholeiitic sheets throughout the area
*3	Tholeiitic and low-alkali tholeiitic dykes
*2	Minor vents, intrusive breccias, gabbroic plug and andesitic sill of Lower Glen Brittle
*1	North-west trending alkalic dykes and basal sill
	Agglomerates of Soay Sound

*Approximate position of the lava sequence as exposed at present (see also figure 47).

CHAPTER 5

THE STRUCTURAL ASPECTS OF THE VOLCANIC FIELD

5.1 The Inclination of the Volcanics

Unless controlled and influenced by the following and infilling of a pre-existing topography during the period of their formation, the volcanic series of west-central Skye has a regional dip varying between north and west. Minor departures from this norm are rare and the overall structure conforms well with the structure of a faulted, shallow oval basin for the Tertiary volcanics of Skye (Fig.2). The degree of inclination is highly variable with little or no systematic change from south to north although many of the lavas around Loch Bracadale are only gently inclined. One reason for the complexity in the amount and directions of dip is the presence of numerous conjugate faults which break the area up into a series of 'fault-blocks' of variable size. This structure is readily observable where exposure is good, such as in the region north of Gleann Oraid. Here, the predominant dip is about 7^{o} to the north-west but a localised reversal of $6^{o}/160^{o}$ at Coille-Ghuail (340348) is present. Many of the fault-bounded blocks appear essentially horizontal while others have marked inclinations. In the sea-cliffs at Sgurr nam Fiadh (328268), 1 kilometre south of Preshal Beg, the thin-bedded lavas are seen dipping at about 15°-20° to the north-west, while the adjacent fault blocks of Beinn nan Cuithean and Sgurr Buidhe are only moderately inclined to the north-north-west (Plate 14). Other extreme values are recorded at Cnoc Scarall and in the region of Sgurr an Duine. At the former, where the feldspathic trachyte occupies part of a former valley, dips of up to 25° are observed and at the latter, the hawaiite in the coastal cliff descends rapidly to near sea-level, dipping at 10°-12°. The olivine tholeiite of Preshal More lies on an uneven base of inclined lavas, and itself, as deduced from the flow banding at its base and the level of the contact between the main columnar zones, is also gently inclined to the north-north-west.

Anderson and Dunham (1966) imply that the majority of the recorded dips are mostly depositional and only partly of tectonic origin but this is not strictly true in west-central Skye where dips of 20°-30° are occasionally encountered. It is difficult to envisage, the considerably fluid and mobile flows as having such large initial inclinations and also some post-eruptive tectonic tilting of the lavas would be expected as magma withdrawal at depth caused the collapse of the lava-field by block-faulting. Geopetal structures in a number of the lavas furnish a clue to this problem and tend to indicate that the dips are mostly tectonically controlled. At present, the

PLATE 14

A view of the coastal cliffs of Sgurr nan Fiadh showing the thick sequences of thin-bedded basalts (B) with intercalated mugearites (M). The north-westerly dip of the lavas can easily be gauged from this vantage point looking across Loch Bracadale towards Macleod's Tables. The rugged and inaccessible coastline is due in part to the presence of two major faults (the Talisker Graben faults - F). The terraced or 'trap-featured' headland of Beinn nan Cuithean is seen on the skyline.

PLATE 15

A massive exposure of the Allt Mor breccia containing angular fragments of basalt and red-pink bole extensively veined by calcite and a range of zeolites.


F
M
F
B

geomagnetic evidence (Wilson et al., 1972) is rather inconslusive.

5.2 The Fault System

The major faulting directions appear to be parallel, normal and slightly oblique to the regional dyke swarm which trends north-west to south-east. The majority of faults recognised have only small displacements and are perhaps more correctly termed 'crush faults', but others, where determination of throw is possible, are found to have notable offsets. As evidenced from the relatively well exposed region north of Gleann Oraid, most of the north-west - south-east faults throw down to the north-east to east by between 10-50 metres, often repeating the lava succession e.g. one of the principal Hawaiites north of Arnaval is successively down-faulted towards the Ardtreck Burn and consequently crops out over a considerable area.

Major north-west - south-east faults such as the Portree fault, Loch Greshornish faults and the Loch Bay faults (Anderson and Dunham, 1966) have down-throws in the order of 350-400 metres and are responsible for the preservation of the later mugearite and trachyte lavas series of the Bracadale region. In west-central Skye, the Ardtreck fault is a major dislocation and may belong to this group. The olivine-tholeiite of Talisker owes its preservation to major faulting with displacements possibly of the same magnitude. Other faults are less significant but the cumulative north-eastern downthrow, despite a few south-westerly throws, must be considerable but due to the lack of distinctive, laterally continuous horizons, correlations between fault blocks is frequently impossible.

The majority of the set approximately at 90°-120° to the above faults, have variable downthrows to the north-west away from the Cuillins and tend to compensate for the north-west to south-east ones. This structure is readily observed in the numerous faults cutting the coastal cliffs north-west of Geodha Dariach (c. 314190). The only fault along this section with a major displacement comparable to the larger north-west - south-east faults, is the north-east - south-west trending Allt Mor-An Cruachan fault south of Loch Eynort. In general this southern region is poorly exposed and the main faulting is oriented south-west - north-east. The Allt nam Fitheach-Tusdale fault is similar.

Faults with marked lateral displacements are difficult to verify in the field but the larger faults all possibly have a lateral component.

Lineations such as narrow gullies and deflected streams recognised in the field or on aerial photographs are inferred to be fault-lines but only in a few cases is it possible to determine the relative movement.

Subsidiary faults, possibly younger than the main conjugate set, trend approximately north-south and east-west. They are not common but form prominent lineaments such as the small graben at Talisker and the prominent gullies of Sgeiteadh (354228) and Geodha nan Gobhar (354222).

The degree to which much of the poorly-exposed moorland may be faulted, is evidenced by the presence of numerous normal faults, with 1-2 metre displacements, cutting the often deeply weathered amygdaloidal basalts in the road-side cuttings of Gleann Oraid (336306), Glen Eynort (376293), Fiskavaig (333344), Glen Brittle (415278) and Fernilea (375320).

Mineralisation associated with the faulting is quite common but not invariably present and is generally of the same type as, and perhaps co-incident with the deposition of the zeolites and allied minerals in the lavas. Many of the small faults are characterised by papery veins of laumontite-montmorillonite-saponite assemblages with accessory stilbite (33344) or commonly chabazite (376293). The large fault 'zone' at the Allt Mor ravine consists of an angular breccia of basalt and red laterite (Plate 15) striking north-eastwards, traversed by thin veins of calcite. The zone is characterised by a well-crystallised laumontite-calcite-stilbite-heulandite (-quartz?) assemblage.

5.3 Structure of the Tertiary Dyke Swarm

Recently, Speight has made a comprehensive structural study of the Tertiary dyke swarms associated with Skye and Ardnamurchan (1972). Within the area covered by this thesis it appears that these dykes mapped as radial intrusions around Glen Brittle and Soay Sound constitute a 'sub-swarm' with a pronounced north-east to south-west lineation and roughly at right angles to the main NW-SE trend. The maximum axis of dilation through the Drynoch area (see also Mattey et al., 1977) makes a small off-shoot into Loch Harport and this may be due to the local concentrations noted around the Carbost area (Fig.4). The overall dilation at Drynoch is around 10% but this decreases rapidly to less than 1% at Talisker. The dykes recorded by Speight mostly have vertical margins whereas the limited study in this thesis indicates a hade more to the north-east. Other aspects of Speight's work including the broader structural relations of the Skye swarm are dealt with elsewhere.

CHAPTER 6

THE TERTIARY LAVAS

6.1 Structural Aspects of Individual Flows

6.1i) Dimensions of Flows

In west-central Skye, barring unusual environmental circumstances, the dimensions of individual flows varies greatly, with the thickness and lateral extent of many flows appearing to be broadly characteristic of certain rock types. This is linked to such physical properties as viscosity upon eruption, temperature and phenocryst content upon eruption, volume and effusion rate.

The highly olivine porphyritic basalts of An Cruachan (c.385225), Talisker Bay (312306), Ben Scaalan (335259), Truagh Mheall(388220) and some of the coastal cliff section e.g. Sgurr nan Boc (361208) are generally only 2-4 metres thick with ellipsoidal, massive central portions enclosed by highly vesiculate and sometimes scoriaceous lava (Plate 16). The thinner flows may be vesicular throughout and only centimetres thick (Plate 17). The lateral extent of such flows is never far and the lavas are seen to inter-digitate with one another. The combination of restricted size, which in part is probably controlled by surface irregularities of the flows beneath, and a high percentage of amygdales, leads to relatively rapid weathering, which, inland away from the coastal-cliffs,results in the development

PLATE 16

The upper cliffs of Sgurr nan Boc showing the numerous lenses of massive basalt lava (B) enclosed within less resistant amygdaloidal basalt (A). The irregular nature of the individual flows is easily seen. This structure characterises much of the lava-field and may represent near surface lava-tubes or points of auto-intrusion by an advancing flow, but is intercalated with more massive, thick, far-travelling hawaiites and mugearites.

PLATE 17

The extremely thin, wholly amygdaloidal olivine-porphyritic basalts of Sgurr nan Boc showing the characteristic reddened top (T) indicative of contemporaneous subaerial weathering, and thin massive centres (C) and surrounding amygdaloids (A). The intrusive sheet is that shown in Plate 12.


B
A
B
B
A
A
B


A
T
C
A
T

of characteristic concave, terracette slopes of scree and ill-exposed lava.

Less basic alkali-olivine basalts containing plagioclase as well as olivine microphenocrysts and a few flows intermediate between Basalt and Hawaiite are of variable thickness and lateral extent but mostly greater than the solely olivine or olivine and spinel porphyritic basalts. Being generally more massive in aspect they are more resistant to weathering and inland the majority of basaltic flows exposed are of this type. The Fiskavaig, Tusdale, Ceann na Beinne, and Biod Mor regions furnish good examples.

The strong terraced features so characteristic of the lava fields of the British Tertiary, were mapped in Skye by Harker as the "Great Group of Basic Sills" (1904). However, Anderson and Dunham (1966) showed that the vast numbers of such major intrusive bodies did not exist within the lavas but rather that the featuring was due to the contrasted weathering styles of massive and amygdaloidal lavas. In the majority of cases observed in west-central Skye these features are caused by the weathering of lavas more evolved than the alkali-olivine basalts but at An Leac and also at Creagan Dubh (352244) and possibly on the Allt Gearraidh Dhroighinn (399207) sill-like bodies of substantial thickness are found within the lavas. Their chemistry and petrography appear to distinguish them from the alkalic lavas (Chapters 7 and 9), but they are numerically subordinate to those lavas and also differ from the alkalic sills of the "Great Group" (Harker 1904 , Anderson and Dunham 1966) that intrude the pre-Tertiary formations. Within a normal sampling traverse of any major hillside no other 'sills' have been found but it is difficult to disprove the extrusive or intrusive nature of many of the massive columnar features along much of the inaccessible coastal cliffs as at Sgurr nan Boc (364205) (Plate 18). Hence the non-existence of major sills within the lavas is certainly implied rather than proved. The Hawaiite-Mugearitic lavas responsible for this featuring are generally finer-grained and less obviously porphyritic than the basalts and volumetrically substantial. On average, a thickness of between 8 and 12 metres is recorded as at Rubha nan Clach (302332), An Cruachan (381225), An Crocan (384191) and Beinn a' Bhraghad (410253) but many flows are considerably thicker e.g. Stockval (349296) and Na Huranan (348309) 22 metres, Talisker (304308) (Plate 19), and Beinn nan Dubh Lochan (315319) 25-35 metres and Biod Mor (371373) 20 metres. Many of these flows are also remarkably uniform with little or no observed thinning even over a distance of a few kilometres. In this respect they are similar to the mugearite capping the Beinn Edra Group of Northern Skye (Anderson and Dunham 1966 , pp.81-86) but do not even begin to approach the extents of some lavas in other Continental Flood-lava Suites e.g. Greenland, Karoo etc.

PLATE 18

A general view of the Sgurr nan Boc cliffs from the south-east across the Allt Mor ravine. The more massive horizons are hawaiites (H). A major fault separates this essentially flat-lying sequence from the north-westwards dipping lavas and conglomerates of the Bualintur and Cruachan Groups.


H
H

PLATE 19

The cliffs of Rubha Cruinn at the north end of Talisker Bay showing a well-developed red bole (R) on a thick mugearite flow (M), the partially brecciated base of which is markedly irregular and is seemingly transgressive to the bedding of the underlying minor agglomerate, olivine and olivine + spinel porphyritic basalts (B). Thinly bedded olivine basalts are also seen to succeed the mugearite. More resistant, massive, olivine + plagioclase porphyritic basalts (P) and a capping of columnar hawaiite (H) form the majority of the 130 metres high cliff.

PLATE 20

The western 'nose' of Preshal More showing the unconformable junction (U/C) of olivine tholeiite (T) on the lavas of the Arnaval Group (A). Hawaiites underlie the crags on the skyline but thin basalts (B) occur within the scree. The thick flow is a major mugearite (M). The crudely 2-tier columnar structure of Preshal More can be seen; a lower zone of wide, regular columns (2) underlying a zone of thinner twisted columns (4). The crush zones, some of which are small faults, characterise the entire lava field and can be seen crossing the precipitous cliffs in this photograph (C).


H
P
R
M
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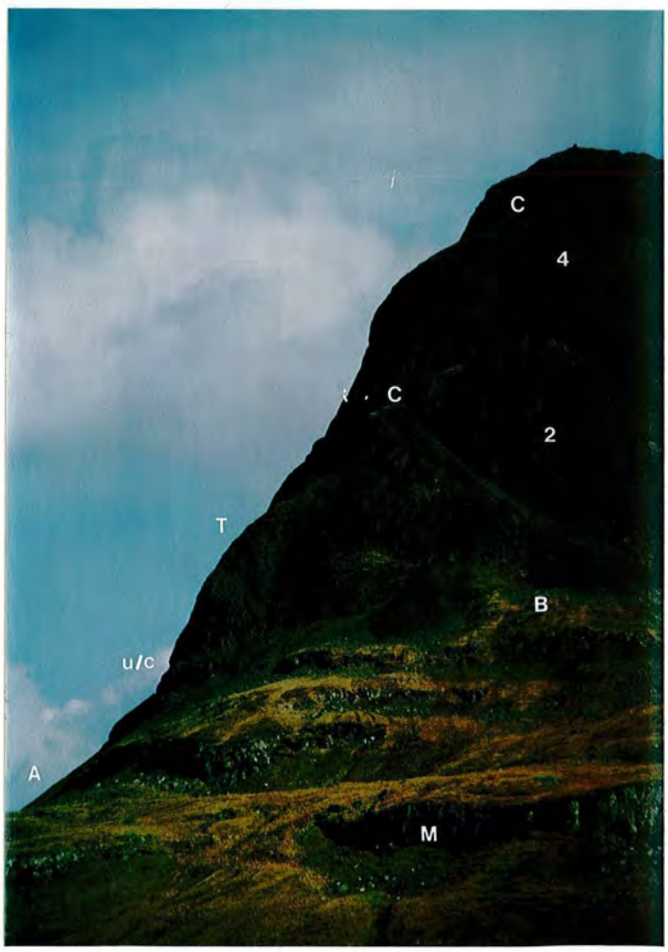
C
4
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M

which may run for many tens of kilometres. Evidence from flow-structures especially implies the more viscous nature of the intermediate melts and so the principal controls on lateral extent must be volume and the effusion rate. However, it is the Hawaiitic lavas that have the greatest lateral extents and it is possible that there is also a geochemical control upon viscosity. The most obvious feature of the hawaiites is an increase in iron-content coupled to titaniferous magnetite appearing as a major microphenocryst phase and this may play a leading role in the control of viscosity. As a consequence of the thicknesses of the intermediate lavas, vesiculation is considerably suppressed and the development of columnar jointing, due to relatively slow cooling rates within the interiors of the flows, is almost universally present to some degree (see 6.liv)).

Few lavas more differentiated than mugearite are recorded from west-central Skye and so no generalisation as to dimensions is relevant here. However, the Mugearite-Benmoreite of Cnoc Glas Heilla (349344) is 25-30 metres thick and in the field closely resembles the associated mugearites and hawaiites. The feldspathic trachyte of Cnoc Scarall (c.390284) and the iron-poor, but more mafic intermediate trachyte of Preshal Beg (c.328282) appear to be substantially thick. The latter, which may represent

PLATE 21

Panoramic view of Preshal More and Preshal Beg looking north and east from Ben Scaalan. The foreground valley is eroded along the line of a major-fault forming the eastern edge of the Talisker Graben. In the background are the characteristically 'trap-featured' slopes of Beinn nan Cuithean with Macleod's Tables visible in the distance across the mouth of Loch Bracadale.

more than one flow is 50-60 metres thick and confined to the slopes north of Preshal Beg, while the former, exhibits a maximum thickness of 90-100 metres. Topographic irregularities at its base, suggest the infilling of a former topographic-low and extent is small. A like, but much more spectacular occurrence is the high-Calcium, low-alkali olivine tholeiite (Thompson _et al_., 1972 , Esson _et al_., 1975) which forms the upper parts of the twin hills of Preshal More and Preshal Beg. Differing substantially in its chemistry from the alkali-olivine basalts and mildly alkaline differentiates upon which it rests, it appears to have infilled a valley eroded into these earlier lavas and to have been retained as a 'ponded' flow (Plates 20 and 21). A maximum preserved thickness of some 130 metres, the identical nature of the two erosional outliers, although now separated by 2 kilometres, and the configuration of the local topography suggest that it may have once occupied the central part of Sleadale prior to faulting and erosion.

6.lii) Structures Associated with the Upper and Lower Surfaces of Flows

The structural division of individual lava flows into 3 to 4 zones as recognised in Northern Skye (1966 , pp.80-81, 101) (Fig.6) is not a universal feature in west-central Skye. However, a feature common to all the exposed lavas is the presence of vesicular and amygdaloidal marginal

FIGURE 6

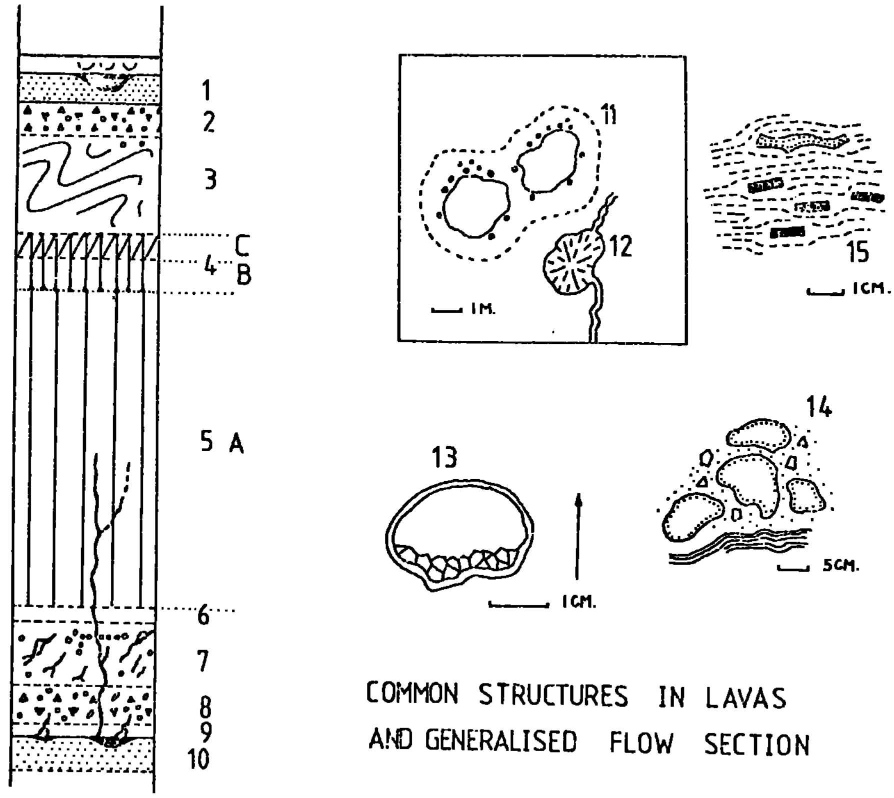
Common structures encountered in the lavas of west-central Skye and a generalised composite section through a flow.

Key Generalised flow

1. Upper surface bole with thin sediment accumulations in localised hollows. The overlying flow may have a crudely pillow-structured basal breccia where in contact with such sediments.
2. Brecciated top with rounded amygdales. Usually deeply weathered and reddened.
3. Flow folding.
4. Upper irregular columnar zone. C-contorted and chevron close-packed columns B-small regular columns.
5. A-Main columnar zone.
6. Structureless but massive zone.
7. Amygdaloidal zone with ovoid, anastomosing and inverted Y-shaped amygdales, inclined in direction of flow. Horizontal strings of amygdales are a common feature.
8. Basal rubble and breccia with sediments and amygdales.
9. Chilled base. Pipe amygdales and vesicle pipes originate here especially where sediments occur on the upper surface of the underlying flow. These pipes may rise considerable distances within each flow.
10. Bole and sediment on underlying flow.

Common structures

11. Lava tubes infilled with massive basalt which may be characterised by highly vesicular tops. Usually totally enclosed in amygdaloidal lava such as at Sgurr nan Boc.
12. Intrusion ending in a blind plug. Such occurrences as at Sgurr Mor near Tusdale may be small feeders to the thin olivine-basalt flows.
13. Geode. Inclination of zeolite infilling may indicate original orientation of lava surface.
14. Pillow-like lobes in brecciated lava and tuff developed on 'wet' sediments between flows.
15. Flow banding deflected around autoliths and phenocrysts.



COMMON STRUCTURES IN LAVAS
AND GENERALISED FLOW SECTION

Figure 6

structures to some degree, and usually reddened upper surfaces.

6.1ii)A. Amygdaloidal Structures

It is commonly the thin, olivine-rich basalts that display the best amygdaloidal structures. Easily accessible exposures at Talisker Bay, densely packed with amygdales containing a variety of zeolites and other minerals have been known for many years (M.F. Heddle late 1800's, 1901), and basal-flow structures are well developed. The proportion of amygdales usually decreases upwards away from the base or may be concentrated in a band a few centimetres above it. Occasionally there is evidence for trapped pockets of air, gas from burning vegetation or steam expelled from soils or water-logged sediments, resulting in bubbles rising en mass from the base of the flow. The normally sub-spherical amygdales-vesicles, become elongated vertically into pipe-amygdales which may coalesce forming inverted Y-shapes and be deflected in the direction of flow (306308) (Plates 22 a & b). Alternatively, the lava may brecciate (Plate 23) or disintegrate into pillow-like masses with interstitial areas of breccia, glass and sediment. This is probably the origin of the globular structures at Geodh 'A' Ghamhna (370297), Beinn nan Cuithean (316285) and the angular breccia directly under Preshal Beg (325280) (Plate 24).

PLATE 22-A

Small scale flow units in olivine-porphyritic basalts as seen at the north side of Talisker Bay. Pipe-amygdales can be seen rising and coalescing from the base of the upper flow which lies on a thin 'bole'.

PLATE 22-B

Close up view of the pipe-amygdales (para-vesicles of Whitford-Stark 1973) of Plate 22-A. Such inverted Y-shaped terminations are common and tilting of such pipes may indicate the direction of flow-movement of the basal parts of the flow but local irregularities in flow surface render the value of such features ambiguous.

PLATE 23

A typical basal flow breccia as exposed within olivine basalts on Loch Harport near Carbost. The flow has a necessarily irregular base which has either sharp or gradational contacts with the breccia.

PLATE 24

The basal breccia of the low-alkali olivine tholeiite of the Talisker Group as exposed at the western end of Preshal Beg, overlain by gently inclined tholeiitic lava (T). This breccia contains numerous lobate (pseudo-pillow) masses of glassy tholeiite (B) which decrease in size upwards towards the crudely laminated breccia (L) directly below the main flow. In conjunction with and associated with some laminated ashes and tuffs on the north face of the hill, these features suggest the presence of a body of standing water at the time of eruption.


T
L
B

Within the thicker basalts and differentiated lavas, basal amygdaloidal structures are relatively poorly developed. Many, small rounded amygdales, often in horizontal strings or layers, are common within a few metres of the base and occasionally ellipsoidal vesicles are found scattered throughout the flow. In these flows vertical or gently inclined strings of amydales or vesicle columns (Waters 1960), rising up through massive, almost amygdale-free lava are infrequently encountered but probably originate in much the same way as the smaller pipe-amygdales. Localised chilling is generally present around these structures.

Amygdaloidal zones at or near flow upper surfaces tend to be considerably thicker than those at the base and reflect the easier release of volatiles from a cooling lava. Amygdales are oval and may or may not coalesce forming swirling masses indicative of viscous flow.

Both the tops and bottoms of many flows are fragmental in nature and closely resemble deeply weathered agglomerates but the blocks are angular and monolitholigic. One of the best examples of such a flow is the 35 metre mugearite at Talisker Bay (Plate 19) which shows the development of a basal rubble, variable thickness amygdoidal zones, a columnar central portion and a brecciated lateritic upper surface. Its subaerial, extrusive character is beyond doubt. These structures are reminiscent of aa-type lavas rather than *pahoehoe* or block-types although all types are necessarily gradational.

6.lii)B. Lateritic Soils and the Reddening of Exposed Upper Surfaces

Primary surface features such as those characteristic of fluid pah-hoe-hoe flows today are readily destroyed by weathering. and intense weathering during the inter-lava episodes in Skye led to the development of reddened ferruginous upper surfaces, and during longer periods of non-activity, of lateritic soils and clays. Such horizons serve to delineate the individual flows and are especially common in west-central Skye along much of the coastal cliff (Plates 17, 19 and 22). Inland, all but the thickest 'boles' as they are known, are hidden by scree and vegetation unless large accumulations of thin basalts are prevalent as at Ben Scaalan, An Cruachan, Beinn a Bhraghad etc. Commonly, the larger laterites are preserved under thick differentiated lavas as is the case at Biod Mor (371272), Stockval (349296), North Arnaval (347322) and Beinn nan Dubh Lochan (315319). In a few cases, the variously-coloured 'boles' are noted to be 'bedded', or contain glassy pisolitic structures, perhaps originating as volcanic glass, indicating deposition by some medium, rather than the in situ weathering of lavas. A variety of similar structures are found among the lavas of Antrim (J. Preston, pers. communication), and may possibly be derived from the deposition of volcanic glass produced during lava fountaining. Many however may be considered true fossil soils of the 'ferralitic' and 'lateritic' types. The deep red to lilac horizons are generally compact and show little or no internal structure being therefore similar to the ferralitic soil type (Bridges, 1970) which today are freely drained profiles forming in areas of abundant water, high temperatures and instances where there is a long and uninterrupted period of weathering. Other interlava horizons may show an interiorly banded structure which possibly results from the washing-in or out of soluable constituents and their concentration in layers. Lateritic soil profiles or profiles containing indurated 'iron crusts' may form in this way, aided by alternate drying and leaching. This process tends to form an irreversibly hard ironstone layer as nodules, cellular masses or slag-like accumulations, and many of the beds at Ben Scaalan and Beinn nan Cuithean fit this description. In addition the lateritic horizons are more 'rust'coloured than bright-red. Vegetable remains are rare but may be preserved as thin carbonaceous streaks and lenses in the upper parts of the profiles. Frequently the soils are observed penetrating down into the weathered flow through cracks and fissures. This is probably due to some movement of groundwater through the rocks concerned carrying away soluble, but redepositing the insoluble, residue at lower levels.

Where a lava has overridden lignite as at Ben Scaalan (335260) (Plate 7), a thin white, clay-rich, occasionally calcareous alteration coats the flow base and may penetrate upwards into it. Similar alterations were noted by Waters (1960) in the Miocene lavas of the Columbia River Plateau, where they had come into contact with wood and accumulated plant debris. In the Midland Valley of Scotland, sills, commonly intruding carbonaceous strata produce an analogous, although better developed alteration known as 'white-trap'.

6.liii) Flow Structures

Apart from elongated vesicles mentioned previously, laminar structures reflecting flow lines within the lavas are commonly encountered but are almost exclusively confined to flows more evolved than basalt. In the field they frequently form an invaluable guide to rock-type.

In hawaiitic and especially in mugearitic lavas, the marked alignment of groundmass plagioclase laths and microphenocryst assemblages, imparts a well laminated and fissile character or fabric parallel to the base or upper surface of the flow. Oriented in the direction of flow, they indicate either of two directions of movement 180^{o} to each other. Where extreme development of this structure has taken place, small-scale folds may be preserved near the upper surface, the banding prescribing intricate contortions. Good examples are exposed at Rubha Cruinn (303308) (Plate 25), Loch Dubh (315328), Arnaval (345315) and Ardtreck Point (c.333360). Where a flow has an uneven base or is seen to follow a surface irregularity the flow lines may be steeply inclined as at Cnoc Scarall (c.390284), Sgurr Mor (303313) and Stockval (350299), or they may define shallow troughs as on the Allt Geodh'a'Ghamhna (371197) (Plate 26).

Orientation of tabular feldspar phenocrysts is less common. In intermediate rocks, it is generally sub-parallel to the flow banding as at Loch Dubh where irregular xenolithic flakes of chilled lava (Autoliths) may also be crudely oriented parallel to the base of the flow. In the comparatively rare 'Big Feldspar' rocks, this igneous lamination is absent or is either poorly or patchily developed as at An Sguman (438187).

A layering due to grain-size contrasts and pegmatitic segregation is occasionally present. Excellent banding attributable to differences in size and habit of the groundmass minerals is seen within the chilled base of the olivine tholeiite of Preshal More (c.331302) and some of the alkalic-olivine basalts near Beinnean Dearga (386295), while a combination of grainsize and opaque mineral modal variation produces a flow banding within the mugearite near the summit of Arnaval (c.345315) and in many hawaiites as

PLATE 25

A close-up view of the intricate minor flow-folding in the mugearite of Macfarlane's Rocks at the north side of Talisker Bay. This structure is superimposed upon a series of larger scale synformal and antiformal folds on the upper surface of the flow.

PLATE 26

The infilling of a small erosional trough in basaltic lavas by a later mugearitic flow near the Allt Geodh'a' Ghamhna is shown here to be excellently accentuated by the fluxion banding (parallalism of groundmass feldspars etc.), so common in intermediate lavas.

at Beinn nan Cuithean (c.316291) and Stockval (350298, 355294).

6.liv) Jointing within Individual Lavas

6.liv)A. Columnar and Block-Jointing

The massive central zones and lenses of thin lava flows of all types, characteristically display widely-spaced and irregular jointing systems parallel and perpendicular to the flow margins, resulting in the formation of cuboid blocks. Columnar jointing is only rarely attained in these flows and almost never in the olivine-rich and thin alkali-olivine basalts - a feature reported to be characteristic of the olivine basalts of the Cascades (Waters 1960). The thicker flows, due to a prolonged cooling period, tend towards a more regular columnar or prismatic jointing but surprisingly few good examples are found in west-central Skye, the majority being rather rudimentary. Occasionally as at Talisker, Beinn nan Dubh Lochan and Stockval, where flows of intermediate composition have been extruded onto a surface of thick bole or sediment, the columnar jointing is more perfect. This suggests that the best jointing is formed when the underlying surface is wet, bringing about more effective initial cooling. Similar evidence for the occurrence of columnar jointing in Hawaiian Lavas is given by Macdonald (1968).

Probably the best, and certainly the most spectacular, example of columnar jointing in a lava flow on Skye, is presented by the olivine-tholeiite of Preshal More and Preshal Beg and the occurrence is reminiscent of the spectacular flows forming the Island of Staffa off Western Mull, and the Giant's Causeway, Co. Antrim, Northern Ireland. As mentioned previously, this flow probably infilled a valley, floored by earlier lavas, agglomerates and water-lain tuffs, forming a vast lava-lake some 150 metres deep by at least 2 kilometres long. Consequently, slow and uninterrupted cooling brought about the formation of an exceptional display of columnar jointing (Plates 20, 27 and 28).

In detail, the columnar jointing is roughly divisable into three major zones (Fig.6). The columns of the basal Zone A are thick, well-formed, essentially non-amygdaloidal and usually have regular polygonal cross-sections. Six and five sided columns are the norm and approximately equally abundant while four to seven sided ones may be found. The columns are also notably variable in size, ranging from about 30 centimetres to around 1 metre in diameter. A notable feature is the presence of a series of joints perpendicular to the length of the columns and roughly parallel to the flow base. These have been termed 'chisel structures' (James 1920) and may represent

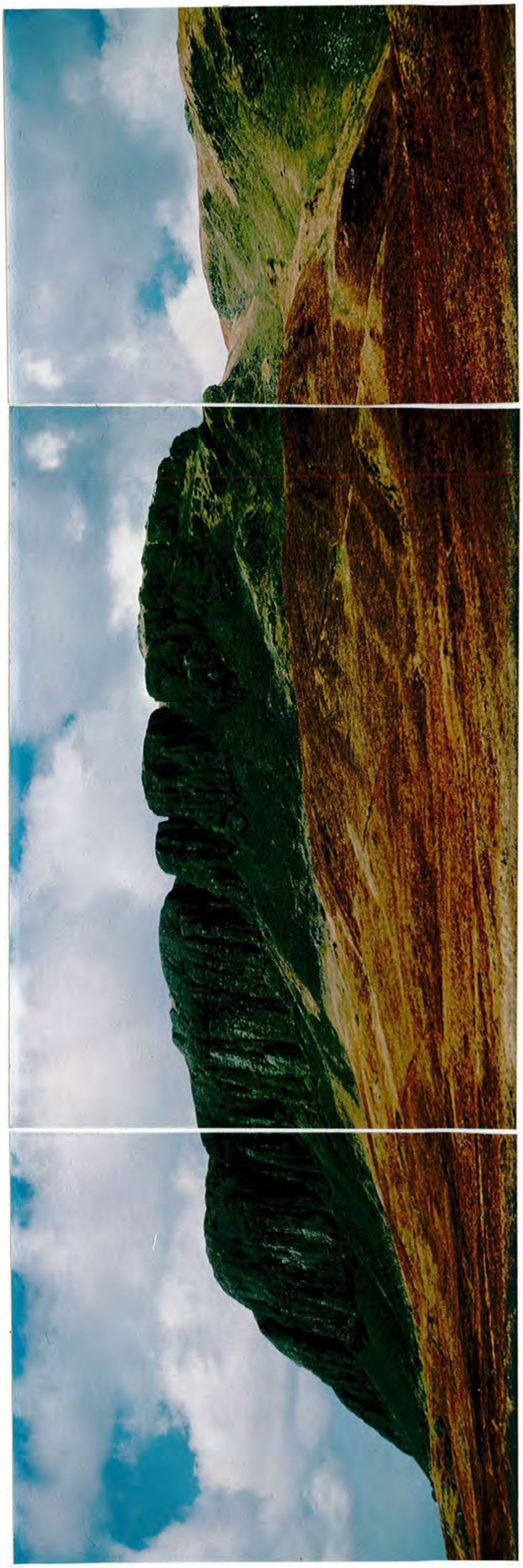
PLATE 27

The low-alkali olivine tholeiite of Preshal More and Preshal Beg is characterised by exceptionally well developed sets of columnar jointing implying rather static, slowly-cooling conditions. This photograph shows the junction between the regular columnar zone (2) and the upper irregular columns which show several sub-divisions (4A, 4B and 4C). The junction is characterised by a thin zone (3) with prominent horizontal jointing and a finer-grain size (the Fissile-Laminar Zone - see text). Photograph of the NW face of Preshal Beg.


4c
4b
4a
3
2

PLATE 28

Panoramic view of Preshal More from Sleadale displaying the planar junction between the upper (4) and main (2) columnar zones, and the minor cross, crush-faults which have been accentuated by gullying and erosion. The eastern boundary fault to the Talisker Graben is situated along the line of the hollow on the extreme right and separates tholeiite from olivine porphyritic alkali basalts overlain by intermediate lavas on the skyline.



successive periods of formation. They vary between 1 and 10 centimetres apart. A thinner, upper sub-zone to these main columns may occasionally be present. The thickness of Zone A is variable but is generally between 35 and 50 metres, representing between a half and a third of the overall thickness of the flow.

The upper parts of the flow may be divisible into two other zones; Zone B and Zone C, although they are often not readily distinguishable. On the north face of Preshal More, Zone B comprises three sub-zones with smaller but still regular columns with a progressive diminution in size and inclination. Zone B is succeeded upwards by Zone C which displays irregular, fan and chevron-shaped columns. The diameter of the columns is generally less than 30 centimetres. Zones B and C also show a progressive increase in vesicularity but nowhere does it reach the proportions attained in thinner flows. Thicknesses are again variable, Zones B and C in a 1:2 ratio and forming the upper two-thirds of the flow. The origin of the irregular columns, here and elsewhere is linked to the more effective cooling brought about by exposure to the atmosphere and may in particular be modified by surface streams and rain trying to percolate down through the flow and consequently disrupting and modifying the isothems and hence the directions towards which the columns will grow.

The main joint-zones A and B are separated by a thin series of joints normal to the junction. This intermediate zone or 'laminar-zone', is only 70-80 centimetres thick but has certain petrographic features indicating some degree of movement of liquid, possibly due to readjustment between the zones during cooling.

The inclination of the columnar structures, being normal to the cooling isotherms is complex but the base of Zone A is often inclined at angles of up to 50^{o} inwards and occasionally appears near vertical as on Preshal More (334300). Preshal Beg and the western margin of Preshal More possess more gently inclined bases (Fig.7) and these contrasted relationships possibly indicate the proximity of Preshal More, especially the north-eastern margin, to the restricting valley wall. This contact is also faulted but whether or not a fault-bounded valley was present prior to the eruption of the tholeiite, is conjectural. Dyke-like sheets of chilled columnar tholeiite also appear at the north-eastern margin; the chilling being most evident close to the fault and so again indicating the proximity of the original valley-wall.

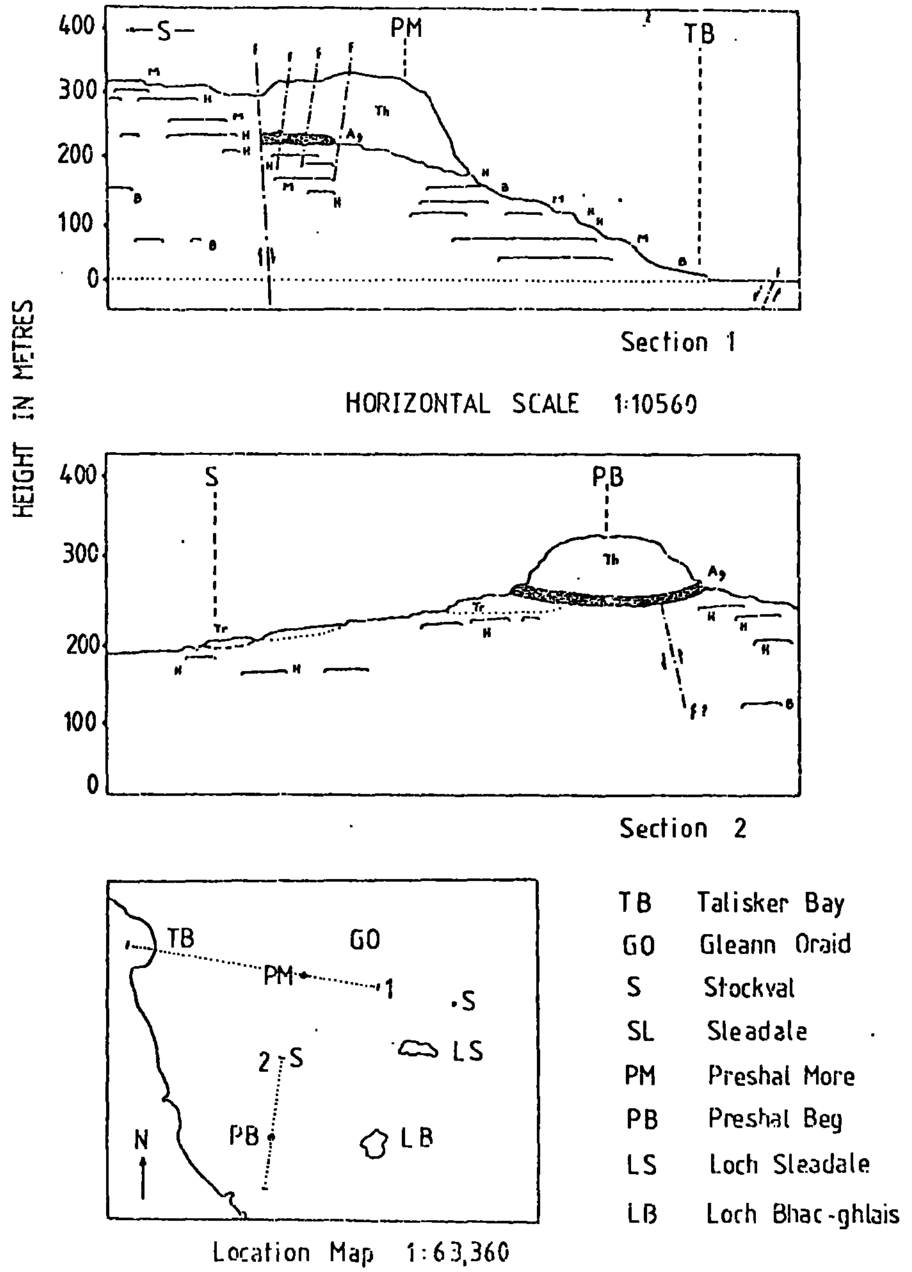
6.liv)B. Other Jointing Systems

Columnar jointing is not the sole form of jointing that finds expression in the lavas of west-central Skye. Commonly, in the intermediate lavas, flow banding is

FIGURE 7

Cross sections of the Talisker lava group at Preshal More (1) and Preshal Beg (2) showing the unconformable heterogeneous junction between the low-alkali tholeiite and the alkalic and sub-alkalic lavas.

■	Ag-Agglomerate and bedded tuff
Th	Tholeiite
B	Basalts of Alkalic/Sub-Alkalic Suites
H	Hawaiite
M	Mugearite
Tr	Trachyte
---·f	Faults



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Location Map 1:63,360
TB Talisker Bay
GO Gleann Oraid
S Stockval
SL Sleadale
PM Preshal More
PB Preshal Beg
LS Loch Sleadale
LB Loch Bhac-ghlais

Figure 7

accompanied and paralleled by close-set joints which break the rock into thin sheets or plates (Plate 29). In the field this may be so well developed that the rock resembles a schist, and the collection of unaltered samples impaired. At high angles to this set of 'flow joints' another, but 'closed', joint series is developed, possibly representing the rupture of the solid shell due to internal movement within the still molten core. In thin section, this structure may resemble the 'strain-slip cleavage' of schistose rocks (Chapter 7). At Loch Dubh (315328), Ardtreck Point (c.333360) and Cnoc Scarall (c.390284) the attitude of the flow jointing is observed to progressively increase from subhorizontal to close to the vertical. The strike of this structure is probably in the direction of flow but determination of the absolute sense of direction is consequent upon the interpretation of other structures. In west-central Skye, the strike is roughly northwest-southeast. Subvertical flow joints are characteristic of the tops of the majority of intermediate flows and are found throughout the area and often large-scale folds are prescribed by this jointing; good examples being Ardtreck Point and Macfarlanes Rocks (c.300314). Minor variation in the morphology of the flow-jointing appears in the Allt Geodh'a' Ghamhna where it accentuates the 'trough' structured flow banding (Plate 26) and at Coir'an Rathaid (388288) where

it visibly plunges into the small valley along the eastern tributary of the Allt a' Chairn.

6.2 The Stratigraphy of the Tertiary Lavas

Complex cross-faulting, the lack of easily distinguishable marker horizons and the poor degree of exposure of much of the area, renders the construction of a comprehensive stratigraphical sequence difficult. The possibility that the lavas originated from more than one fissure and commonly interdigitate with one another also complicates the overall picture, but by employing the interlava sediments, as indicators of hiatii in eruption, to divide the sequence in west-central Skye into a series of locally correlatable sequences known as 'lava groups', a basic stratigraphy may be constructed. This technique was also used by Anderson and Dunham for Northern Skye (1966) and for that region, appears to be valid on supporting geophysical evidence from Wilson et al. (1972).

For convenience, the lava groups have been given local names, characterising the region in which they are best exposed. Details of each group are summarised in figures 8 to 15 and the proposed correlation between them given in Figure 16. The groups are as follows:

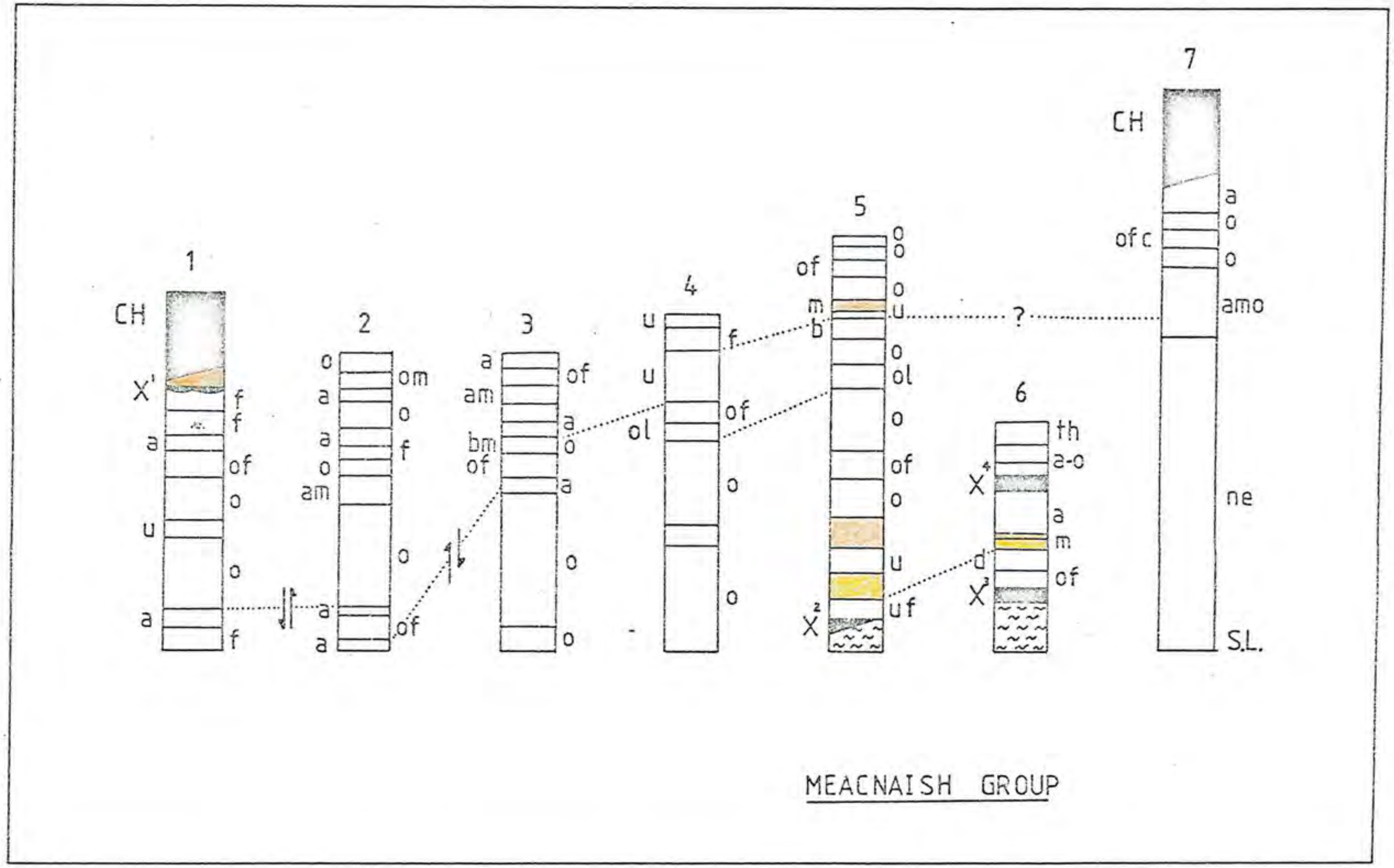
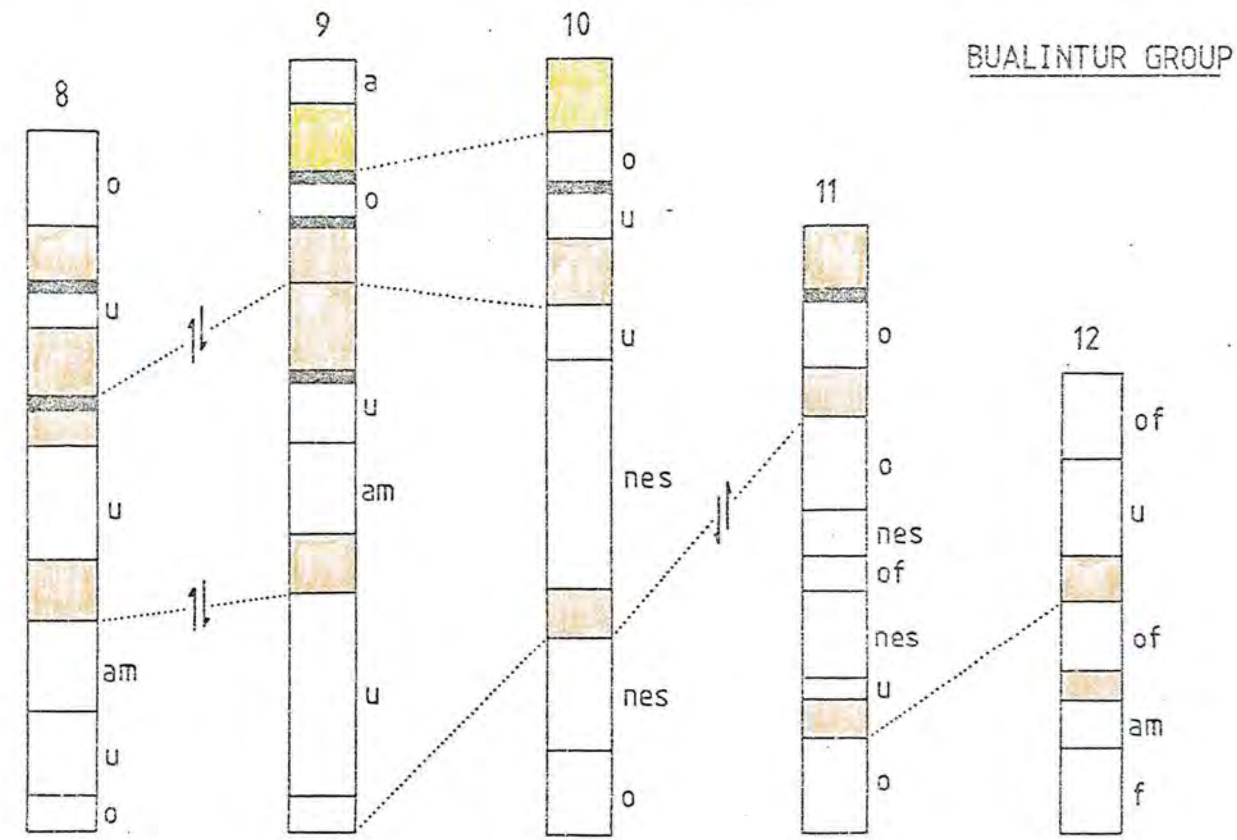


Figure 8



Thick, possibly partially sedimentary 'boles' in cliff sequences

Figure 9

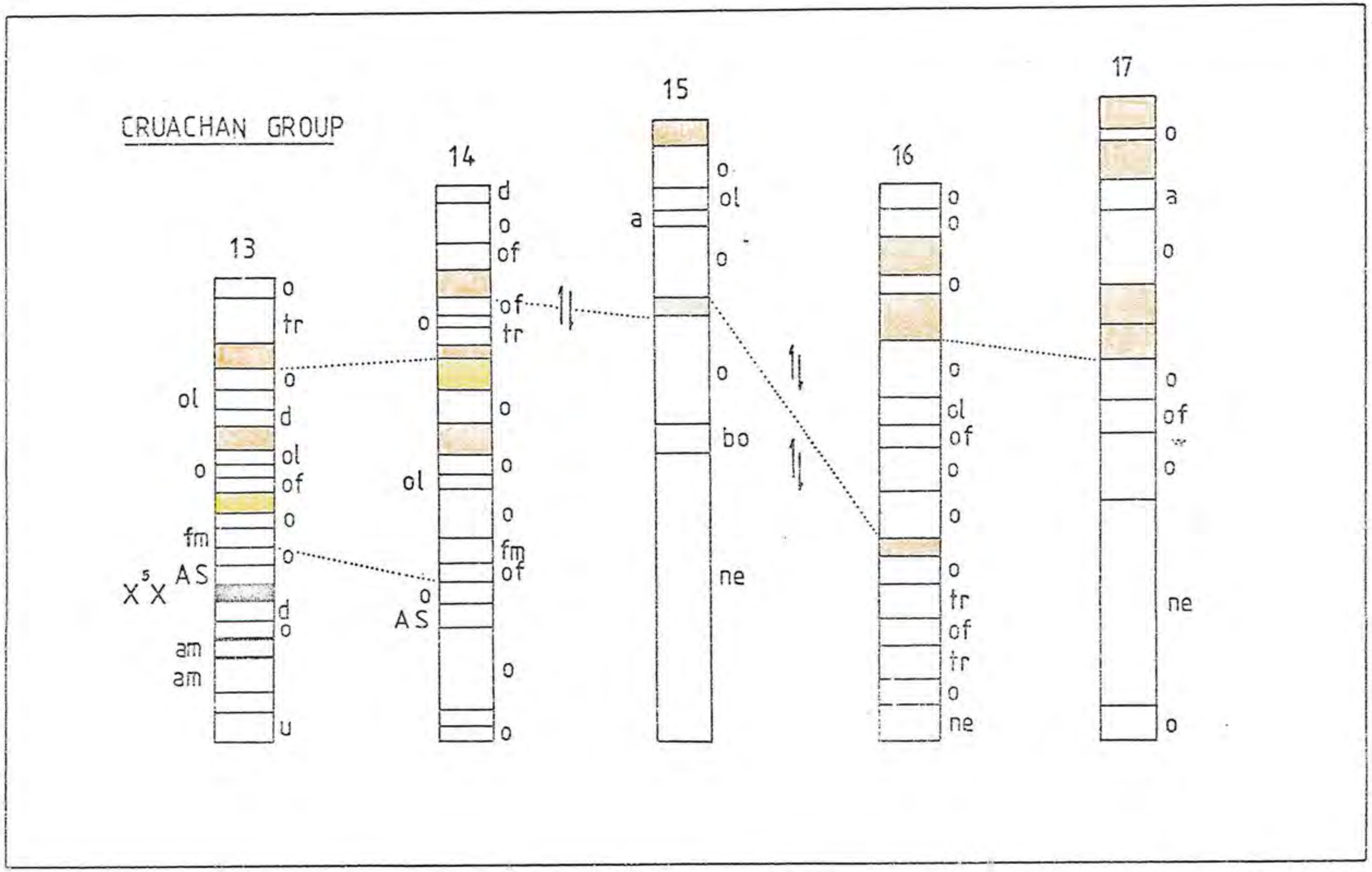

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Figure 10

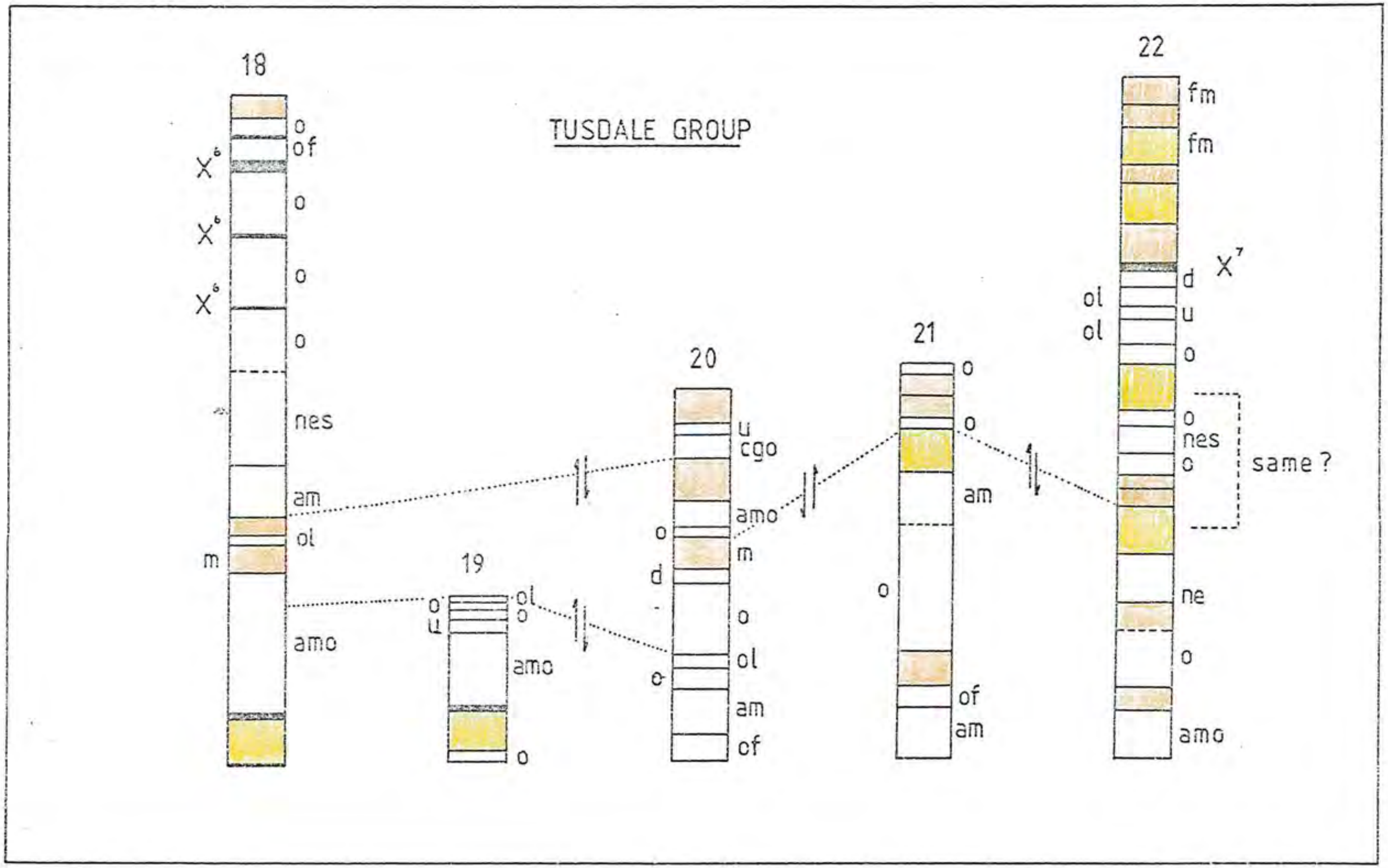

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Figure 11

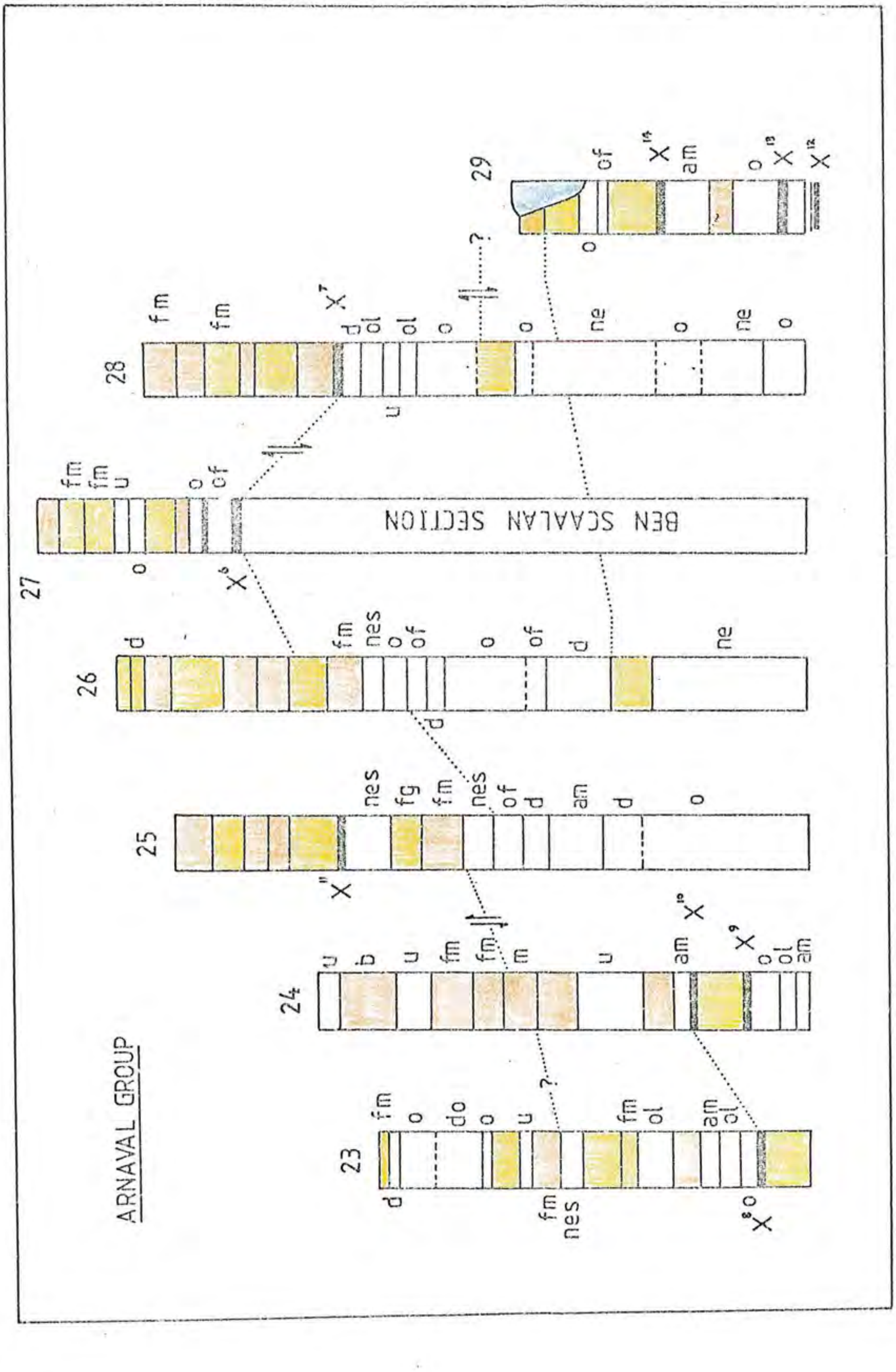

Figure 12

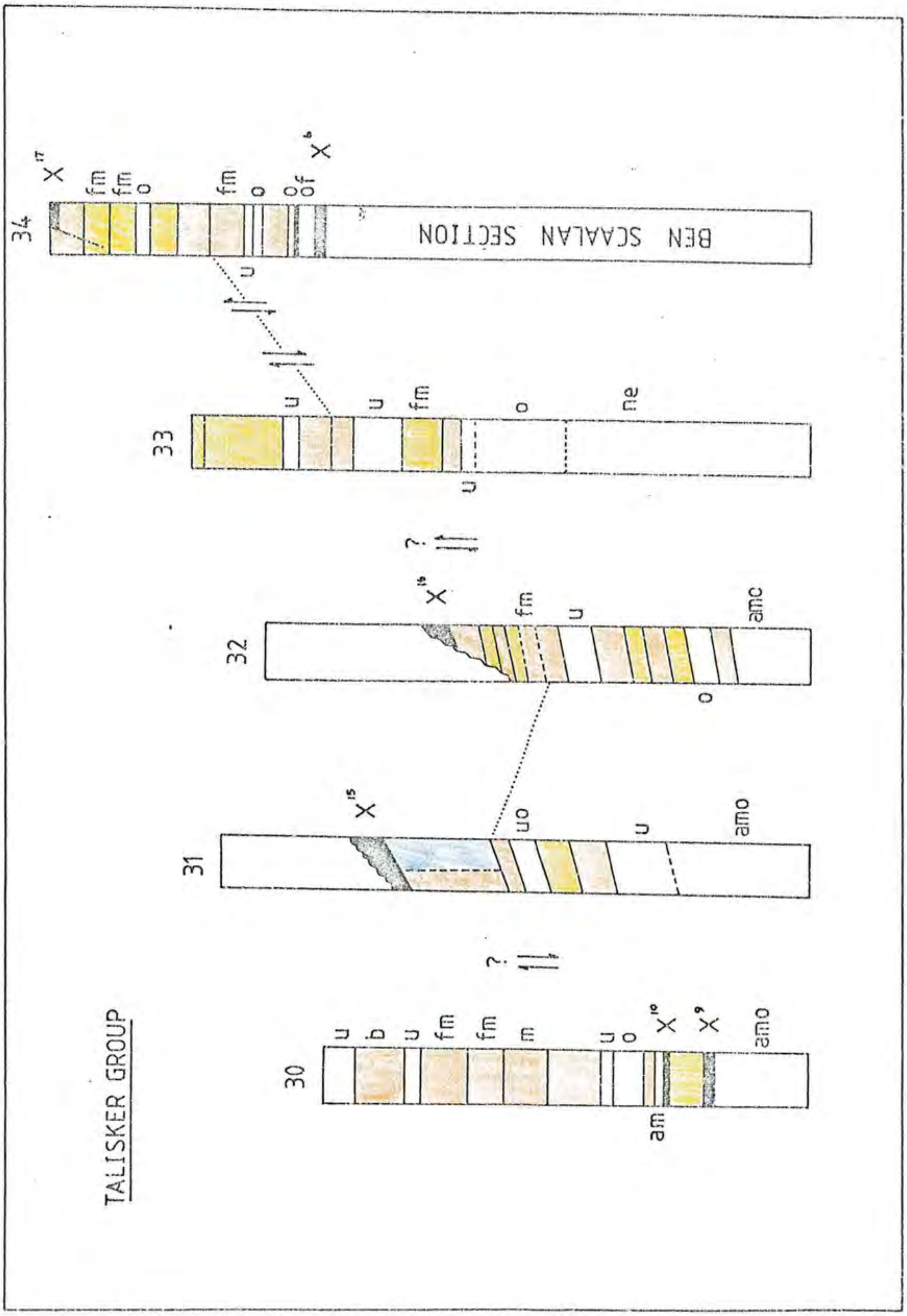
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Figure 13

PLATE 29-A and 29-B

Typical horizontal or gently inclined jointing in a mugearite from the slopes west of Cnoc Scarall. This structure is developed along planes of weakness, ~~parallel~~ to ~~and partly caused~~ by ~~the~~ parallel flow banding of tabular groundmass constituents and phenocrysts.

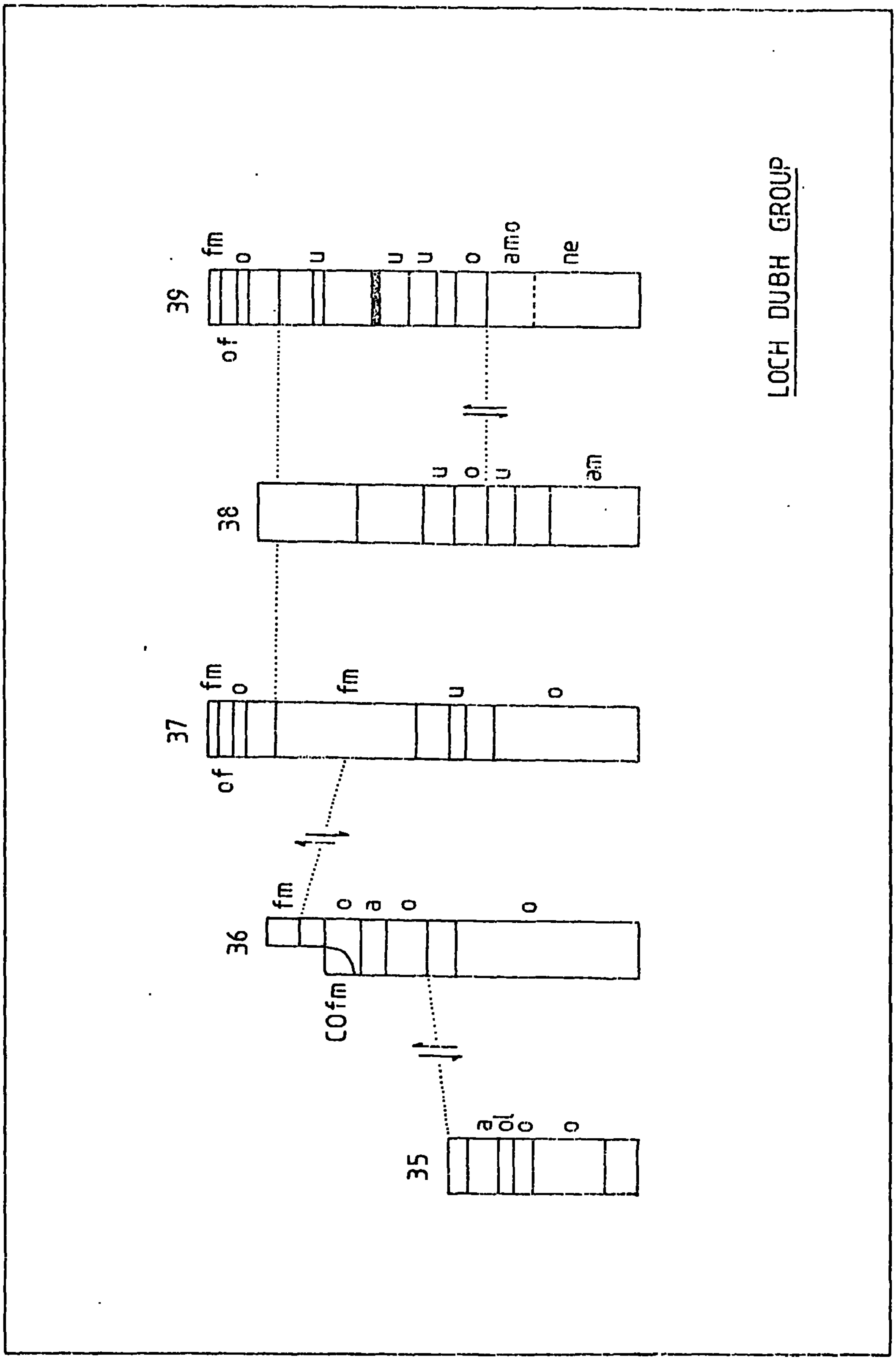


Figure 14

FIGURE 15

Map of the Skye Tertiary lava field showing the present day aerial distribution of the various lava groups as distinguished by Anderson and Dunham (1966) for Northern Skye and this thesis for West-Central Skye and the positioning of the cross-sections of figure 16.

Key

North Skye	West-Central Skye
Osdale Group	Talisker Group
Bracadale Group	Loch Dubh Group
Beinn Totaig Group	Arnaval Group
Ramascaig Group	Tusdale Group
Beinn Edra Group	Cruachan Group
	Bualintur Group
Central Intrusive Complexes	Meacnaish Group
Pre-Tertiary sediments and Tertiaty sill-complex	NW. Cuillins Group (fig.15) (and intergroup sediments fig.16).

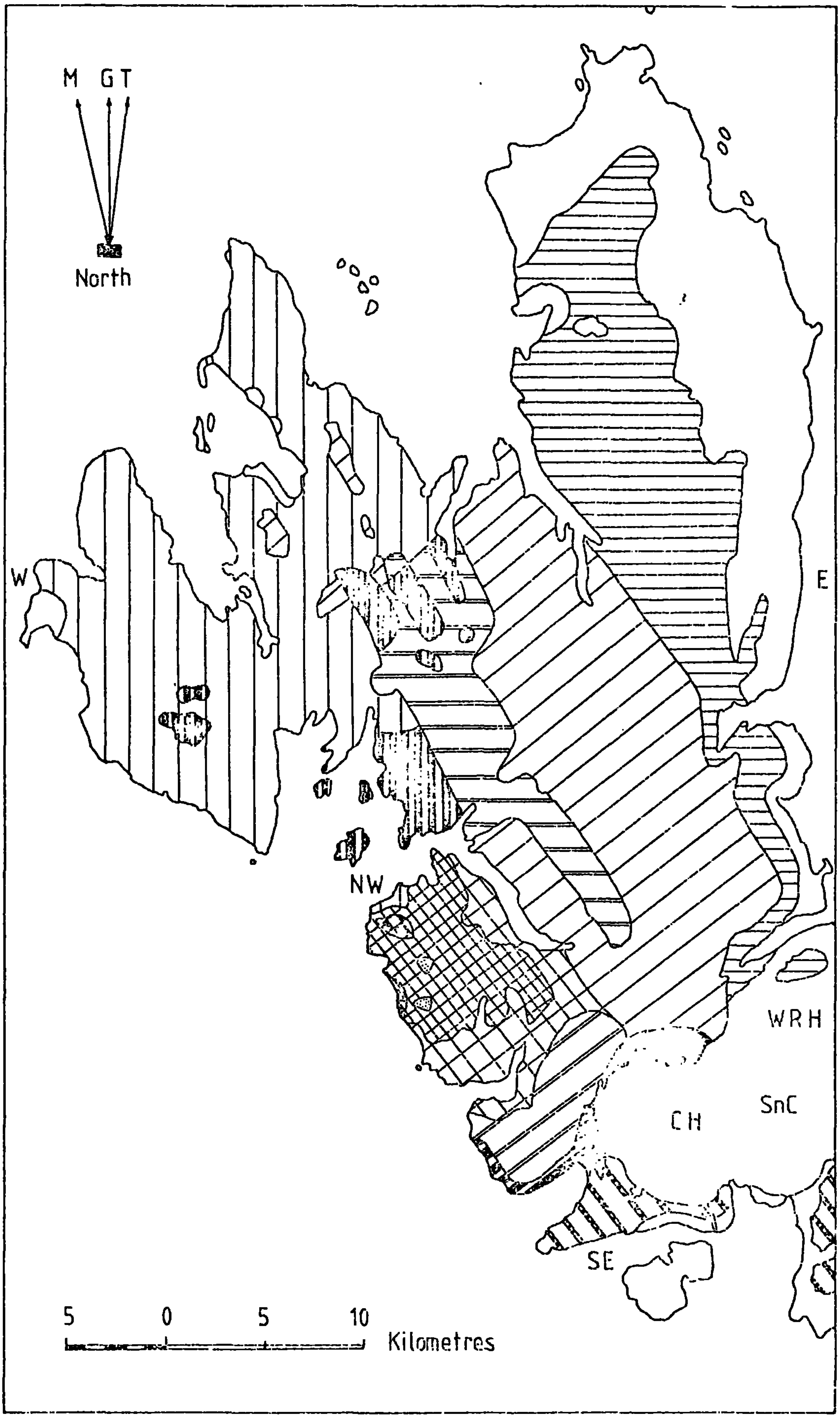


Figure 15

FIGURE 16

Schematic sections across the Skye Tertiary Lava field showing the supposed original relations of the various lava groups and their associated intergroup sediments and pyroclastic accumulations.

1. Northern Skye E - W section
2. West-Central Skye NW - SE section

Northern Skye intergroup formations

a. Plant beds in Hamra River, Glen Osdale, Forse River, Bracadale and Red Burn
b. Allt Mor, Airigh Neil and Allt Ruairidh sediments
c. Portree sediments
d. Camas Beag and Lyndale Tuffs
e. Tungadal Tuffs

West-central Skye intergroup formations

f. Agglomerate and bedded tuff below Preshal More and Preshal Beg
g. Agglomerate of Beinn Bhreac
h. Sgurr an Duine agglomerates and unconformity at Cnoc Scarall
i. Glen Brittle sandstones and conglomerates
j. Geodh'a'Ghamhna and Allt Mor sandstones, coals and conglomerates
k. Ben Scaalan, Biod Mor and Beinn na Cuinneig sediments
l. Beinn nan Cuithean sediments

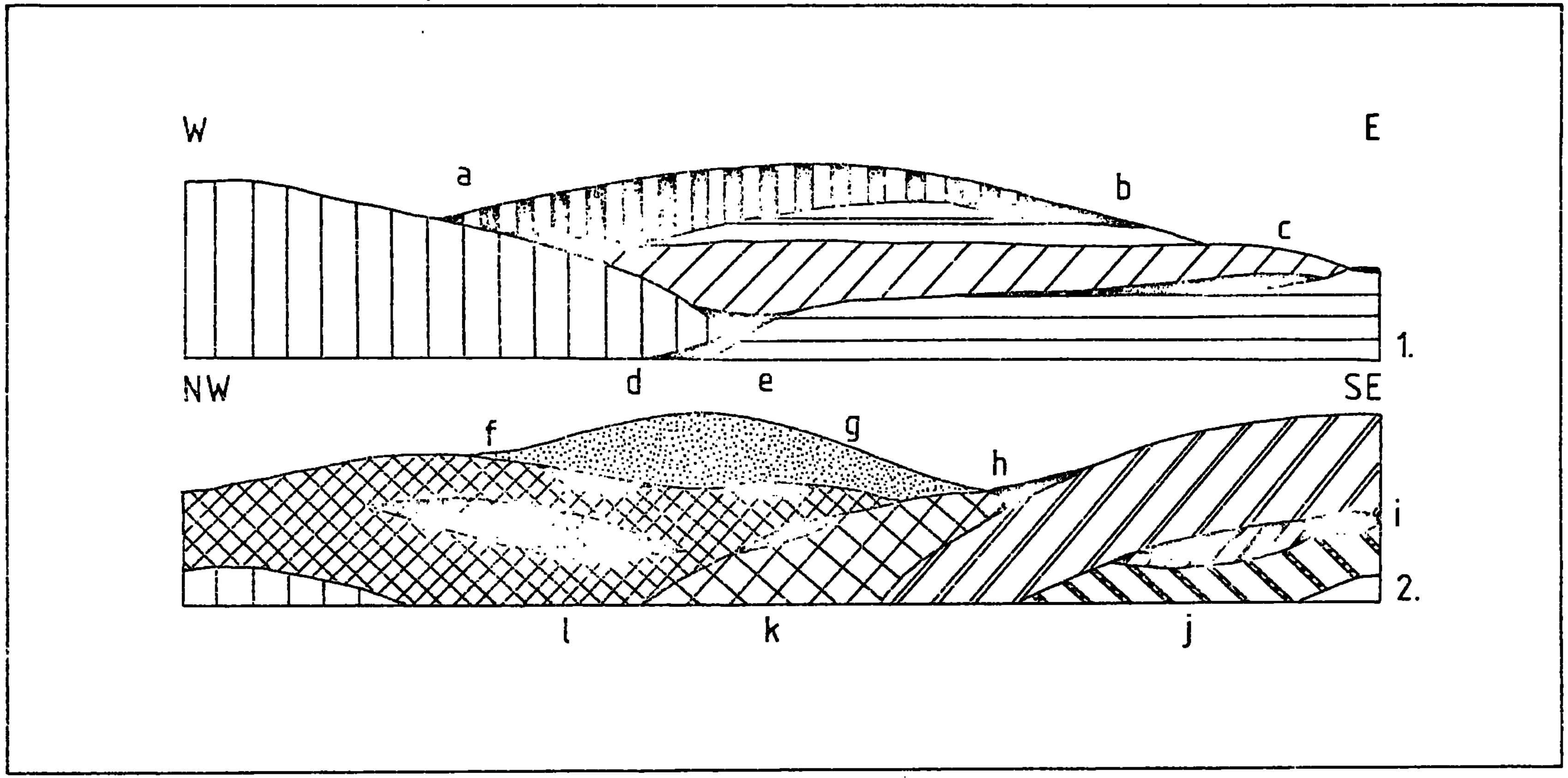


Figure 16.

1. Meacnaish Group	400 metres
2. Bualintur Group	250 metres
3. Cruachan Group	400-500 metres
4. Tusdale Group	400-450 metres
5. Arnaval Group	400-450 metres
6. Loch Dubh Group	75-80 metres
7. Talisker Group	125-140 metres

The majority of lavas belonging to the Meacnaish, Bualintur and Cruachan Groups lie within the various zones of the thermal aureole around the Central Complex. Consequently they are altered both petrographically and chemically to varying degrees further complicating correlation. The alterations observed around the Central Complex are dealt with in Chapter 10.

6.2i) <u>The Meacnaish Group</u>

The basal lavas assigned to the Meacnaish Group are exposed unconformably overlying a series of pre-Tertiary sedimentary rocks on the north shore of Soay Sound. They are characterised by the early appearance of differentiated rocks as well as alkali-olivine basalts resting upon an earlier agglomerate indicating that as in northern Skye (1966) , the initial activity was locally explosive. As exposed on Cnoc Leathan and Ceanne na Beinne, the lavas are frequently accompanied by thin tuffs and shaley sediments.

The upper part of the group, separated from the basal flows by thin-bedded, often olivine-rich alkali-olivine basalts, consists of a series of alternating porphyritic and non-porphyritic basalts capped by one or more 'Big-Feldspar' basalt, the best exposures of which are seen in Glen Brittle and at An Sguman. At the former locality, a hornfelsed trachytic-textured flow, possibly originally hawaiitic, intervenes above the highest porphyritic rock and the outer gabbros of the Complex, while aphyric, ophitic basalts only mildly recrystallised are recorded at the latter.

The thickest, uninterrupted sequence of approximately 250 metres is exposed on the southern slopes of Ceann na Beinne and the composite thickness of the group is probably not in excess of 400 metres.

The top of the Meacnaish Group is obscured by later intrusions but is associated with at least three related exposures of fluviatile sediments along the margins of the Cuillin Hills in Glen Brittle.

6.2ii) The Bualintur Group

Possibly lying above or laterally equivalent to the upper parts of the Meacnaish Group, at the south-western end of Glen Brittle, an alternating sequence of porphyritic olivine basalts and hawaiites overlain by a mugearite has been named the Bualintur Group. The presence of differentiated lavas increasingly upwards in the sequence distinguishes the main parts of the group from the Meachnaish Group although in part they may have been contemporaneous.

Some of the hawaiitic lavas apparently thin to the north and west and the original fissure may have been sited somewhere around the Glen Brittle region. The group reaches a maximum thickness in the sea-cliffs at the mouth of Loch Brittle and a composite thickness of only some 250 metres is preserved.

6.2iii) The Cruachan Group

The lavas included in the Cruachan Group take their name from the hill of that name to the west of lower Glen Brittle, and comprise a complex series of rock types. In detail, the conglomerates of Geodh 'a' Ghamhna and Allt Mor, which separate the group from the Bualintur Group, are overlain by a thin sequence of highly amygdaloidal alkali-olivine basalts, containing a 'Big Feldspar' basalt and overlain by a conspicuously flow-jointed mugearite. Porphyritic and non-porphyritic olivine basalts with frequently interdigitating hawaiites, make up the bulk of the group, which may be divided into two cycles. Towards Beinn an Eoin and Truagh Meall, alternating basalts of various petrographic types (olivine, plagioclase or clinopyroxene phenocrysts) are succeeded by from between two to four hawaiitic lavas. Another cycle of massive, olivine-porphyritic and picritic olivine basalts with an hawaiite capping overlies this sequence and forms the approaches to An Cruachan as well as the summits of Beinn an Eoin and Truagh Meall. To the north-east, the hills of Beinn Staic and Beinn a Bhraghad, overlooking Glen Brittle may consist of the upper parts of the group (cycle 2) although differences in detail, such as the lack of major differentiated lavas lower in the sequence are noted. No major interlava sedimentary horizons are encountered and it is suspected that lavas from more than one source, especially to the north and north-east, interdigitated to make up the group. The thickness is at least 500 metres as in Glen Brittle itself. The lavas of Beinn a'Bhraghad and Beinn Staic, unless faulted progressively down the glen, possibly directly overlie the lavas assigned to the Meacnaish Group and the associated sediments, but lack of exposure in the Glen and the Glen Brittle forest may hide lavas equivalent to the Bualintur Group.

6.2iv) <u>The Tusdale Group</u>

The lower lavas of the Tusdale Group, exposed north and west of Loch Eynort (Fig.15) are an alternating sequence of olivine and/or plagioclase porphyritic alkali-olivine basalts with several intercalated olivine-rich flows towards the base. Midway up the group, whose composite thickness is certainly not less than 400 metres, major differentiated lavas of hawaiite and more rarely of mugearite are present, overlain by a thick sequence of thin alkali-olivine basalts with thick boles and sedimentary lenses. The top of the group is marked by a succession of laterites, mudstones and ironstones overlain by an impure lignite at Ben Scaalan.

The upper Tusdale Group sequence of alkali-olivine basalts succeeding a series of differentiates is reminiscent of the upper division of the Cruachan Group, but the lavas below these differ considerably in detail. Unfortunately, the junction of the Cruachan and Tusdale Groups is nowhere exposed for examination; the major sea loch - Loch Eynort - separating the two, as does part of the Glen Brittle Forest and the Allt nam Fitheach fault to the north-east. This situation questions the validity of the groupings but the lava successions in these regions differ sufficiently from one another so as to require separate treatment and this is most simply and effectively done in the way described.

6.2v) The Arnaval Group

As the region around the mouth of Loch Bracadale is approached, a group of lavas, possibly equivalent to the Osdale Group of the Northern Skye Memoir (1966), are exposed. The group is a complex one and is separated from lavas of the preceeding Tusdale Group by the sediments of Ben Scaalan. The fissure from which this group originated must have been in or near Loch Bracadale as the character of the group is noted to change away from that centre. In detail, the group has three main divisions from the base:

A. Alternating thin-bedded basalts and mugearite	150 metres
B. Alternating porphyritic and non-porphyritic massive basalts with rare hawaiites and olivine-rich flows	100 metres
C. A thick group of alternating hawaiites and mugearites with subordinate basalts	175-200 metres

The overall thickness of the group is probably in excess of 400 metres. A full sequence is found from Talisker Bay to the Arnaval-Stockval ridge (Plate 30) but to the south on Biod Mor and Beinn Bhreac only the top subdivision is present directly overlying the Tusdale Group lavas and intergroup sediments. North Arnaval, the area around Fiskavaig and the slopes of Beinn nan Dubh Lochan also show most of the sequence but on the latter, parts of the upper Arnaval division are intercalated with lavas probably belonging to another group - the Loch Dubh Group. At Beinn nan Cuithean, the lower division is present overlying some sediments capping thin-bedded alkali-olivine basalts but is directly followed by a thick sequence of relatively differentiated lavas and the middle division is consequently absent, its place perhaps being

PLATE 30

A view of Talisker Bay from Rubha Cruinn looking south-eastwards towards the slopes of Preshal More which dominates the whole valley. The foreground cliffs to the left and right are predominantly olivine ± spinel porphyritic alkalic basalts overlain by a series of more massive basalts and intermediate lavas. Light weathering intermediate lavas (mugearite) are visible beneath the low-alkali olivine tholeiite above Talisker House.

PLATE 31

The composite hawaiite/mugearite of Dun Ard an t'Sabhail near Fiskavaig looking north. The bulk of the exposures are of the feldspar macroporphyritic upper unit and the slight break of slope to the right marks the approximate position of the contact with the near aphyric lower unit. The gully to the left of the main hill summit marks the course of a small fault downthrowing the upper unit to the west by some 5 to 6 metres.

taken by minor flows of the Loch Dubh Group also intercalated with the evolved lavas. It, however, appears to the north-east in Huisgill and Gleann Oraid. The latest lavas of the Arnaval Group appear to be the most differentiated lavas in the entire area being represented by benmoreites and trachytes. In Sleadale, below Preshal Beg, one or two mafic, intermediate trachytes or trachyandesites are exposed while at Cnoc Scarall 6 kilometres to the east, feldspathic trachyte lies on the slopes of a broad valley carved out of various earlier lavas. At Cnoc Dubh Heilla near Portnalong, benmoreite forms a capping to massive basalts and an hawaiite. The occurrences at Cnoc Scarall and Cnoc Dubh Heilla lie to the east of the Ardtreck fault which is estimated to throw the Arnaval Group down to the east by about 100-150 metres.

At Dun Ard an T-Sabhail (318333), north-east of Beinn nan Dubh Lochan, a composite flow of hawaiite-mugearitic affinities crops out overlying a sequence of both doleritic and thin-bedded alkali-olivine basalts (Plate 31). This flow is usually linked with the other 'composite' flows of northern Skye at Roineval, Druim na Criche and elsewhere, but, as mentioned by Harker (1904), Kennedy (1931), Anderson and Dunham (1966) and Boyd (1974) it is a more basic variety than those of northern Skye. It still however displays the characteristic 'Big

Feldspar' or feldspar macroporphyritic upper member overlying and here grading into a sparsely porphyritic lower member. Anderson and Dunham assign the majority of these porphyritic composite flows to the upper part of the Totaig Group (1966) (Table 1) but as these lavas crop out several miles to the east of this occurrence, it is possibly interstratified with the Arnaval Group. Big-Feldspar mugearites, not of a composite nature, occur in association with trachytes to form the Bracadale Group of northern Skye but this single flow does not appear to belong to that association. It is dealt with more fully in succeeding chapters.

6.2vi) The Loch Dubh Group

On the northern and western slopes of Beinn nan Dubh Lochan, towards the head of Loch Bracadale, a sequence of plagioclase and olivine microporphyritic hawaiites and thin alkali-olivine basalts is apparently intercalated with the upper division of the Arnaval Group. They do not correlate laterally with any of the more differentiated lavas to the east of Huisgill and are judged to be an interleaving set contemporaneous with the Arnaval Group. The summit of Beinn nan Dubh Lochan is capped by the remnants of a feldspar macroporphyritic hawaiite which has no lateral equivalents and is also assigned to the Loch Dubh Group. The estimated thickness of the group in west-central Skye is between 75 and 80 metres only.

At Rubha nan Clach (c.303333) the Arnaval - Loch Dubh Groups rest upon a sequence of lavas with the same general characteristics as the Ramascaig Group of the northern Skye memoir (1966) (Table 1). These lavas appear to be equivalent to or interdigitating with the lower parts of what here is termed the Arnaval Group.

6.2vii) The Talisker Group

In west-central Skye only one lava flow of low-alkali, high-calcium olivine tholeiite has been found. This forms the hills of Preshal More and Preshal Beg near Talisker (Plate 21) and the obvious time interval between the eruption of the lavas of the upper division of the Arnaval Group and the olivine tholeiite, as well as their contrasted chemistries, set it apart from the other groups. The tholeiite averages 120 metres in thickness and overlies pyroclastics, sediments and trachyte of the Arnaval Group, occupying a position high in the stratigraphic sequence, but at Edinbain, near Loch Greshornish in northern Skye, a lava of similar chemistry (Thompson et al., 1972 ; Esson et al., 1975) crops out within the lower sequences of the Osdale Group lavas (1966) (Table 1).

6.3 The Secondary Mineralisation associated with the Volcanics

6.3i) Introduction

The secondary mineralogy developed within cavities and vesicles of the Tertiary volcanics of Skye has been known for many years. In the Nineteenth Century these zeolites and their associates were reasonably comprehensively collected and described by mineralogists such as M.F. Heddle. The "Mineralogy of Scotland" (1901) was a posthumous publication of much of Heddle's collective works and contains descriptions, localities and lists of minerals recorded within the Skye lavas. The Memoir of 1966 gives a short description of the zeolites associated with the lavas but goes into no great detail.

Not all the species identified by Heddle are recognised here, as an intensive sampling programme was not undertaken and the inaccessibility of many of the cliff sections to full investigation necessarily results in an incomplete picture. However, Table 4 lists the minerals found and identified using X-ray Diffraction, and occasionally optical techniques.

6.3ii) Occurrence

These minerals do not occur at random throughout the lava pile but rather are grouped in associations which may be characteristic of the depth of burial and the prevailing geothermal gradient within the volcanics. The hydrothermal environment and the chemistry of the lavas with which they are associated may also be important in their paragenesis. Table 5 lists the various species by locality and the

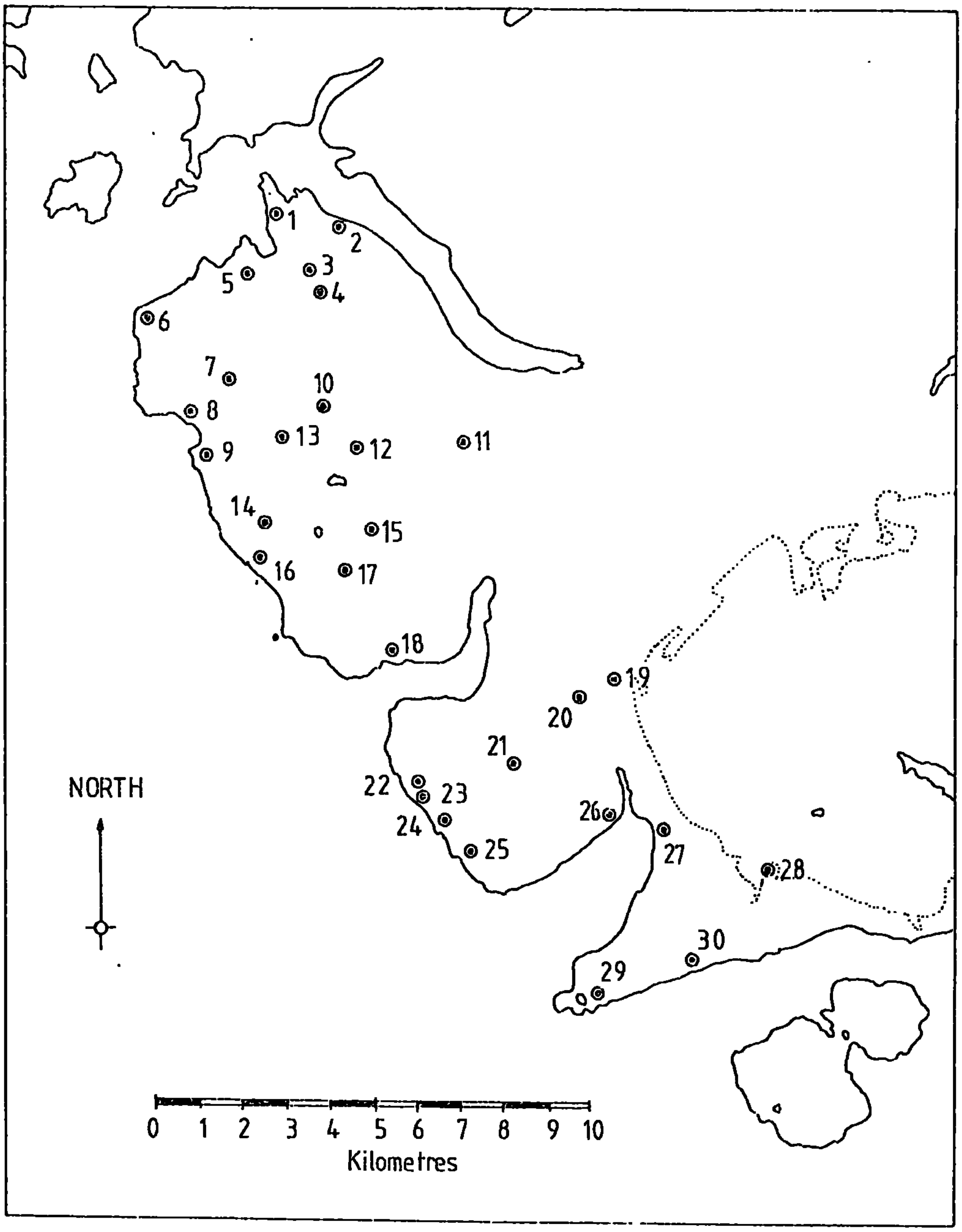
TABLE 4

Secondary minerals, including zeolites recorded within the amygdales and geodes of the lavas of west-central Skye.

Normal Series	Outer Aureole of Central Intrusions	Not positively identified
1. Analcite	19. Analcite	29. Apophyllite
2. Calcite	20. Amphibole	30. Native Copper
3. Chabazite	21. Biotite	31. Sulphides
4. Chalcedony	22. Chlorite	32. Epistilbite
5. Chlorite	23. Calcite	33. Faroëlite
6. Gyrolite	24. Epidote	34. Gmelinite
7. Heulandite	25. Prehnite	35. Okenite
8. Laumontite	26. Quartz	36. Pectolite
9. Montmorillonite	27. Scolecite	
10. Mesolite	28. Zoisite	
11. Natrolite		
12. Phillipsite		
13. Quartz		
14. Saponite		
15. Scolecite		
16. Stilbite		
17. Thomsonite		
18. Tobermoreite		

FIGURE 17

Map showing localities where representative selections of zeolites and other secondary minerals were collected in west-central Skye. The numbers are those referred to in Table 5.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Kilometres

Figure 17

TABLE 5

Localities and secondary minerals collected in west-central Skye. Those minerals underlined were recorded from the relevant localities by M.F. Heddle (1901) but not during the course of the present study. The numbers refer to the mineral species tabulated in Table 4.

Number	Locality	Mineral species present
1.	Ardtreck	1 2 3 17
2.	Portnalong shore	1 17
3.	Ardtreck road junction	10 11 15
4.	Allt Ribhein	14
5.	Fiskavaig	1 8 10 11 15 16 17
6.	Rubha nan Clach	1 2 3 14 16 29
7.	Huisgill	12 17
8.	North Talisker Bay	1 3 9 10 11 17 29 30 31 32 34 36
9.	South Talisker Bay	1 2 3 5 9 11 14 17 32 34 36
10.	Gleann Oraid	1 11 17
11.	Glen Eynort road cutting	3
12.	Stockval	1 11 17
13.	Preshal More	1 2 3 9 16 17 31
14.	Preshal Beg	2 31
15.	Kearra Burn	1 6 18
16.	Sgurr nam Fiadh	2 3 6 7 8 15 16 31
17.	Beinn Bhreac summit	3
18.	Tusdale	1 2 16
19.	Glen Brittle	22 27
20.	Beinn Staic	22 25
21.	An Cruachan	1 5 10 11 16
22.	Sgurr an Duine cliff	2 3 6 8 16 29
23.	Sgurr nan Boc	16 29
24.	Allt Mor ravine	2 5 8 16
25.	Geodh'a'Ghamhna	6 7 8 11 13 16 33 35
26.	Bualintur	20 22 24 25 26 27
27.	East Loch Brittle	20 22 24 25 26 30 31
28.	An Sguman	20 24 28 31
29.	Rubh'an Dunain	19 24
30.	Sgurr nan Cearcall	26 24 2

localities are shown in figure 17.

They are found mostly within the scoriaceous, vesicular and hence porous tops and bases of flows and only rarely in the massive central portions. Their widespread occurrence and the vertical zonation of types suggests a temperature controlled range of assemblages deposited by lateral transport and convection of solutions through the lavas. In detail, the zonation is slightly discordant with the stratification (P.M. King. Pers. Communication) as in other provinces.

Large parts of the area appear to lie within the Analcite-Natrolite Zone of Walker (1960), passing upwards into a 'zone' in which Chabazite becomes dominant. Both contain accessory Stilbite as well as Thompsonite, Mesolite and Scolecite. Stratigraphically, the upper division of the Arnaval Group is associated with a Chabazite-Thompsonite-Calcite assemblage, while the lower divisions at Talisker Bay contain an abundant Analcite-Natrolite-Thompsonite-Chabazite-Mesolite assemblage. Further south, the Cruachan Group is associated with similar assemblages but Laumontite-Heulandite-Natrolite-Stilbite assemblages are recorded north-west of the Allt Mor (Heddle 1901) possibly indicating the thickest regions, a greater depth of burial or a higher temperature gradient perhaps due to the proximity of the Central Complex or other intrusions in some cases. However in Walker's scheme, the Stilbite-Heulandite assemblage occurs near the base of the north Antrim lava-pile where it is thickest and this may suggest that, assuming the same conditions are broadly operative in Skye, that the base of the Skye lavas may be at no great depth below sea-level, at least between Loch Brittle and Loch Eynort. The base of the Talisker Group consists of an agglomerate which is distinctly mineralised in its upper portions. Here, a calcite-stilbite-analcite?-thompsonite assemblage is common; the calcite and stilbite frequently forming large, well-formed crystals in the larger open cavities. Sparse chabazite is recorded at Preshal Beg but to date, not at Preshal More. The lavas of the Meacnaish and Bualintur Groups are mostly within the thermal aureole of the Central Complex and their initial zeolite assemblages may have consequently been destroyed and replaced by new assemblages (Chapter 10). However, the lavas of Rubh'an Dunain (c.387163) and Sgeir Mhor (c.396160) and the immediate sea-cliffs lie outwith the main aureole and an Analcite-Natrolite assemblage, not dissimilar to that found to the north-west is preserved. Well-formed quartz is commonly associated with the basal mugearite of the Meacnaish Group at Sgurr nan Cearcall (415166) but it is totally lacking in the more basic lavas. Calcite is a common, constituent in the lavas immediately overlying the unconformity. Analcite with Natrolite and occasional Thompsonite and various green to black chlorites is a common assemblage in the outer lavas of the aureole to the west of Glen Brittle.

Among the zeolite assemblages throughout the area, clay minerals of the Montmorillonite group are found infilling or partially infilling vesicles, as veins or alteration products of the silicates nearby. They are variously coloured and may, where primary, be intergrown with some of the more finely-crystalline and fibrous zeolites such as Thompsonite and Natrolite. At Talisker Bay most varieties are found, while veins of pale-blue Saponite are recorded from the dam on the Allt Ribhein near Fiskavaig (Mackenzie 1957). Their occurrence is summarised in Table 6.

6.3iii) Order of Deposition of Amygdale Minerals

The relatively limited observations made on the zeolites indicate that the order of deposition of these minerals commonly follows a similar pattern and reflects the temperature of crystallisation and relative stabilities of the various phases as in Mull (McLintock 1915, Walker 1971).

Commonly, the vesicle is lined firstly by a greenish, often acicular, mildly pleochroic chlorite followed by the

TABLE 6

Occurrence of clay minerals intergrown with zeolites and other secondary minerals recorded from the thin-bedded olivine-porphyritic basalts (amygdaloidal zones) of Talisker Bay.

	Colour	Approx. Hardness	Texture	Mineral
1.	White to light brown	2	Very finely cryst-alline aphanitic	Analcite + Thomsonite + Montmorillonite
2.	Brown to green	1½	"	Montmorillonite + chlorite
3.	Green rimmed with red centre	1½	Aphanitic to waxy	Montmorillonite + haematite + goethite (bole weathering)
4.	Green to milky pink	2-2½	Finely crystalline	Mixture of Thompsonite and/or natrolite with Montmorillonite
5.	Green to creamy white (occasion-ally bluish)	1	Amorphous Waxy flakes	Saponite

fibrous zeolites. These form the usual base for the larger platey or rhombohedral minerals such as Stilbite Chabazite and Analcite. Simultaneous or overlapping crystallisation is also frequently encountered; as for example Natrolite or Thompsonite commonly form a base for Analcite with the very interior of the cavity being occupied by hair-like, second generation Natrolite. When associated with Stilbite or Chabazite, the Analcite is almost invariably of late crystallisation. The latest minerals to form are calcite, which may coat stilbite as at Preshal More and Preshal Beg, occupy the centres to even Analcite-lined cavities at Talisker (312297) or form as large rhombs on top of late-stage Heulandite at Allt Mor (365204). The calcite, may derive from a number of sources. At Preshal More and Preshal Beg, as well as along the Allt Mor it is possibly formed by circulating solutions near a central vent or localised heat source, as postulated for the Carbonate assemblages of Iceland (1960) and Mull (1971) by Walker. The calcite may also be a secondary product due to the hydrothermal alteration of calcic plagioclase. Another late mineral, Gyrolite, is found to succeed Analcite along the Kearra Burn (349274) near Beinn Bhreac.

6.3iv) The Timing and Origins of Zeolitisation

That the majority of the secondary minerals were deposited prior to the intrusion of the Central Complex is evidenced by the absence of zeolites and by their alteration to other assemblages near the Cuillins. The heat source for the production of a widespread vertical zonation and the free circulation of the depositing solutions to all parts of the region could have come from the developing intrusive centre, minor intrusions at depth or perhaps even the exothermic reactions of minerals such as olivine as they hydrated at depth. Walker (1960) reports that in Iceland, a critical thickness of between 150 and 300 metres is the minimum overburden of younger volcanics necessary before the process of zeolite formation can become self-initiating in areas where no centre of volcanic or hydrothermal activity is present. This also applies to the lava-fields of Antrim where no large vents or volcanic centres pierce the lavas and is probably true of Skye also. In Northern Ireland (Walker 1960) it is locally possible to relate the period of maximum zeolitisation to a period of movement along cross-faults but in west-central Skye, only the Allt Mor fault zone appears to be associated with intense zeolitisation; the assemblage Stilbite-Heulandite-Calcite-Laumontite being predominant. Apart from the Laumontite, which is associated in its hydrated form of Leonhardite, almost exclusively with minor faults throughout the area (see Chapter 5.2), the Stilbite-Heulandite assemblage suggests a relatively high temperature of formation, in a region associated with, but at the base of the Analcite-Natrolite zone. Perhaps, the Allt Mor breccias are in part due to an intrusion at depth.

The most likely mode of formation of the zeolites is from the reactions of water of meteoric origin, seeping through the lava pile occupying vesicles and larger voids, and the enclosing lavas themselves. The intensity of zeolitisation increasing with depth, reflects the temperature zonation and supports the above. Further evidence comes from the appearance of, for example, Analcite in mugearitic lavas above the Analcite-Natrolite zone (P.M. King, Pers. Communication).

6.3v) Applications of the Zeolites and Zeolite Zones

It is possible to use the partially filled amygdales, especially those containing primary montmorillonite-zeolite intergrowths, as crude geopetals and although difficult to assess, results from both Talisker and Bualintur suggest moderate tilting of the lavas subsequent to zeolite deposition. The direction varies between west and north, roughly in the direction of tilt of the lavas in general. No particular increase or reversals are noted near to the Central Complex, and its intrusion, especially the outer ring-eucrite appears to have had little structural effect on the lavas of south-west Skye. This is in marked contrast to the lavas adjacent to the gabbros in Strathaird and around the Central Complex of Mull where anular folding is developed.

There is no direct means of determining the amount of overburden removed by erosion from west-central Skye but the zeolite zones may give a clue. Walker (1960d+e) reports that the top of the Icelandic lava pile stood some 650-800 metres above the top of the Analcite zone and that the depth to the Laumontite Zone was 640-1000 metres below this. He roughly computed that more than half the Antrim lavas had been removed and in applying similar considerations to Mull (1971) calculated the original thickness of the pile as a maximum of approximately 2150 metres of which 1800 metres are now preserved. In west-central Skye, the Laumontite Zone is only tentatively identified and placed near sea-level along parts of the Loch Eynort-Glen Brittle region. This, using Walker's criteria, would place the Skye lava-pile top at a maximum height of 1800 metres above sea-level in this region and give an estimated overall thickness of just over 2000 metres and hence directly comparable to Mull. Today a thickness of only some 650 metres is preserved above the Laumontite Zone if one takes into account the interdigitating nature of the lava groups described previously. Hence some 1.1 kilometres appear to have been removed by erosion. If however, Walker's minimum figures are used in the calculation, along with the estimated thickness of the Analcite-Natrolite zone in west-central Skye, a figure of only 700 metres is arrived at. It is also possible that towards the centre of the basin (Fig.2) the lava-pile is considerably thicker.

In a paper dealing with the hydrous melting relations of some granites from Rhum and Skye, Brown (1963) noting the appearance of inverted Tridymite in the Coire Uaigneich granophyre estimated that a cover of 1 kilometre of basalt must have been present, while the fusion of adjacent Torridonian arkoseto produce the granophyre could take place at less than 700 metres below the level of intrusion. In Rhum, the metamorphism of Torridonian arkose to produce Tridymite crystals probably also took place at about 1 kilometre depth. Again in Skye, the Beinn Dearg Mhor Epigranite of the western red-hills was probably generated under a 3-4 kilometre cover but emplaced at about 1 kilometre below the surface and post-Tertiary erosion of basalt in the order of 1.5 kilometres was estimated for the valleys of central Skye. Thus, the derived figure for west-central Skye of between 700 and 1100 metres compares well with those of Brown. However, there is adequate evidence from the various events in the history of the Central Complexes, especially the presence of bedded agglomerates in the Srath na Creitheach region indicating 'open' vents, that erosion was probably acting on these acid rocks for considerable periods of time and that some uplift also took place. In this case all the estimates of the amount of erosion that has taken place may turn out to be somewhat conservative.

CHAPTER 7

The Petrography of the Tertiary Volcanics and Associated Rocks

Introduction

In this chapter, the general petrography of the lavas and associated rocks is described, the division for example of the lavas being based upon considerations of both geochemistry and phenocryst content. The petrography of the fragments and pebbles collected from both agglomerates and conglomerates is also recorded as a comparison with the lavas and the Tertiary Granophyres described elsewhere. All modes are given as volume percent and purely mineralogical aspects are referred to in a succeeding chapter.

7.1 Petrography of the Lavas

7.1i) Basalts

Among the basaltic lavas of west-central Skye, classified as having a differentiation index (Normative Percent Qtz + Alb + Or + Ne) less than 30-32 and possessing a normative feldspar in the Laboradorite range (Thompson *et al.*, 1972), there is considerable textural, grain-size and phenocryst content variation. All carry considerable olivine in the norm (10-40%) and irrespective of whether they are Nepheline or Hypersthene normative, they may be subdivided, according to their phenocryst content, occurrence and in some cases, chemistry, as follows:

A. Olivine + Spinel Porphyritic Basalts

B. Olivine Porphyritic Basalts

C. Olivine + Plagioclase Porphyritic Basalts including Doleritic Types

D. Clinopyroxene Porphyritic Basalts

E. Olivine + Plagioclase + Clinopyroxene Porphyritic Basalts

F. Plagioclase Macrophyric or 'Big Feldspar' Basalts

G. Aphyric Basalts

H. Olivine + Plagioclase Porphyritic Olivine Tholeiites of Talisker Type

By volume, the 'basalts' constitute more than three quarters of the total outcrop in the area but except along the largely inaccessible coastal cliffs they are often poorly exposed as their mineralogy and the possession of a coarser grain-size and generally more 'open' structure with well developed amygdaloids, compared to the more evolved lavas, facilitates the oxidation and weathering processes. Types A,B,C,F and G can largely be considered as alkali-olivine basalts, while those that are hypersthene normative are slightly more transitional and the title 'Transitional Olivine Basalts' seems appropriate. Types D and E belong to this group and may be more allied chemically to the minor intrusions (Chapters 4, 7 and 9).

Further consideration of this aspect is dealt with subsequently in Chapter 9.

7.1i)A. Olivine and Spinel Porphyritic Basalts

Lavas of this type, apart from carrying conspicuous amounts of olivine and chrome-spinel as phenocrysts also contain greater than 10% MgO in their analyses (Chapter 9, Figs.29 & 30 Appendix 1). Generally, but not invariably, they form rather restricted flows (Chapter 6.1) often occurring as massive, reddish-weathering, compact, lenticular pods among the amygdaloidal basalts so characteristic of many of the coastal cliff sequences as south of Talisker or at Sgurr nan Boc. This may be due to restricted volumes and irregular topography at the time of eruption with the lavas infilling small hollows and depressions. They may contain, in addition, a mesostasis of several percent zeolites.

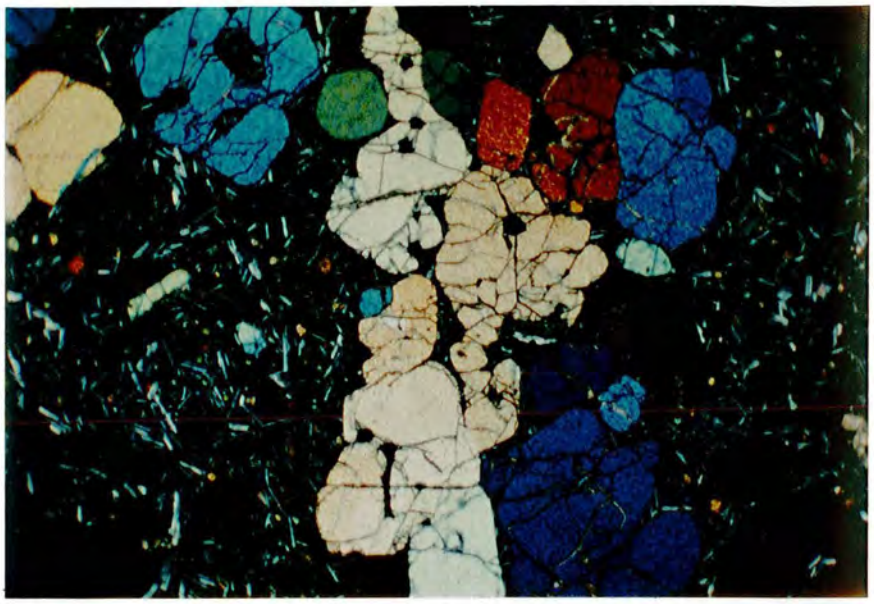
In hand specimen the lavas are either dark and compact aphanites or more leucocratic and more coarsely crystalline dolerites, but in both cases, lime-green to yellow olivine phenocrysts are generally visible to the naked eye. In exceptional cases (e.g. Sk750301, Sk7706, Sk7717, Sk751212) the spinel phase may also be visible with the aid of a hand lens.

Olivine phenocrysts, ranging from about 8-17% modal (Sk750602, Sk751212) and $Fo_{89.5}$ - Fo_{82} in composition, are mostly found as well-formed euhedra, although skeletal and embayed euhedral to subhedral phenocrysts are abundant in most of the lavas. In the 'picritic basalt' of An Cruachan (384225), the most basic lava encountered (Sk751212), they are only slightly zoned and may attain 9-10 millimetres in length either as single embayed crystals or as glomeroporphyritic aggregates (Plate 32), but in most lavas are more strongly zoned towards the margins and considerably smaller, ranging up to 3 millimetres in length. Occasionally, the olivines are altered and partially pseudomorphed by a greenish-brown mineraloid but are more commonly rimmed by iddingsite, opaque oxides and a yellow-green acicular chlorite, while in many instances they remain surprisingly fresh.

The other common factor of this lava type in the presence of red-deep brown to translucent euhedral chrome-spinels associated with and often enclosed within the olivine phenocrysts. They are obviously an early crystallising phase and as such are considered phenocrysts although they may in part be xenocrystic. In size they commonly range from 0.10 to 0.40 or 0.15 to 0.50 millimetres (Sk751202, Sk7717 etc.). Occasionally, where the spinel is not totally enclosed by an olivine, trapped within embayments along the margins of an olivine or within a skeletal olivine (Plate 33), it may appear corroded or

PLATE 32

Photomicrograph of the olivine + spinel porphyritic basalt SK751212 from An Cruachan in the Cruachan Group showing aggregates of olivines with enclosed chrome-spinels and large embayed, skeletal olivines.



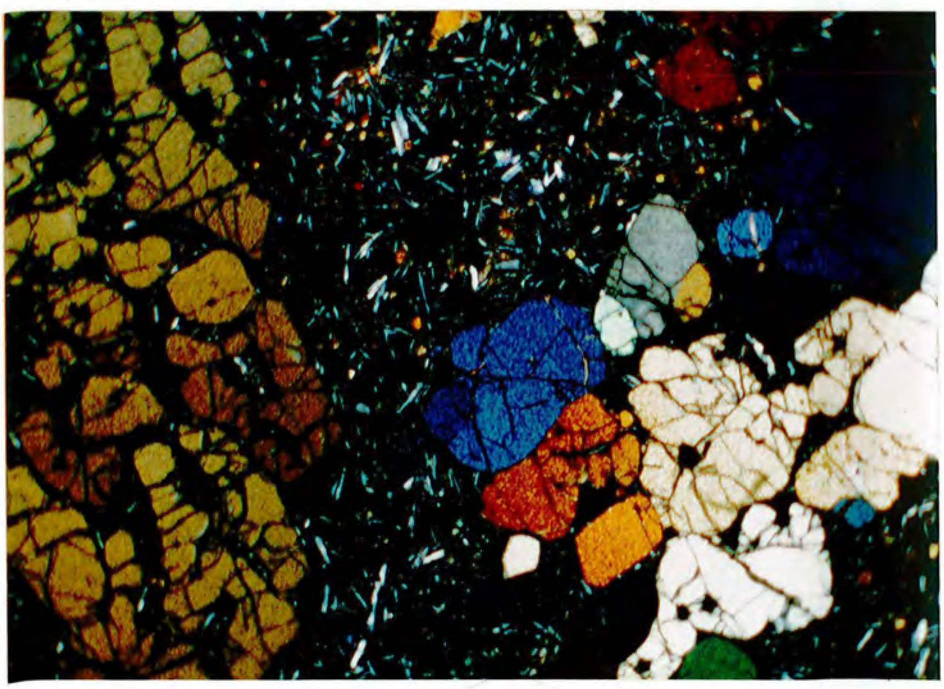


PLATE 33

Photomicrograph of a chrome-spinel crystal not enclosed in olivine phenocrysts from Sk751212. Note the irregular embayed outlines. Reflected light microscopy shows a thin reaction rim of titaniferous magnetite about such crystals. Interstitial titaniferous magnetite is common in this rock.

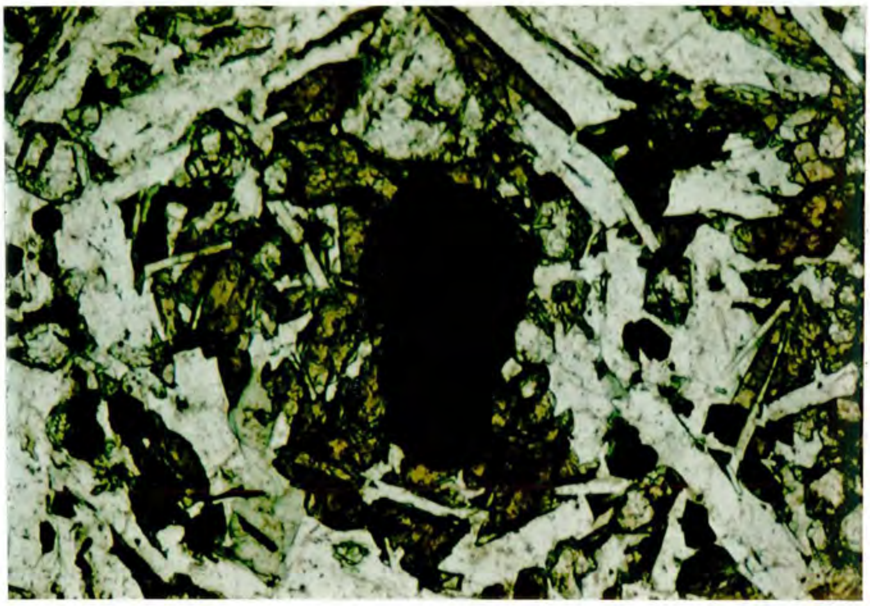
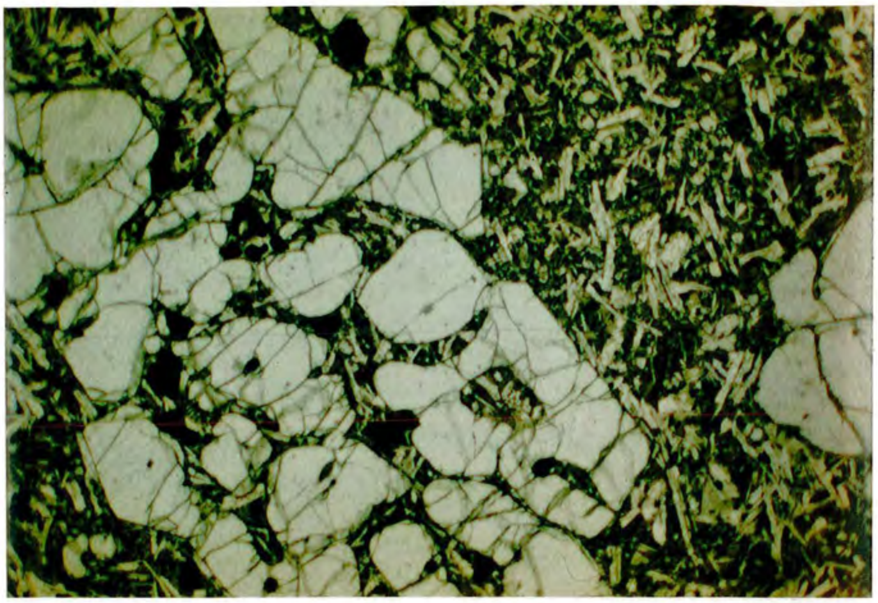


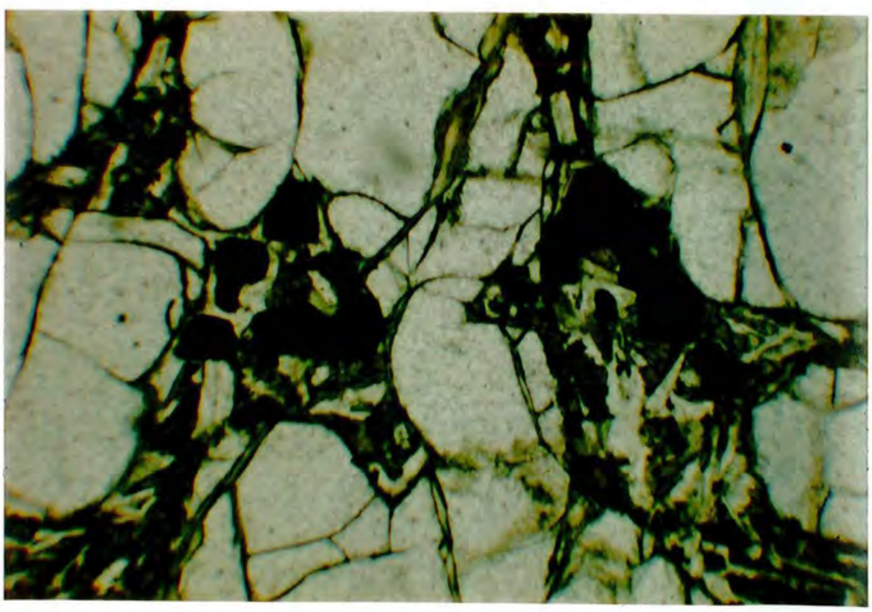
PLATE 34-A

Photomicrograph of a large skeletal olivine in the olivine + spinel porphyritic basalt Sk751212 showing numerous subhedral or euhedral chrome-spinels within the olivine or trapped in liquid-filled embayments.

PLATE 34-B

Close up view of 2 chrome-spinel crystals trapped in embayments as noted in Plate 34-A. These also show a skeletal form and appear unreacted with the groundmass.





embayed and possess a faint opaque rim perhaps indicative of reaction with the groundmass, (Plate 34).

Plagioclase feldspar is not a phenocryst phase in these rocks but it may occur as trace amounts of 0.5-0.6 millimetre microphenocrysts in a few of the less basic lavas of this type (Sk750602).

The groundmass generally consists of small, 0.25 millimetre rounded olivines, granular to sub-ophitic, rarely ophitic, weakly pleochroic titaniferous augite which may be brown, often with darker brown to mauve margins, mauve or colourless and up to 1.5 millimetres in diameter, thin plagioclase laths up to 1.5 millimetres in length and euhedral 0.2 millimetre grains or subophitic interstitial clots of opaque oxide. Accessories include occasional small grains of biotite, chlorite and amphibole mostly as alteration products nucleating upon the clino-pyroxene, feldspar or opaque oxide. In some lavas there is a considerable amount of interstitial analcite (Sk750301, Sk7706, Sk7717) resulting from deposition from hydrothermal solutions at depth under zeolite facies conditions rather than from late-stage crystallisation. A range of zeolites (Chapter 6) may be present within the amygdales. Alkali feldspar has not positively been identified but in a number of the lavas, the interstices are of anhedral, strongly zoned alkali-rich plagioclases (Sk750604).

7.1i)B Olivine Porphyritic Basalts

As with the Olivine + Spinel Porphyritic lavas into which they grade, the lavas containing olivine as the sole phenocryst phase tend to form thin flows or flow-units of restricted extent. The majority of the basaltic lavas exposed in the coastal cliffs and inland scree slopes of west-central Skye belong to this group and this type is more commonly known under the title of the Plateau Type of Alkali-Olivine Basalt (Bailey et al., 1924; Tilley et al., 1962).

In hand specimen the lavas are dark and compact when fresh but somewhat fragmented and more leucocratic when weathered. In the field they are usually deeply weathered and may possess a mottled appearance due to the high percentage of zeolite-filled amygdales and to the habit of the clinopyroxene. Well exposed sequences are at An Cruachan, Sgurr nan Boc, Tusdale and Talisker.

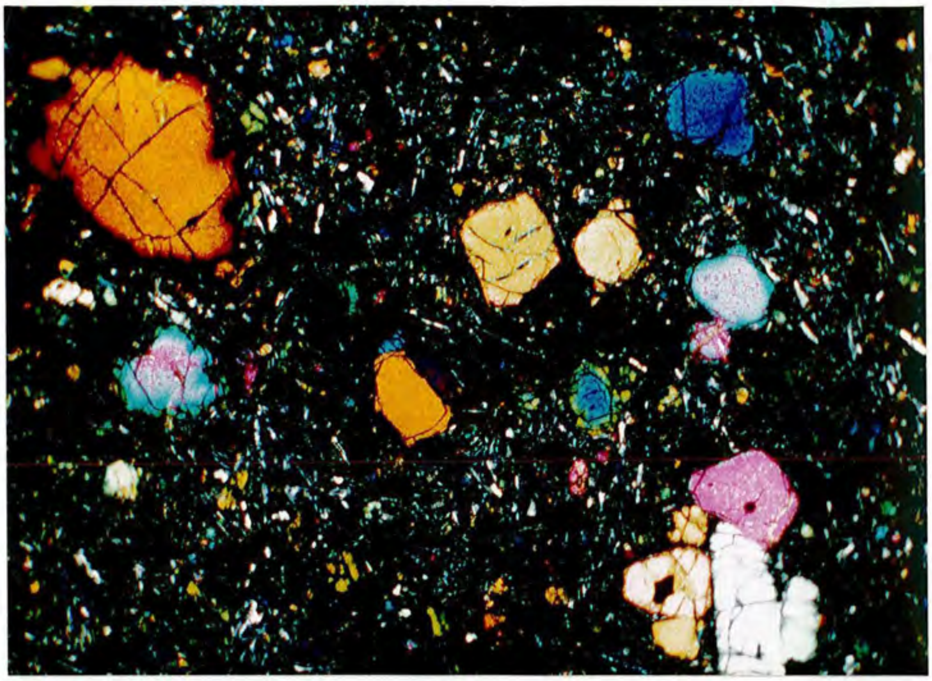
Euhedral and subhedral fractured phenocrysts of olivine occasionally with corroded or embayed margins make up 5-12 percent of the rock e.g. Sk751206, Sk750203 and vary in size from 0.5 to 2 millimetres. Normal zoning of the margins to more Fayalitic olivine is frequently observed but is not a ubiquitous feature e.g. Sk760308, Sk740305 (Plate 35). The cores have compositions in the order Fo_{75}-Fo_{85} and consequently are less magnesium-

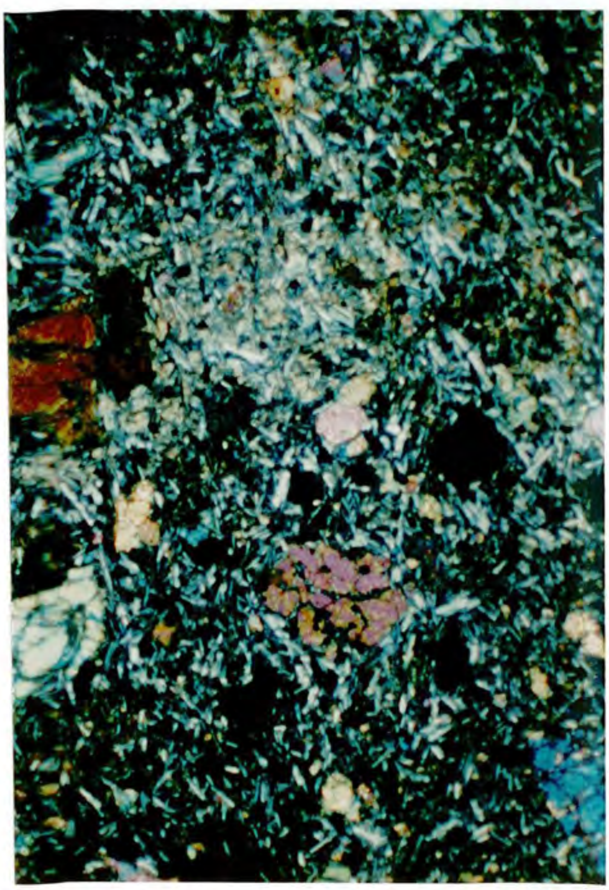
PLATE 35

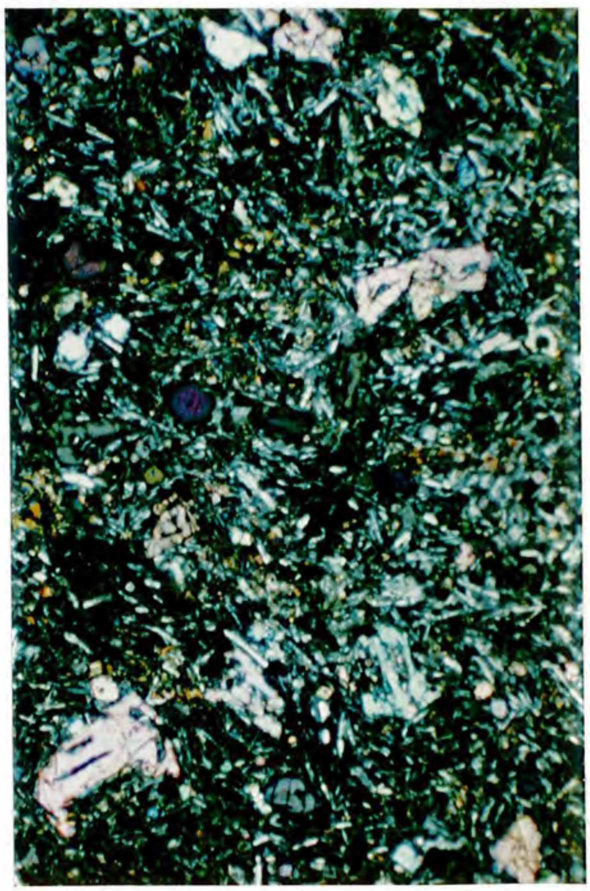
Photomicrograph of zoned olivines in an olivine porphyritic basalt flow Sk760308. There is a tendency for small glomeroporphyritic aggregates to form in such rocks.

PLATE 36-A and 36-B

Photomicrographs of a typical alkali-olivine basalt Sk761703 showing some zoned, skeletal olivine phenocrysts in a groundmass of poikilitic, titaniferous augite, interstitial titaniferous magnetite and disoriented labradorite laths.







rich than their Olivine + Spinel Porphyritic Basalt counterparts. Plagioclase feldspar, as in type A Basalts, is not a major phenocryst phase although scattered, tabular, simply-twinned microphenocrysts up to 1 millimetre in length may be present (Sk751703, Sk751207).

The groundmass of the 'plateau type' basalt varies only slightly from that of the Olivine + Spinel porphyritic lavas. The clinopyroxene is a mauve-brown pleochroic, titaniferous augite which may rarely form a granular to sub-ophitic texture (Sk751214) but more commonly exists as large 3-5 millimetre poikilitic plates (Plate 36) e.g. Sk751703, Sk751207, Sk750203, and Sk760308, which may have darker, weakly zoned margins as in Sk760306. The plagioclase laths are generally small, zoned, in the Bytownite-Labradorite range and 0.1 to 0.25 millimetre randomly oriented crystals with weakly potassic margins. A trachytic texture may be developed in some instances as in samples Sk751208, Sk740305 and Sk741002 but is not common. Small intergranular olivines up to 0.1 millimetre in diameter are common. Titaniferous magnetite forms small euhedral to subhedral crystals varying from 0.05 to 0.2 millimetres in diameter and appears to have crystallised before or during the early stages of crystallisation of the clinopyroxene which behaves partially ophitically towards it and the other groundmass constituents (Sk751703) and possibly continued its late-stage crystallisation subsequent to the plagioclases, magnetites and olivines. Microprobe analyses suggest an alkali-feldspar residuum in these rocks (Chapter 8), although as with the previous basalts the interstitial feldspar is a strongly zoned potassic plagioclase. Commonly the interstices are full of fibrous zeolites and grey, near isotropic anhedral analcite. A late-crystallising biotite may also be present nucleating on the magnetites.

Lavas of this type, as stated earlier, are frequently heavily altered; much chlorite, greenish amphibole, serpentine and iddingsite attacking and tending to replace the mafic phases, while the feldspars although slightly clouded or with a dusting of sericitic mica, remain comparatively fresh. Olivine phenocrysts are almost invariably rimmed and invaded along fractures by iddingsite and opaque oxides. The majority of zeolites collected (Chapter 6.3) were obtained from flows of this type.

7.1i)C Olivine + Plagioclase Porphyritic Basalts

Commonly associated with the olivine and olivine + spinel porphyritic alkalic basalts, one finds flows which carry olivine and plagioclase feldspar as the phenocryst phases. The lavas may be distinctly porphyritic or grade into a coarse-grained rock of doleritic type in which the phenocrysts are masked by the coarseness of the groundmass. Flows of this type are variable in thickness and extent;

the thicker, more massive and laterally continuous ones (e.g. Sk740201, Sk740801 and Sk740904 of Gleann Oraid) acting as recognisable marker horizons within a series of olivine porphyritic basalts.

In hand specimen, rocks of this type are relatively coarse-grained doleritic basalts with the microphenocryst phases usually but not always visible to the naked eye. This basalt type is essentially that of the 'Vaternish Hebridean' and 'Feldspar-phyric Olivine-Basalt Types' of Anderson and Dunham (1966 , Table III) with their 'Hebridean Type' encompassing the olivine and olivine plus spinel porphyritic basalts.

Olivine of variable composition (Fo_{85}-Fo_{70}) forms euhedral to subhedral, only occasionally skeletal, phenocrysts up to 2.5 millimetres in length but averaging around 1 millimetre. Modally it is present from between 3-10 percent and although generally subordinate to the plagioclase, may predominate over it as in sample Sk750707. In most cases they are distinctly zoned and may have an undulose extinction and exhibit some crude alignment parallel to the groundmass feldspars where a subtrachytic texture is developed (Plates 37, 38 and 39). Rarely, the olivines may contain pale-brown inclusions of spinel as in Sk750707, Sk751704 and Sk760304 but the lavas are distinctly more felsic than the main Olivine + Spinel Porphyritic type. These inclusions are generally minute.

PLATE 37

Photomicrograph of an olivine + plagioclase porphyritic basalt Sk751001. Both phenocryst types are normally zoned and in addition the plagioclase may be oscillatory zoned and apparently sub-ophitic towards the olivines.

PLATE 38

Photomicrograph of an olivine + plagioclase porphyritic basalt Sk740801 with small euhedral peripherally zoned olivines and stellate plagioclase aggregates. Some degree of flow banding of the groundmass feldspars is evident in this photograph.

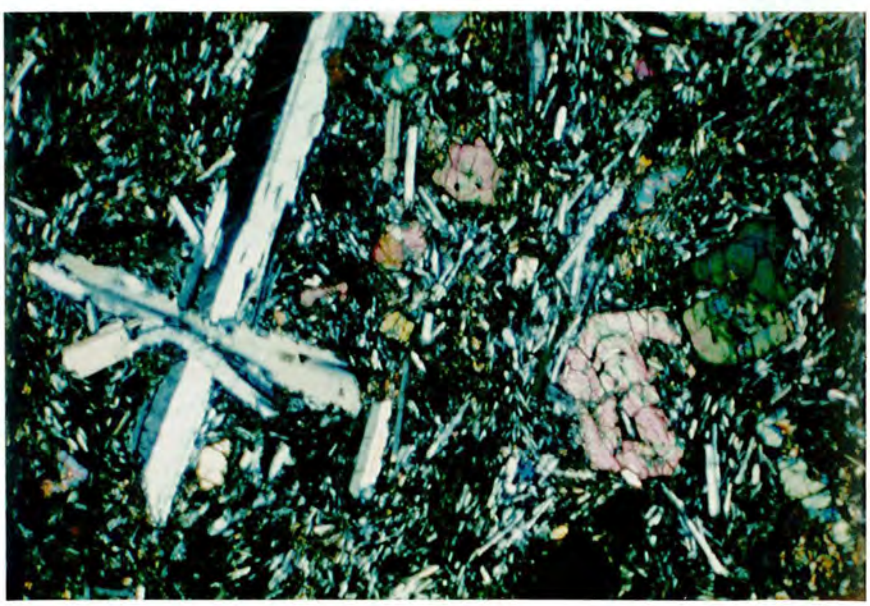
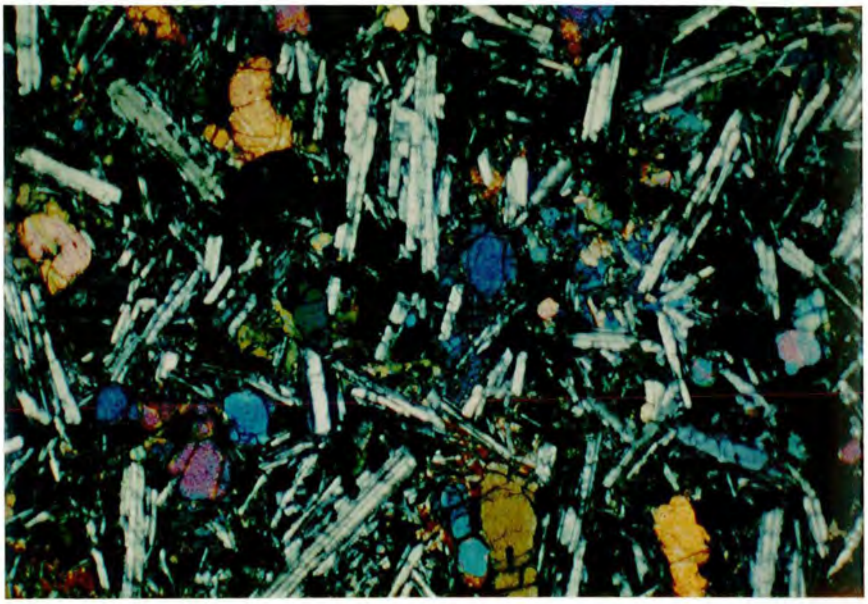


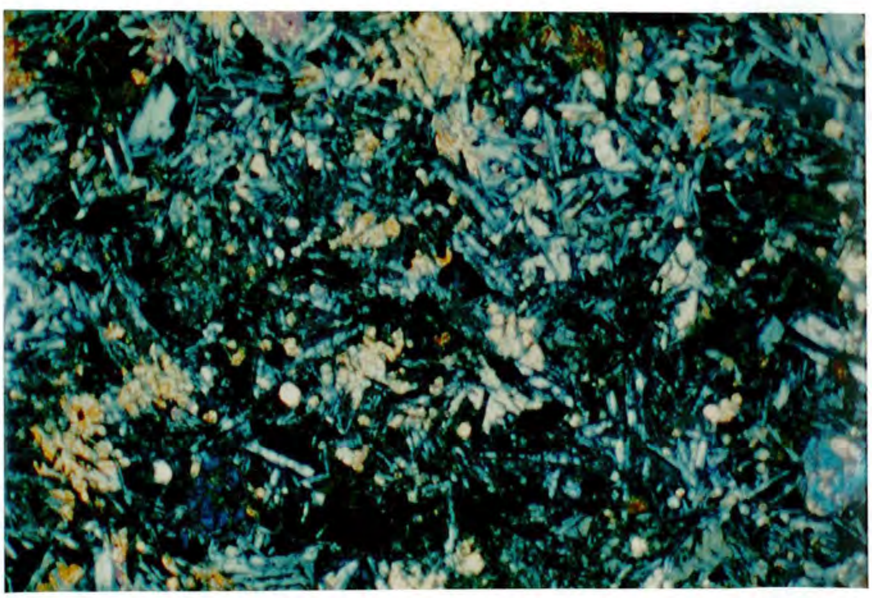
PLATE 39

Photomicrograph of an olivine basalt with a doleritic texture Sk741104, in which the groundmass is coarse enough to conceal microphenocrysts of olivine and plagioclase. Such lavas are a common feature of basaltic sequences in west-central Skye.

PLATE 40

Photomicrograph of a doleritic basalt Sk750614 from Biod Mor. This type is usually aphyric with large poikilitic groundmass clinopyroxenes but may contain trace amounts of olivine phenocrysts.





Glomeroporphyritic aggregates with plagioclase feldspar are common (e.g. Sk760304) and true dolerites are also present as Sk741104 and Sk750614 (Plates 39 and 40).

Microporphyritic plagioclase feldspar within the range An_{55}-An_{70} is the common feature of this basaltic type and is usually in the form of subhedral tabular laths or crudely hexagonal plates 1-2.5 millimetres in length or diameter and often partially aligned parallel to the matrix fluxion structures (e.g. Sk750707, Sk760304). Albite twinning is almost always present and is frequently combined with some development of pericline twins (Sk740801) but more commonly with carlsbad twins. Combined twins are the rule but single carlsbad-type twinning may be fairly common. Subhedral to anhedral, slightly zoned crystals are found in all basalts of this type and oscillatory zoning is frequently developed (e.g. Sk740507, Sk751502 and Sk760304) with thin, normally zoned euhedral outer rims around the more subhedral crystals. In some instances, the plagioclases also have inner rims of mafic inclusions - probably clinopyroxene. As a phenocryst phase it is usually dominant over the associated olivine or equally abundant and appears to behave subophitically towards some of the olivine phenocrysts in glomeroporphyritic and stellate aggregates as are found in Sk751001 and Sk760304 (Plate 37).

The groundmass is essentially identical to that of the other basaltic types comprising an intergranular (Sk750707, Sk760304) or poikilitic to subophitic, brown-neutral titaniferous augite generally less than 4 millimetres diameter (Sk740904), plagioclase laths with cores of approximately An_{55} and strongly zoned less than 1 millimetre in length and trachytic (Sk750707) or randomly oriented and an euhedral, occasionally subhedral, opaque phase of 0.03-0.10 millimetres diameter or subophitic titaniferous magnetite. Small granules of olivine are ubiquitous. Anhedral interstitial feldspar is relatively common and is again found to be a more alkali-rich plagioclase (zoned approximately An_{45}-An_{30}) rather than a true alkali feldspar. Areas of high K_2O were investigated with the microprobe on these specimens but contamination from neighbouring pyroxenes and more calcic plagioclases rendered the results meaningless. However, these results indicated that a potassic oligoclase was probably the residual feldspar in these basalts.

Alteration minerals are the same as for the other basaltic types.

7.1i)D <u>Clinopyroxene Porphyritic Basalts</u>

Basaltic rocks carrying clinopyroxene as a microphenocryst phase are not common in west-central Skye. However, the 'Transitional Olivine Basalts' and related types such as Sk740501 within the lower divisions of the Arnaval Group carry platey clinopyroxenes which began as phenocrysts but continued their crystallisation after the groundmass plagioclases. The result is a zoned clinopyroxene with ragged intersertal or subophitic edges but with a non-ophitic core.

Situated stratigraphically midway in the Cruachan Group to the west of Glen Brittle, a number of flows characterised by a granular to microporphyritic clinopyroxene phase and a transitional whole-rock chemistry as described above, crop out. In the field they tend to appear more leucocratic than the 'alkali-olivine' basalts and are essentially aphyric but upon close examination are found to carry trace amounts of olivine and plagioclase microcrysts as well as the clinopyroxene. At least three flows are recognised on Beinn an Eoin and the lower slopes of Beinn Staic within the outer zone of thermal alteration around the Central Complex.

Petrographically, the rocks are all very fine-grained with a moderately trachytic textured groundmass plagioclase and intergranular colourless clinopyroxene. Olivine is pseudomorphed and present in the groundmass, often abundantly, but may also form an euhedral microphenocryst phase 0.1 to 0.15 millimetres in diameter (e.g. Sk751215) or 0.25 to 0.75 millimetres (e.g. Sk751201-B). Plagioclase feldspar is also present as a trace microphenocryst phase but although approaching 0.5 millimetres in length as in Sk751201-B, merely seems to be an extension of the groundmass plagioclase (An_{58}-An_{62}). The important feature of these rocks is the fine-grained granular texture and the habit of the larger clinopyroxene crystals. These are relatively calcium-poor augites compared to those of the alkalic basalts and appear as ragged, tabular, neutral to colourless subhedra up to 0.35 millimetres long with brownish, subophitic, perhaps zoned margins (e.g. Sk740501, Sk751202) (Plate 42). Some crystals exhibit a concentric, wavy extinction similar to the hour-glass structure. This feature is common in specimen Sk751218 (Plate 41).

Some of the alteration effects found in these lavas are attributable to normal weathering processes but the proximity of the Glen Brittle examples to the Central Complex means that the alterations commonly experienced in the outer zone of the aureole (Chapter 10) are super-imposed by or overprinted by weathering alteration types. This results in deeply weathered, much altered rocks in which the ferromagnesian phases, especially olivine are seldom found in the fresh state, but rather, are mostly pseudomorphed by various minerals and mineraloids.

7.1i)E Olivine+Plagioclase+Clinopyroxene Porphyritic Basalts

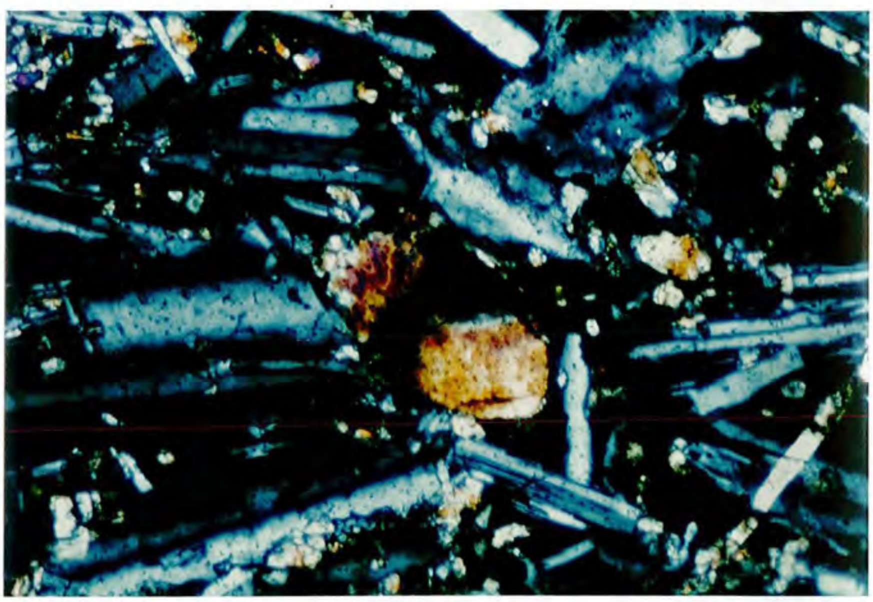
In west-central Skye only two flows are recorded containing the phenocryst assemblage Olivine + Plagioclase + Clinopyroxene. Both are found near Glen Brittle as fairly massive flows of restricted outcrop but are not identical

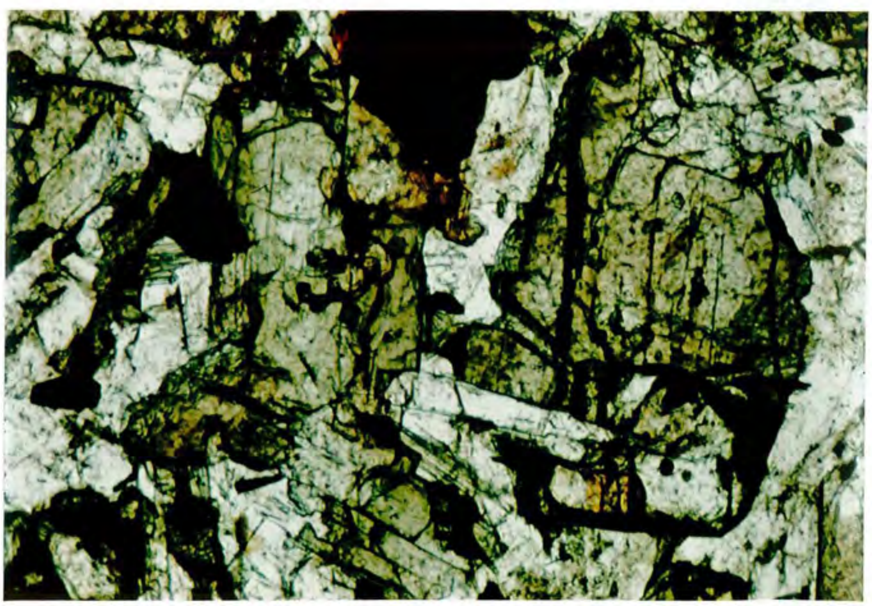
PLATE 41

Photomicrograph of small subhedral clinopyroxene (augite) microphenocryst in the Transitional basalt Sk751218 showing crude hour-glass structure.

PLATE 42

Photomicrograph of subhedral clinopyroxenes in the olivine basalt Sk740501. This type of augitic pyroxene habit is common and is often very faintly zoned with denser coloured rims. They may have originally been microphenocrysts, especially where the cores are euhedral and inclusion-free.





to each other although they are possibly closely related in time. The occurrences are considered separately.

Occurrence 1. Allt Gearraidh Dhroighinn

(NG 399208, Specimen Sk7627)

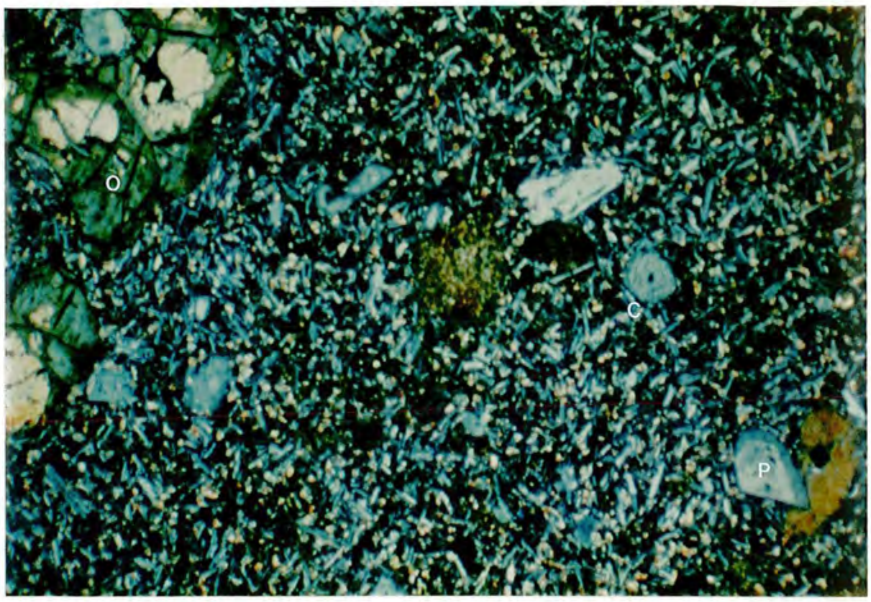
Euhedral Bytownite plagioclase phenocrysts up to 5 millimetres long, showing a mixture of Carlsbad and Carlsbad-Albite twinning, some development of oscillatory zoning and inclusion filled margins, modally constitute some 5-6 percent of the flow. A second generation of plagioclase microphenocrysts tend to show little or no twinning but are strongly zoned with euhedral overgrowths. Slightly glomeroporphyritic with the plagioclase or occurring independently, partially pseudomorphed euhedral olivine phenocrysts 0.35-0.5 millimetres in diameter are also fairly abundant with rare 3.5 millimetre skeletal crystals present. Clinopyroxene is not a major phenocryst phase but very rare 1 millimetre subhedral or even euhedral, neutral clinopyroxene crystals are found (Plate 43). It is partially ophitic towards the larger feldspars but does not behave in a similar manner to the clinopyroxene of the groundmass and it has obviously had a prolonged history of crystallisation. The groundmass consists of 0.1 to 0.2 millimetre plagioclase laths, an intergranular colourless olivine and pyroxene less than 0.1 millimetre in diameter and a 'bladed' irregular opaque phase, possibly ilmenite.

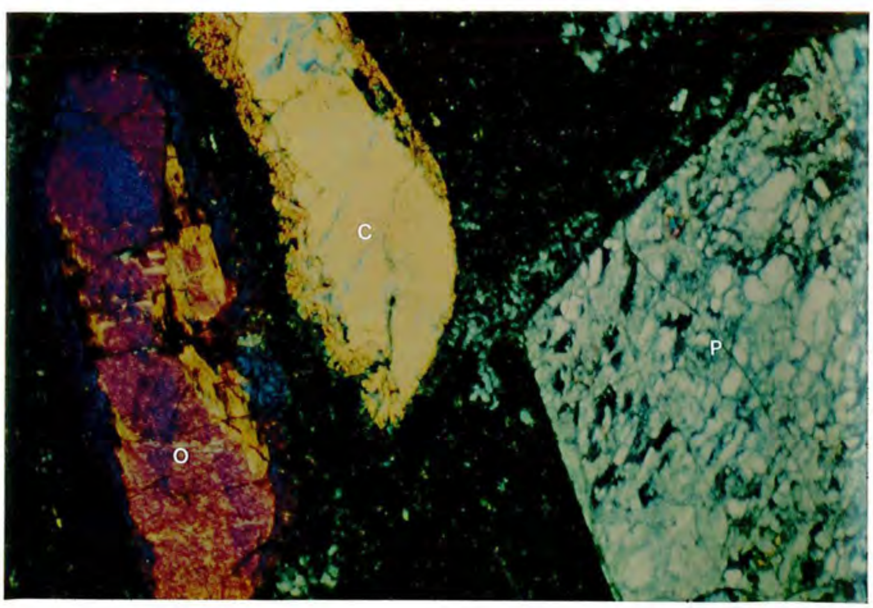
PLATE 43

Photomicrograph of the olivine + plagioclase + clinopyroxene basalt Sk7627 as exposed in the Allt Gearraidh Droighinn near Bualintur. The olivines are partially pseudomorphed (D) and the plagioclases undergoing resorption (P) and zoned. Clinopyroxene (C) is somewhat rare as a microphenocryst phase but occurs typically with rounded outlines.

PLATE 44

Photomicrograph of the olivine + plagioclase + clinopyroxene flow Sk760814 from the slopes of An Sguman. This rock has suffered severely from both thermal and hydrothermal alteration resulting in corroded, rounded and reacted phenocrysts. The olivines (O) are surprisingly fresh, as are the clinopyroxenes (C) considering the altered state of the groundmass and the conversion of plagioclase phenocrysts (P) to aggregates of epidote + clinozoisite + albite + sericite.


O
C
P


C
P
O

There is considerable interstitial chlorite, with the olivines being replaced by beautifully pink to green pleochroic micas and iddingsitic rims.

Occurrence 2. An Sguman

(NG 439188, Specimens Sk760814 and Sk7725)

At An Sguman, on the margins of the Central Complex, the lava flow 3-4 flows from the top of the preserved succession of the Meacnaish Group is highly porphyritic containing over 40 percent phenocrysts. The majority are Bytownite plagioclase An_{70}-An_{75} which is notably tabular, subhedral and has a range of size in the order of 4-15 millimetres and is markedly flow oriented. Some resorption and overgrowth has occurred but apart from the alterations imposed by the thermal metamorphism, they are recognisably zoned with Carlsbad, Albite, Pericline and combined twins. The olivines are totally pseudomorphed by a dark, dirty-looking chlorite or bowlingsite and occasionally by mica. Magnetite, biotite and chlorite are common associates. The euhedral form is retained and crystals are fairly large; up to 2.5 millimetres. Large, ovoid and much resorbed anhedral phenocrysts of clinopyroxene, low in iron content compared to those of the alkalic lavas but more calcium-rich than the clinopyroxene microphenocrysts of the clinopyroxene porphyritic basalts of type D, are also present, making this lava flow unique within the area (Plate 44). It is a colourless, relatively titanium poor, colourless augitic pyroxene up to 4 millimetres in length with an outer, ragged and inclusion filled margin. Some degree of zonal structure or undulose extinction is recorded.

The groundmass has suffered severely from the thermal metamorphism by the adjacent gabbros and shows signs of the incipient development of a hornfels texture and comprises intergranular, colourless to neutral 0.1 millimetre clinopyroxene, rounded 0.2 millimetre pseudomorphed olivines, subhedral titaniferous magnetite less than 0.1 millimetre and dusty, opaque-charged plagioclase laths generally less than 0.5 millimetres long.

7.1i)F Plagioclase Macroporphyritic Basalt

Basaltic lavas containing large plagioclase feldspars as the sole major phenocryst phase are comparatively rare, although in the field, lavas of the more differentiated types ie. hawaiites and mugearites are found frequently to carry large solitary, widely distributed, resorbed plagioclase phenocrysts.

In hand specimen, the large, yellowish-weathering, glassy plagioclases are easily visible, occasionally constituting about 30 percent of the rock as isolated lenses within less porphyritic lava. An example from

Gleann Oraid (Sk740209) is a fine-grained, dense rock unfortunately very poorly exposed. The main occurrence of this lava-type is in and around Glen Brittle near the top of the Meacnaish Group or within the Bualintur and basal Cruachan Groups but an isolated and extremely poorly exposed example (above) occurs within the Arnaval Group.

The plagioclases are tabular or elongated laths of Bytownite (An_{75}+) and usually exhibit either euhedral or anhedral cores with euhedral overgrowths of normally zoned sodic plagioclase and untwinned potassic andesine or oligoclase. Oscillatory zoning is common (Sk751902, Sk751101-A) and all the major twinning lavas are represented. In the Glen Brittle lavas, modal percentage varies from around 5 percent to over 20 percent, and in size, phenocrysts as large as 1 centimetre are found, but are not common, the average being around 7-8 millimetres. The phenocrysts are frequently embayed and resorbed (Sk751407) but still have a strongly zoned margin and internal rim of opaque and clinopyroxene inclusions (Plate 45).

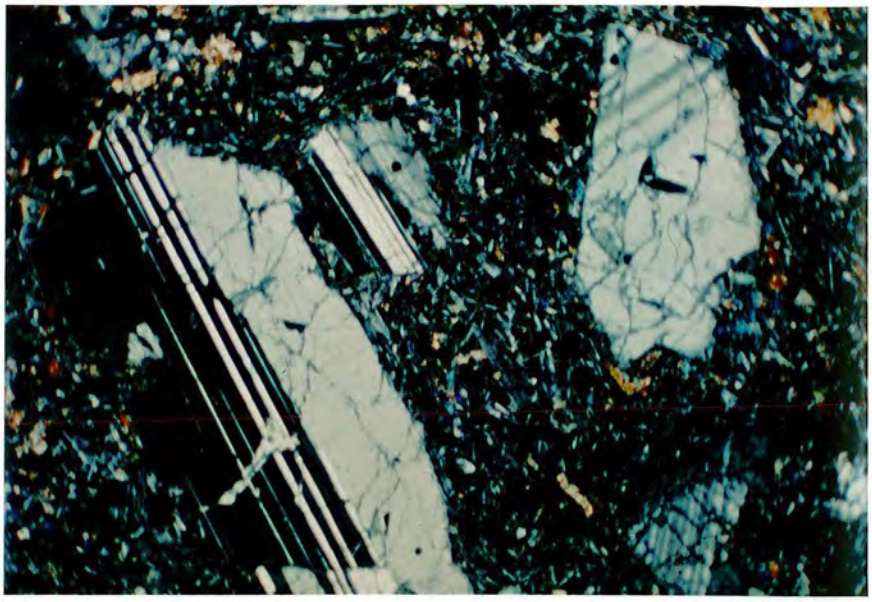
The groundmass is highly variable in texture. Clinopyroxene, ranging from a granular or 0.3 millimetre subophitic brown-purplish titaniferous augite, to large 2.5 millimetre ophitic plates of brown-neutral pyroxene (Sk751101-A, Sk751101-B), is present and olivine may be granular or possibly microporphyritic as in specimen

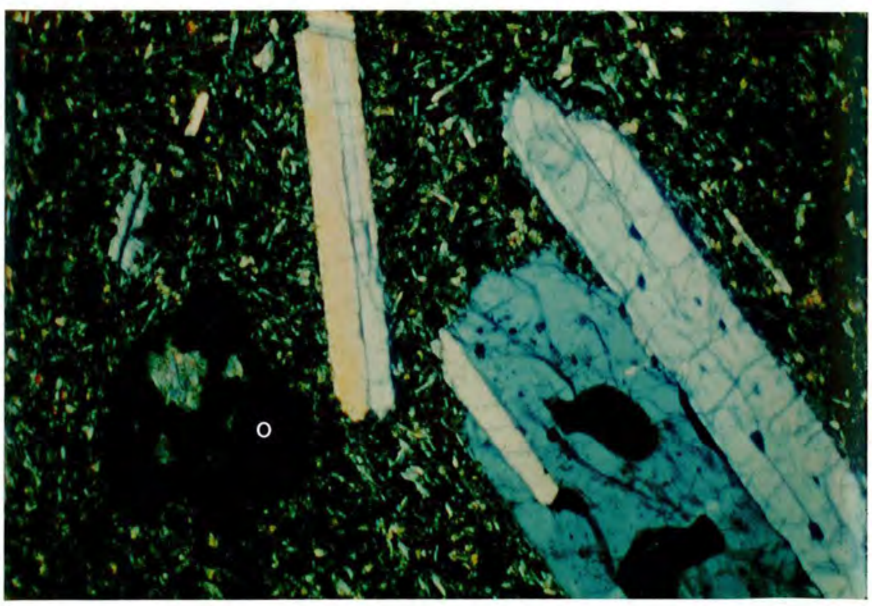
PLATE 45

Photomicrograph of the plagioclase macroporphyritic basalt Sk751407 from the cliff sequence at Geodh'a' Ghamhna showing well developed twinning and slightly resorbed and rounded euhedral outlines. Many lavas contain trace amounts of plagioclase macrophenocrysts but few possess them in sufficient quantities to be termed true porphyritic basalts, hawaiites or mugearites.

PLATE 46

Photomicrograph of the plagioclase macroporphyritic basalt (+ olivine microphenocrysts) Sk760401. This flow lies within the outer metamorphic zones of the Central Intrusive Complex within the Meacnaish Group to the east of Loch Brittle and consequently is highly hydrothermally altered. Olivines (O) are pseudomorphed by talc or iddingsite + chlorite and rimmed and penetrated by magnetite while the feldspars are typically corroded and fractured but little altered.




O

Sk760401 (Plate 46). Trachytic textured, polysynthetically twinned and zoned plagioclase is met with but is not common, the plagioclase being for the most part randomly oriented. The opaque phase is invariably euhedral or slightly subhedral but may rarely be fine-grained and granular.

Specimens Sk751101-A and Sk751101-B were collected within a few metres of each other within the same flow at Glen Brittle Beach south of Bualintur (406204) and show a striking range in percentage phenocryst content, a feature which however was not captured in the making of the thin sections. The former is notably porphyritic whereas the latter carries only minor amounts of plagioclase phenocrysts.

Again within the outer zones of the thermal aureole around the Cuillin Gabbros, this lava-type has been modified variously by the metamorphism. Some incipient albitisation of the feldspar is noticed (Sk751902) but the common replacement minerals are sericitic mica and stilbite (Sk751407). The olivines are commonly, partially or wholly pseudomorphed by a watery-green to pink pleochroic mica so characteristic of the Glen Brittle region in general. The groundmass plagioclases, near the Central Complex, are clouded with opaque inclusions and other accessory alteration products include biotite, amphibole, fibrous zeolites and considerable serpentine, magnetite and chlorite.

7.1i)G Aphyric Basalts

Petrographically, few of the basaltic lavas are completely aphyric in nature and most contain at least trace amounts of olivine, plagioclase or both as microphenocrysts. However, in handspecimen, many are essentially aphyric. Those basalts defined here as aphyric, are not easily classified with any of the other basaltic lava-types, although they are invariably associated with them and characterise the same sequences. They form rather dark, almost doleritic, rough weathering, reddish-brown hued crags and are frequently amygdaloidal throughout and consequently, deeply weathered.

Texturally, they are similar to the groundmass of the more porphyritic lavas containing an often highly coloured, mauve, ophitic to subophitic titaniferous augite with randomly oriented or sub-trachytic plagioclase laths 0.1 to 0.2 millimetres long. The clinopyroxene may impart a mottled appearance to the rock (eg. Sk760815) and reach 2.5 or 3.0 millimetres diameter, but mostly it is finer-grained, subophitic or rarely intergranular. Many coarse-grained, doleritic examples are recorded but are frequently gradational with the olivine + plagioclase lavas (eg. Sk 740105, Sk740606, Sk740608 and Sk750111). Granular olivine is ubiquitous and usually altered while larger olivine and plagioclase crystals approach microphenocryst dimensions but are not common. The opaque phase may be either an euhedral titaniferous magnetite ranging in size up to 0.25 millimetres (Sk760404) or of a more bladed-dendritic interstitial habit (Sk760815).

7.1i)H Olivine+Plagioclase Porphyritic Olivine Tholeiite of Talisker

Due to its unique position both stratigraphically and chemically, setting it aside from the alkali-olivine basalt lineage, the petrography of the olivine tholeiite forming the hills of Preshal More and Preshal Beg near Talisker is best considered apart. The manner of its occurence also distinguishes it from the earlier lavas and is dealt with more fully elsewhere.

Considerable variation in grainsize and phenocryst content is developed; being controlled to some degree by height within the flow and reflected in the hand specimen characteristics. The basal 0.5 to 1.0 metre is a fine-grained, dense and chilled melanocratic rock, often lobate in form and carrying rare feldspar phenocrysts. Generally, with increasing height away from the base, the grainsize steadily increases; the rock becoming more leucocratic, and yellow-tinged with a distinct mottled or knobbly texture due to coarsely crystalline poikilitic clinopyroxene. Plagioclase phenocrysts, although not abundant are present throughout and are often accompanied in glomeroporphyritic aggregates by olivine. Compositionally, the large plagioclase feldspars have cores of Bytownite-Anorthite (An_{90}-An_{95}) and zoned outwards to compositions around An_{70}. Esson <u>et al</u>. (1975) estimate a bulk composition of between An_{82}-An_{86}. The olivines also show a considerable compositional range from cores of Fo_{82} to rims of Fo_{66} although Esson <u>et al</u> report a wider range (Fo_{91}-Fo_{55}) with a grouping around Fo_{80}. The clinopyroxenes are relatively calcium-rich, iron-poor augites which may in some cases be slightly zoned towards the margins. The calcium content is generally below that of the equivalent alkalic rocks and further details of the mineralogy are discussed in Chapter 8. Textural changes also accompany the transitions across the main columnar zones (Chapter 6.1). Although the phenocryst content of the two outliers (never reaching above 7-8 percent) differs slightly, perhaps reflecting a deficiency in the sampling or a slight difference in occurrence ie. position within the 'lava-lake', rather than any definite genetic difference between them, the lava is considered as a single flow. Its petrography is most simply dealt with by a consideration of the main structural divisions (Figs. 6 and 18).

1. <u>The Basal Zone</u>

Immediately below the lowest massive basalt on Preshal Beg, a thin, tholeiitic breccia composed primarily of lobate, glassy lava and angular blocks, crops out intermittently (Plate 24). This rock (Sk750809) possibly representing the initial outpouring onto an irregular surface with the presence of standing water indicated by the 'pillow-like' masses, carries scattered, resorbed or partially resorbed plagioclase microphenocrysts up to 0.5 millimetres in length and rare 5.0 millimetre plagioclases associated with 0.2 millimetre olivines. The groundmass is composed of 0.05-0.1 millimetre needles of plagioclase, 0.1 millimetre granules of olivine, dendritic-quench-textural opaques and clouded, opaque-charged subophitic to granular, colourless clinopyroxene in a yellowish devitirfied glassy mesostasis. Small rounded vesicles infilled by chlorite and with glassy margins are present (Plate 47).

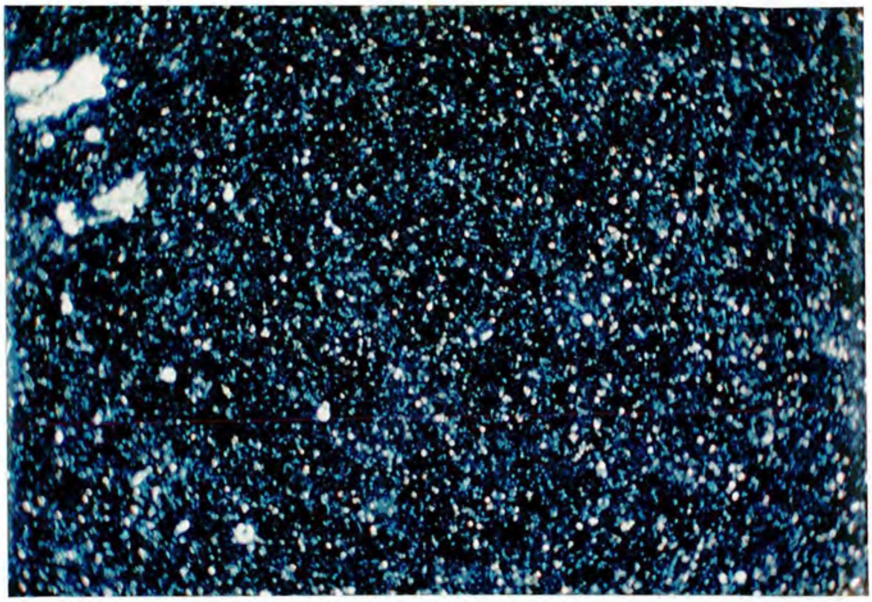
Above the breccia, the lava is more compact and massive (eg. Sk750808) with conspicuous glomeroporphyritic aggregates up to 7 millimetres across and composed of 2-3 millimetre, tabular, frequently zoned and inclusion rimmed plagioclase with smaller 0.5 millimetre plagioclases and associated olivine microphenocrysts (Plate 48). The groundmass is fine-grained with 0.25 millimetre maximum, granular, neutral to colourless pleochroic clinopyroxene which may in part have begun its crystallisation as a minor microphenocryst phase, small granular olivines and randomly oriented plagioclase laths. The opaque phase occurs as

PLATE 47

Photomicrograph of the glassy, chilled basalt from the lobate breccia at the base of the low-alkali olivine tholeiite of Preshal Beg Sk750809 showing small granular olivines and clinopyroxenes in a glassy but altered groundmass which also contains scattered plagioclase microphenocrysts.

PLATE 48

Photomicrograph of tholeiite Sk750808. This represents the chilled base of the low-alkali olivine tholeiite of Preshal Beg and reveals glomeroporphyritic euhedral plagioclase and olivine microphenocrysts in a dark, altered groundmass.



discrete anhedral to subhedral grains of titaniferous magnetite with exceptionally rare ilmenite lamellae. It may aggregate to form subophitic clots with brownish-translucent margins. Specimen Sk750808, within 5 centimetres of the base is texturally variable, with slightly coarser patches consisting of the usual mineralogy plus small clinopyroxene microphenocrysts with ragged margins.

On Preshal More, the chill-zone, sampled at an intermediate height to the previous samples (Fig.18), is again fine-grained but with only rare 0.4-0.5 millimetre microphenocrysts of plagioclase and olivine. The groundmass is somewhat heterogeneous due to the presence of a somewhat indistinct, wavy-banding caused by grainsize variations and a subtrachytic textural groundmass feldspar. The clinopyroxene is in the form of small granules but coarser, ophitic patches, perhaps slightly pegmatitic in nature are present. Also, in the specimen sliced (Sk750915), an aggregate of granular, yellowish clinopyroxene, rimmed successively by olivines and strongly zoned plagioclase may be pegmatite in origin.

2. <u>The Main Columnar Zone</u>

Directly above the chilled base, an abrupt increase in grainsize takes place, being maintained throughout the zone of regular columns. On Preshal Beg (Sk750807) only

FIGURE 18

Sampling points within the low-alkali olivine tholeiite of Preshal More and Preshal Beg and the structural and petrographic divisions of the flow.

Key (A + B)

Agglomerates and bedded tuffs

Key (C + D)

1. Basal chill zone
2. Main central columns and small subdivisions
3. Fissile-laminar zone
4. Upper irregular columnar zone

a. Scattered porphyritic with general clinopyroxene increase in size upwards and more dendritic form
b. Fine-grained, no flow orientation of plagioclase
c. Fine-grained with poorly developed flow orientation of plagioclase
d. General increase in clinopyroxene size upwards to a maximum at the top of zone 2
e. Scattered porphyritic
f. Mixed zone with handing of granular and poikilitic clinopyroxene and flow aligned plagioclase
g. Fine-grained/glassy tholeiite with glomeroporphyritic olivine and plagioclase.

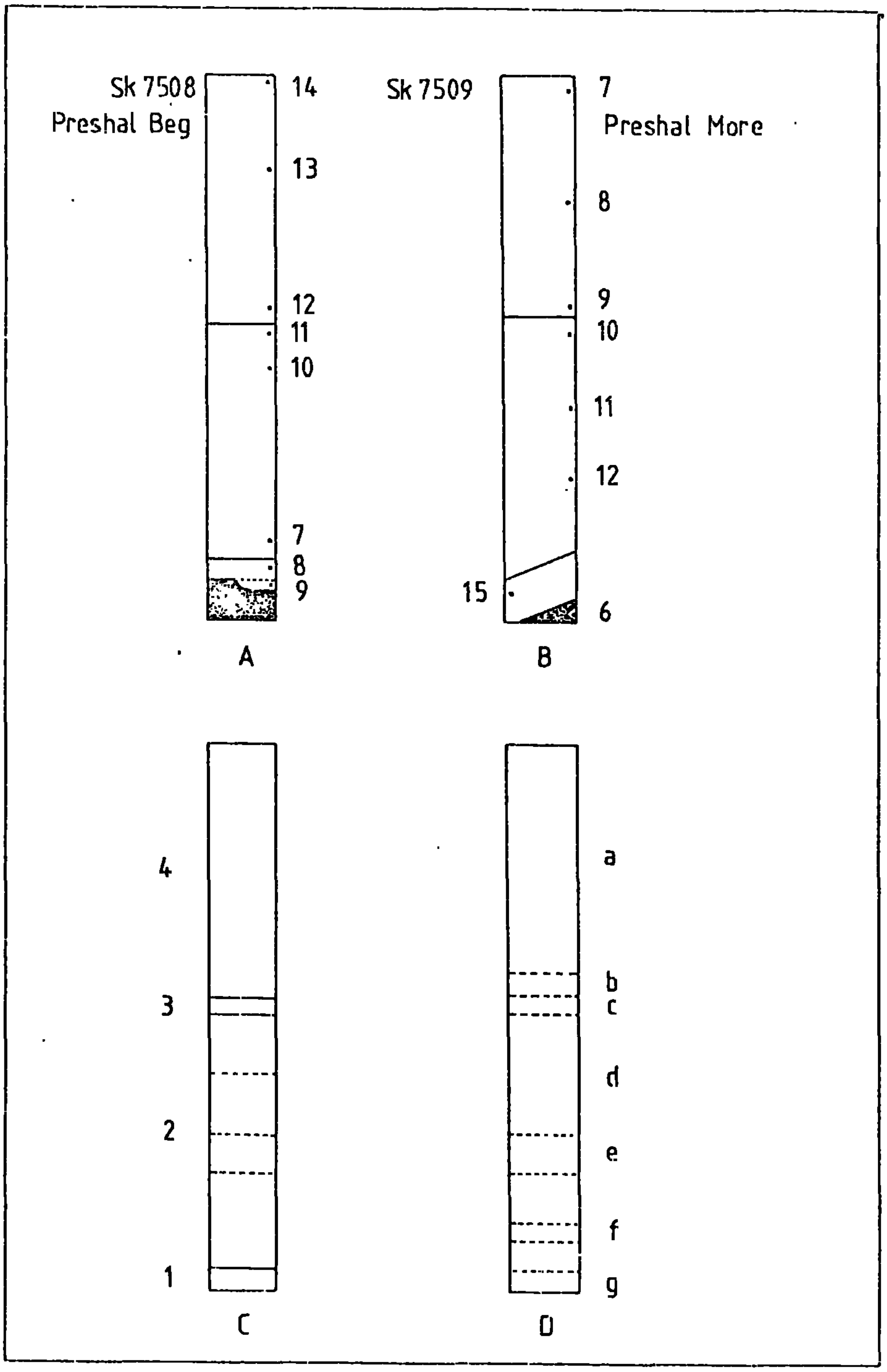

Sk 7508
Preshal Beg
14
13
12
11
10
7
8
9
A
Sk 7509
Preshal More
7
8
9
10
11
12
15
6
B
4
3
2
1
C
a
b
c
d
e
f
g
D

Figure 18

trace amounts of phenocrysts are present in a groundmass characterised by 3-4 millimetre diameter, highly poikilitic brownish-neutral clinopyroxene plates enclosing subtrachytic plagioclase laths with both Carlsbad and Albite twinns, and anhedral granular olivines. The opaque phase is interstitial, being confined to the margins of the clinopyroxene plates. The rare plagioclase phenocrysts are invariably zoned and often subhedral with thin outer rims of a more sodic plagioclase enveloping a thin zone of small mafic inclusions. Some resorption and rounding of the phenocrysts has taken place. The feldspar may contain primary inclusions of a brown spinel reminiscent of the olivine+spinel porphyritic alkalic lavas. This is found in specimens Sk750807 and Sk750810.

Samples were collected at roughly 20-25 metre intervals on Preshal More (Fig.18) and all exhibit similar features to Sk750807 but differ slightly in having a finer-grain size and groundmass textures. Specimens Sk750911 and Sk750912 are both slightly fissile in the field due to the subtrachytic alignment of the groundmass plagioclase laths and an internal banding due to the grain-size and texture of the clinopyroxene. Zones up to a few centimetres thick of fine-grained and intergranular clinopyroxene textured tholeiite with glomeroporphyritic 0.5-3.0 millimetre plagioclases and 0.25-0.7 millimetre olivines, alternate with a coarser-grained, ophitically textured tholeiite carrying fewer but larger (to 5 millimetres) phenocrysts of zoned plagioclase and subhedral to anhedral zoned olivines (Plate 49). Aggregates occasionally reach 1 centimetre in diameter. Texturally, the top of the main columnar zone (Sk750810) approaches the basal type with conspicuously poikilitic clinopyroxene as the distinguishing feature. A highly-zoned, more-sodic plagioclase may be present interstitially. Specimen Sk750910 is fine-grained and the clinopyroxene is typically granular 0.15 millimetre crystals and more rarely as microporphyritic plates with a maximum length of 0.4 millimetres and sub-ophitic, zoned margins.

3. The Fissile-Laminar Zone

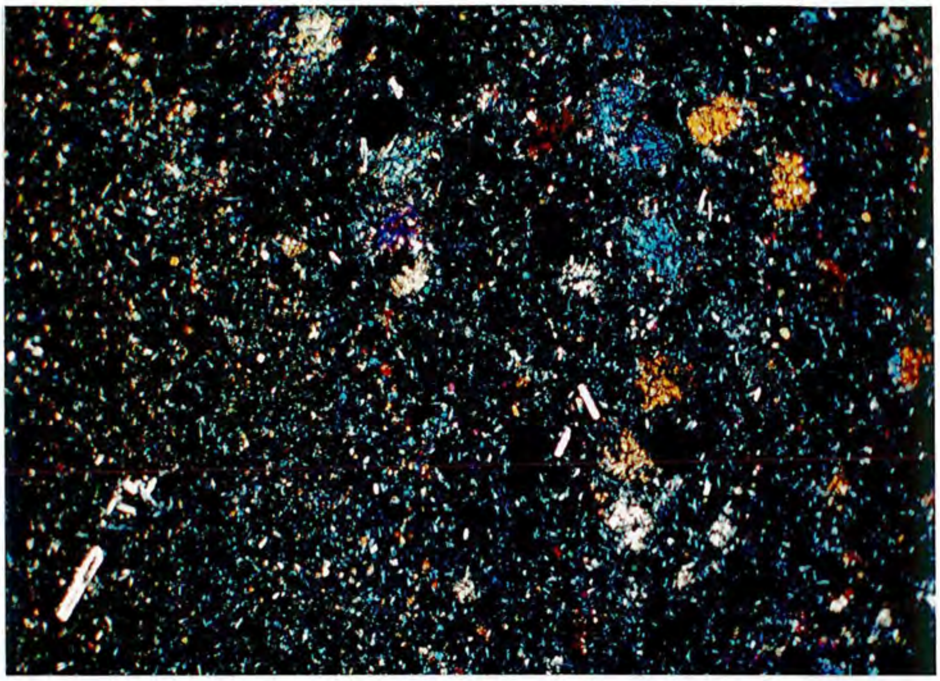
As mentioned in Chapter 6, the junction between the zones of regular and smaller irregular fanning columns is marked by a fissile or laminar zone about 75-80 centimetres thick. Petrographically, the rock is a considerably finer-grained version of the main zone but is characterised by a marked alignment of the groundmass plagioclase laths and either granular (Sk750909), subophitic (Sk750812) or a highly poikilitic and occasionally feathery growths of clinopyroxene (Sk750811). Glomeroporphyritic, up to 5 millimetre plagioclases and olivines are found; the olivine phenocrysts being more abundant on Preshal More than on

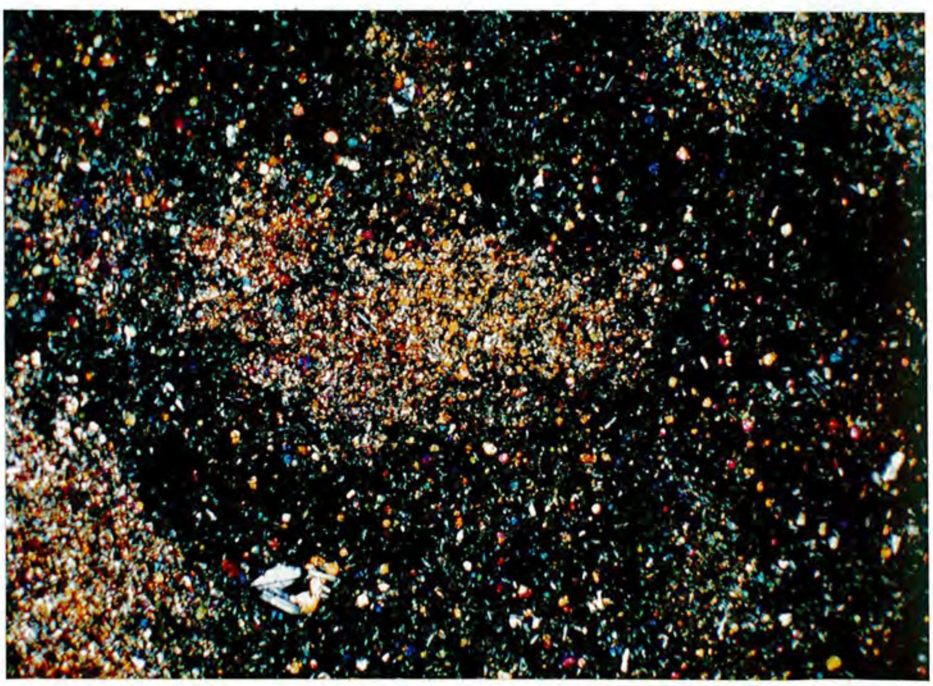
PLATE 49

Photomicrograph of the low-alkali olivine tholeiite Sk750911 from Preshal More showing the microscopic variations in texture due to varying habit in the clinopyroxene phase. Alternating bands of tholeiite characterised by poikilitic or granular sub-calcic clinopyroxene are common in this part of the flow near the fissile-laminar zone. Plagioclase micro-phenocrysts may appear slightly more common in the granular portions.

PLATE 50

Photomicrograph of some large ovoid poikilitic clino-pyroxenes in the central zones of the low-alkali olivine tholeiite of Preshal Beg Sk750807. Trace amounts of glomeroporphyritic plagioclase may also be present and olivine is small and granular in contrast to elsewhere in the flow where it forms large zoned phenocrysts.





Preshal Beg, a feature characteristic of the tholeiite in general.

4. Zone of Irregular Columns

Mineralogically, the upper columnar zones of the tholeiite are identical to the lower zones. An increase in grainsize takes place upwards away from the fissile zone and scattered plagioclase and olivine phenocrysts are found throughout. In contrast to the large sub-spherical, poikilitic clinopyroxenes of the middle zones (Plt.50), the clinopyroxenes may form dendritic, feathery 7 by 2-4 millimetre growths of smaller, anhedral, slightly zoned crystals, while the plagioclase microphenocrysts, up to 2 millimetres, may partially enclose 0.35 millimetre olivines (Sk750907). The opaque phase is again of late crystallisation and is made up from minute euhedra confined to the interstitial spaces between the clinopyroxene plates (Plate 51). Corresponding specimens from the top exposure levels of Preshal More (Sk750907) and Preshal Beg (Sk750814) having contrasting grain sizes, indicate that Sk750814 comes from closer to the original flow top.

The chilled zone is characterised by small spherical vesicles infilled by a yellow-green pleochroic chlorite while the upper zones become progressively more vesicular, although amygdaloidal structures are never present to the same degree as in the other lavas, due to the original

PLATE 51

Photomicrograph of the low-alkali olivine tholeiite Sk750907 showing the confining of minute titaniferous magnetite crystals to the interstitial areas between the large and often dendritic, poikilitic clinopyroxenes.

roof of the tholeiite having been removed by subsequent erosion.

The same alterations experienced by the other lavas are found to act upon the olivine tholeiite. The olivines are occasionally rimmed by serpentine with or without a blue-green chlorite and small magnetite octahedra, iddingsite or may be wholly or partially pseudomorphed by a pleochroic (green-pink), highly birefringent mica. The plagioclases are often clouded or sericitised and chloritic rims are frequently developed, especially where resorption is strongest. The clinopyroxenes may develop some dusty inclusions but mostly appear unaltered or with some indication of marginal reaction to amphibole.

Individual flows other than the tholeiite above do not generally exhibit much internal variation. However, the amygdaloidal zones, whilst preserving the overall textures of the central zones are heavily altered. Apart from the ubiquitous zeolites, there is usually much chlorite readily attacking the feldspars and pseudomorphing the olivines and the rest of the groundmass is invariably dark due to a high proportion of opaque-charged glass, haematite and finely divided clay minerals.

In addition, hypersthene and nepheline-normative basalts were, in most instances, found to be petrographically indistinguishable except where the hypersthene-normative rocks were deeply weathered. Further considerations of this aspect and the petrographic features attributable to the thermal and hydrothermal alterations near the Central Complex are considered in succeeding chapters.

7.1ii) Hawaiites

As with the basaltic lavas, those of Hawaiitic composition (Differentiation Index 32-45, Normative Feldspar An_{30}-An_{50}) can be subdivided into various petrographic types as follows:

A. Olivine + Plagioclase + Magnetite Microporphyritic Hawaiites

B. Olivine + Plagioclase Microporphyritic Hawaiites (The Feldspathic flows of the Loch Dubh Group are included in types A and B).

C. Coarse-grained and Transitional Hawaiites

D. Aphyric Hawaiites

E. Plagioclase Macroporphyritic Hawaiites

F. Composite Hawaiite of Dun Ard an t-Sabhail.

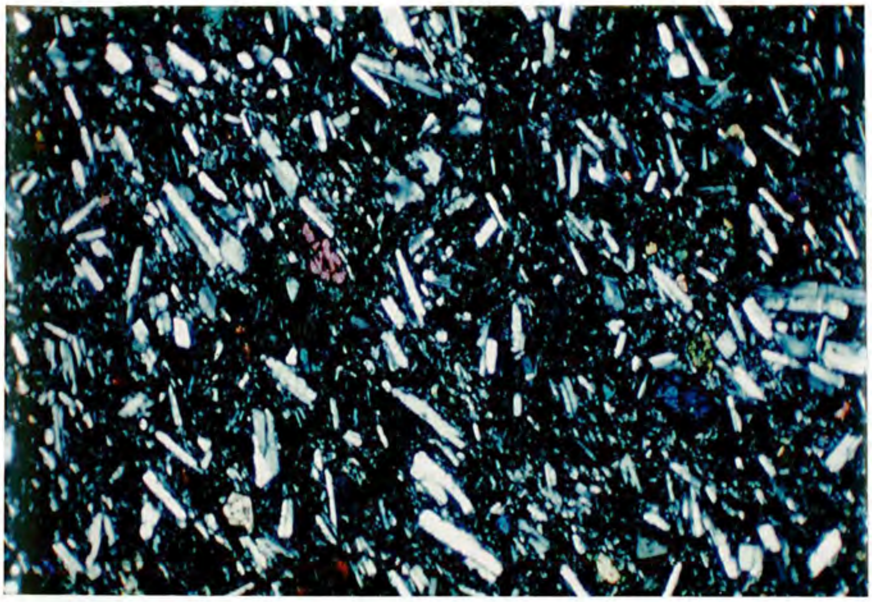
Hawaiitic lavas frequently form thick, bold, laterally continuous, pale-grey lichen covered escarpments and weather to a brownish soil or gravel. Columnar jointing, although infrequently well developed and the almost ubiquitous presence of fluxion structures, serve to distinguish hawaiites from basalts although they are almost indistinguishable from mugearites in the field. Types A-D are the most common with those lavas carrying large phenocrysts of plagioclase feldspar present but not abundant. Lavas of this type are classified here as hawaiites although it is recognised that in some cases, the presence of substantial volumes of a moderately calcic plagioclase will tend to lower the Differentiation Index. Consequently some are possibly more allied to the mugearites. The best examples of this are probably the flow capping Beinn nan Dubh Lochan and the Composite flow, located 2.5 kilometres southwest of Fiskavaig Bay forming the small hill of Dun Ard an t-Sabhail (318333) (Plate 31). Because of the latter's unique structure and its phenocryst content it is dealt with separately. Mineralogical and geochemical aspects are dealt with more fully in succeeding chapters.

7.1ii)A Olivine + Plagioclase + Magnetite Microporphyritic Hawaiites

The most common petrographic type distinguished is that of a fine-grained, melanocratic rock carrying varying amounts of olivine, plagioclase and titaniferous magnetite and often possessing a marked fissility in handspecimen.

Microphenocryst olivines (Fo_{66}) are generally small (<1 millimetre) subhedral rhomb-shaped or tabular crystals with their long axis parallel to the fluxion textures developed by the groundmass. In some instances the microphenocrysts may be skeletal and attain dimensions up to 1.5 millimetres long (Sk750104) although average dimensions range between 0.7-0.8 millimetres (Sk740512). Normal zoning, especially of the outer margin, towards a more fayalitic olivine is usually present.

Plagioclase feldspar with core compositions as basic as An_{56-57} (Sk740301) is nearly always a microphenocryst phase and although varying from only a few scattered crystals to being the dominant phase (1-10% modal), is often obscured by the grainsize of the groundmass. In the finer-grained examples (Sk740511, 740512, 741112 and 7702) strongly zoned acicular crystals 0.5-1.5 millimetres long are abundant along with olivine and titaniferous magnetite (Plate 52). The plagioclases are euhedral to subhedral, flow-oriented laths displaying carlsbad, pericline and combined polysynthetically-twinned cores within some instances unzoned, ragged subhedral margins of more sodic feldspar. Some ascillatory zoning may also be present. The percentage of plagioclase microphenocrysts is highly variable and has a range in the order of 1-25 percent, with the majority between 1-10 percent as indicated already. Those hawaiites with a relatively high percentage of microphenocrysts (>10%) are not common but they may be locally important as in the hawaiites making up part of the Loch Dubh Group of lavas



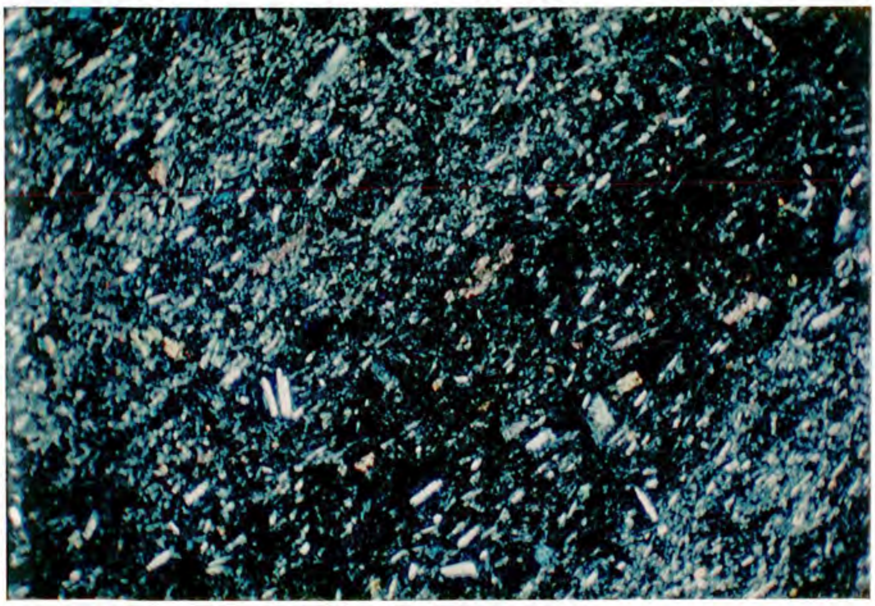


PLATE 52

Photomicrograph of a fine-grained olivine + plagioclase + magnetite microporphyritic hawaiite Sk740512 showing well developed flow banding. Rocks such as this are generally near aphyric.

PLATE 53

Photomicrograph of a Loch Dubh-type (feldspathic) olivine + plagioclase + magnetite microporphyritic hawaiite Sk750104 showing well developed flow banding and simple twinning of the plagioclases.

(Chapter 5). Specimen Sk750104 from this group contains a modal analysis of approximately 4% olivine, 3% magnetite and 25% plagioclase, all as microphenocryst phases. Only the percentage feldspar varies greatly from the main hawaiitic modal types (Plate 53).

Apparently homogeneous, titaniferous magnetite is again somewhat variable. As a microphenocryst phase it is present from trace amounts to about 4 percent modal. Texturally it occurs as single octahedra 0.2-0.5 millimetres in diameter or as coalesced aggregates, up to 1.8 millimetres diameter, of smaller octahedra. Occasionally it is skeletal but more commonly is found as 0.3-0.5 millimetre cruciform aggregates apparently behaving subophitically towards the finer-grained groundmass constituents and hence presumably with an overlapping history of crystallisation.

The groundmass consists of strongly zoned, trachytic (occasionally with 2 directions of alignment e.g. Sk740108, Plate 54) textured plagioclase laths 0.1-0.4 millimetres long. The cores of the feldspars are as calcic as An_{50} but zone outwards to potassic oligoclase-andesines, or calcic anorthoclases with the plagioclase component usually dominant (Muir and Tilley, 1961). Intergranular or 0.25-0.5 millimetre, subophitic, occasionally oriented (Sk750922), brown-neutral to pinkish relatively moderately iron-rich clinopyroxenes, granular olivines and small

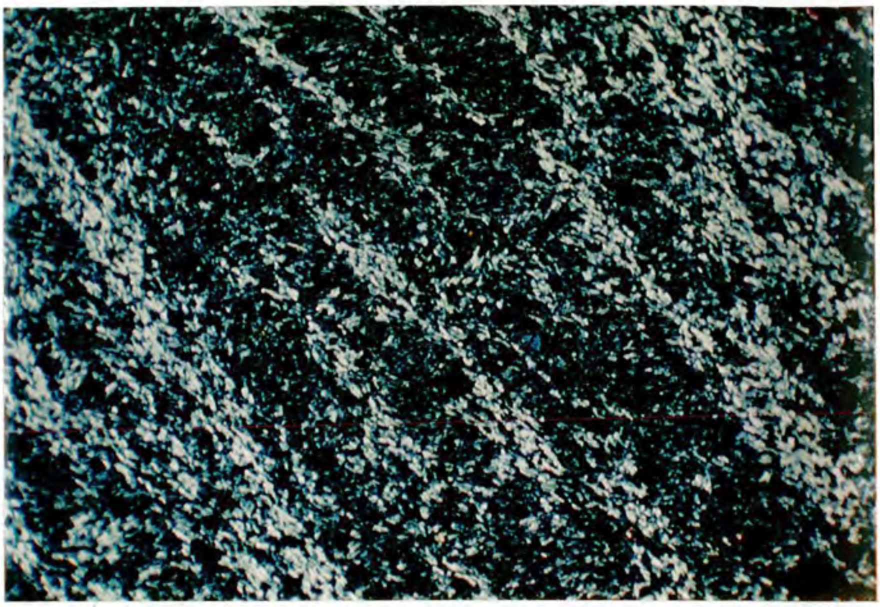


PLATE 54

Photomicrograph of the flow banding in the groundmass plagioclase laths in hawaiite Sk740108 from Ardtreck showing the development of two directions of orientation. This results in a cleavage-like jointing in the rocks concerned parallel to the strongest direction which in this case slopes from top left to bottom right.

PLATE 55

Photomicrograph of the olivine + plagioclase microporphyritic hawaiite Sk750117 with large aggregates of titaniferous magnetite granules.

granules or octahedra of opaque oxide make up most of the remainder but considerable interstitial alkali-plagioclase to alkali feldspar may be present. Also in these interstitial areas, minute crystals of late stage apatite and amphibole, although not common, may be present. Flakes of red-brown-colourless highly pleochroic biotite is a common constituent of the groundmass (Sk741112 etc.) but mostly biotite is of post-consolidation hydrothermal or deuteric origin being associated solely with the reacted margins of the opaque phases and the olivine pseudomorphs.

In the finer-grained examples, which are possibly transitional towards mugearites and represent the chilled lower surfaces of flows, the rock may be distinctly banded. This is due to a combination of grainsize layering and to the modal percentage of groundmass magnetite, which varies between 5 and 15 percent. In the mugearitic-hawaiites (e.g. Sk7701) the banding is regularly developed and is parallel to the other flow-structures, while in some (e.g. Sk741112) the banding is less regular and may in part be due to the presence of chilled autolithic material. Larger autholiths, up to 1 metre long are found scattered within the porphyritic hawaiite of Loch Dubh (Sk750101) (316329).

7.1ii)B <u>Olivine + Plagioclase Microporphyritic Hawaiites</u>

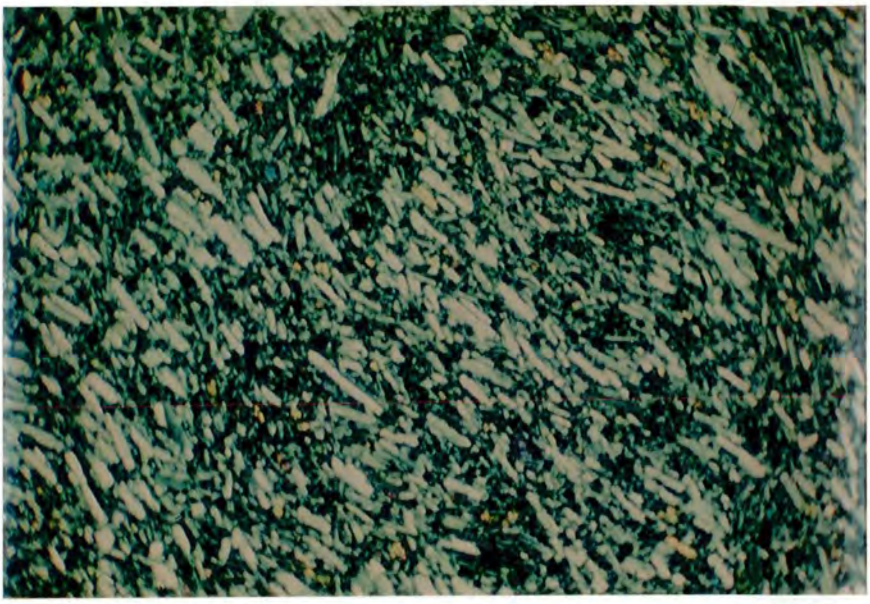
Apart from those hawaiites transitional towards basalts, microphenocrysts of magnetite are missing or very rare in only a few of the flows sampled. In hand-specimen, the rock appears identical to type A Hawaiites in appearing aphyric, fine-grained and melanocratic.

The commonest type is that of an extremely fine-grained rock in which the opaque phase consists of minute octahedra within the groundmass and only occasionally aggregating into poikilitic-like, rounded plates up to 0.5 millimetres in diameter (e.g. Sk750117, 750606, 750512 and 750817) (Plate 55). Minute acicular plagioclases and euhedral olivines appear to be microphenocrysts in those rocks due to their aphanitic nature. However, phenocrysts may be abundant in the coarser types as on the slopes of Beinn nan Dubh Lochan where two such flows (Sk740405 and Sk750105) are highly feldspathic with the plagioclase microphenocrysts constituting over 20 percent modal (Plate 56). These feldspar laths are strongly flow-aligned, and are occasionally up to 2 millimetres long with euhedral cores and strongly-zoned subhedral outlines.

The groundmass consists of subophitic often brownish-purple titaniferous augite up to 1 millimetre diameter, 0.25-0.5 trachytic plagioclase laths and granular olivine and magnetite.

7.1ii)C <u>Coarse-grained and Transitional Hawaiites</u>

Coarser-grained hawaiites, in which the microphenocryst phases are almost obscured by the grainsize of the groundmass



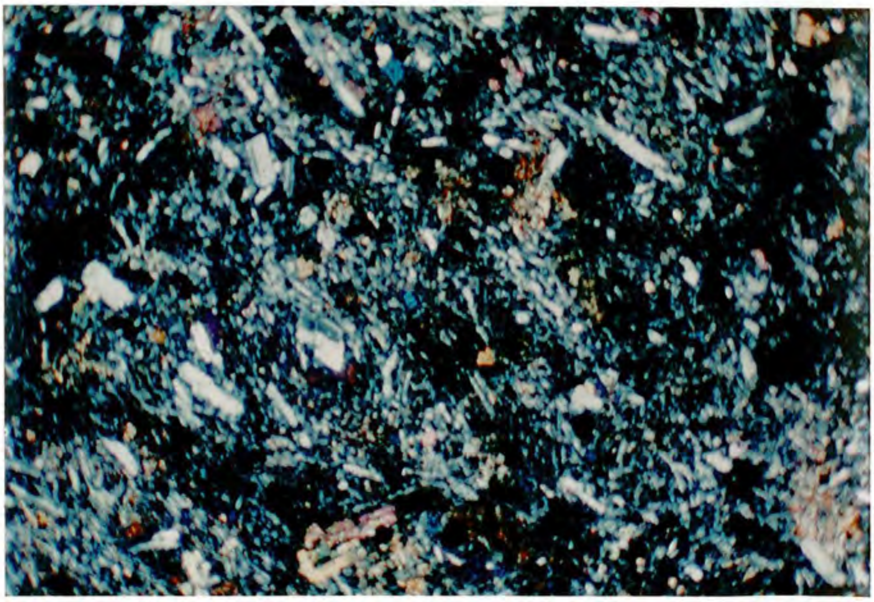


PLATE 56

Photomicrograph of the olivine + plagioclase microporphyritic hawaiite Sk750105 of Loch Dubh-type (feldspathic). The rock is typically dominated by plagioclase microphenocrysts (small groundmass plagioclases can be seen in the interstitial spaces) accompanied by subordinate but aligned olivine microphenocrysts.

PLATE 57

Photomicrograph of the doleritic textured basaltic hawaiite Sk750905. The clinopyroxene and olivines are more characteristic of alkali-olivine basalts but the plagioclase microphenocrysts and those of the groundmass are distinctly flow oriented and there is a sodic plagioclase residuum.

are not common but a few examples are recorded (e.g. Sk740504, Sk750901, 750902, 750904 and 750905). Specimens Sk750904 and Sk750905 have relatively low Differentiation Indices (34 and 35 respectively) and are considered as transitional hawaiites or basaltic-hawaiites. They have some features in common with the basalts; namely the large subophitic clinopyroxene plates and interstitial to micro-phenocryst titaniferous magnetite. The groundmass and microphrnocryst plagioclases may be subtrachytic textured (Plate 57) and the olivines fresh or partly corroded.

The remaining specimens above (Sk740504, Sk750901 and 750902) are true hawaiites with Differentiation Indices of 41,39 and 40 respectively and although coarser-grained than most hawaiites retain a flow alignment of groundmass feldspars. These are commonly up to 1 millimetre long, with low extinction angles and obscure the slightly larger microphenocrysts which attain 1.5 millimetres with Carlsbad-Albite twinning and rare oscillatory zoning. Microphenocryst olivines measure 0.3 to 1 millimetre along the long axis but show little tendency for a preferred orientation. The magnetite is finer-grained being represented by 0.1-0.2 millimetre octahedra.

The groundmass consists of trachytic to subtrachytic plagioclase laths with strongly zoned overgrowths, subophitic neutral to brown clinopyroxene and granular olivine and magnetite. Interstitial alkalic feldspar with accessory apatite is common, albeit patchily developed as in Sk740504. Other accessories include a highly pleochroic orange-red-pale brown biotite and a possible brown amphibole.

7.1ii)D Aphyric Hawaiites

Totally aphyric hawaiitic lavas are very rare indeed, and although in handspecimen many appear to satisfy this condition, they are observed to carry at least trace amounts of the common microphenocrysts upon examination in thin-section. Some hawaiites, can, however, be considered essentially aphyric.

In specimens Sk750606, 750512 and 750708 the rock is aphanitic and consists of minute oriented plagioclase laths enclosed in large 0.5 millimetre neutral to colourless, poikilitic to subophitic clinopyroxene plates. Olivine and a titaniferous magnetite are present as small rounded granules with the former showing a tendency towards coalescing to form aggregates up to 0.5 millimetres in diameter in close association with coarser olivines. Other near-aphyric rocks such as Sk750924 consist of euhedral titaniferous magnetite (0.05-0.1 millimetre), granular to small subophitic slightly pleochroic titaniferous augite and plagioclase laths. The plagioclase has an irregular habit and the euhedral cores are surrounded by ragged, anhedral or subhedral, strongly zoned, straight extinction outlines gradational with larger patches of interstitial alkali-rich plagioclase. There is no strong flow orientation of these plagioclase laths and olivine is scarce and invariably pseudomorphed by chlorite or amorphous greenish bowlingsite.

Petrographically, hawaiites of types B and D may be almost identical in a number of instances; the distinction being made on the presence or absence of very small crystals of olivine or plagioclase, which are however marginally larger than the groundmass, in type B. Both contain aggregated titaniferous magnetite which is not here considered as a microphenocryst phase as under reflected light conditions, microscopic examination reveals a number of subhedral grains forming together.

7.lii)E <u>Plagioclase Macroporphyritic Hawaiites</u>

As previously mentioned in the introduction to this section, several hawaiites carry large plagioclase phenocrysts (0.5-2.0 centimetres) as well as the micro-phenocryst phases, olivine, plagioclase and titaniferous magnetite. On the abundance of these macrophenocrysts, three types are distinguished:

1. Phenocrysts scarce
2. Phenocrysts numerous
3. Phenocrysts scattered in Hawaiite/Mugearite of Beinn nan Dubh Lochan.

1. <u>Hawaiites with scarce macrophenocrysts</u>

In the field, the hawaiites of this type appear as those of type A, but occasionally large feldspars are found scattered, often irregularly, throughout the flow. It is common for this porphyritic feature not to be evident in thin section due to the scarcity of phenocrysts. In many cases (e.g. Sk750101) the phenocrysts are aligned parallel to the flow banding and trachytic texture of the rock but this is not invariably the case. Harker (1904 , pp.250-251) noted that many of the 'sills' intruded into the basaltic lavas of Skye were sporadically or 'quasi-feldspar porphyritic' rocks. The present study equates these 'sills' directly with the hawaiitic and mugearitic lavas. Hawaiites fitting this description are exposed throughout the region although due to the greater proportion of differentiated lavas to the north-west, most come from north of Loch Eynort, characterising the Arnaval group.

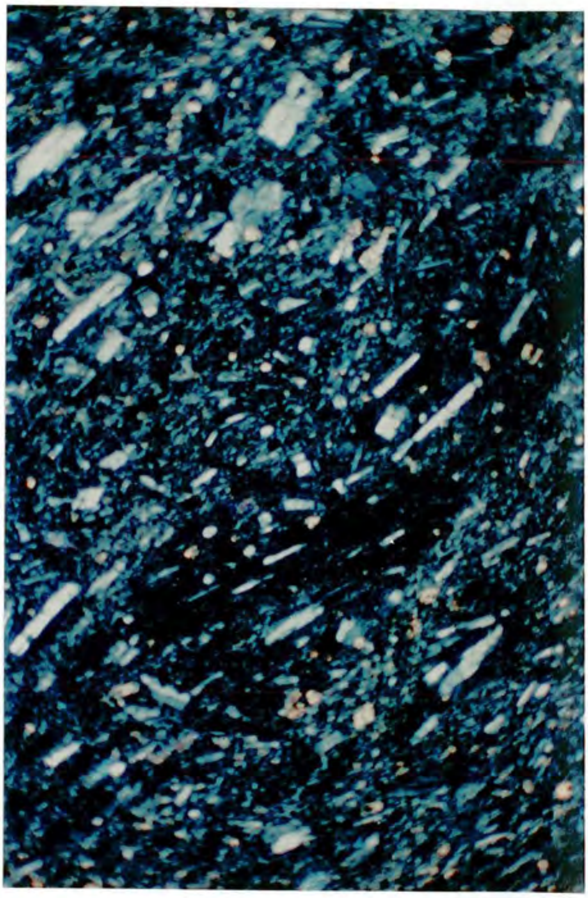
Petrographically, excepting the macrophenocrysts, the lavas (e.g. Sk740705, 0706, Sk750101, 0503 and 0605) are identical to the other types previously described. The feldspars (An_{48+}: Optical Determination) varying from 0.5-1.5 centimetres long commonly exhibit signs of having undergone some resorption in that they are frequently rounded, embayed and with inclusion-filled strongly-zoned borders. Pericline and combined carlsbad-albite twinning is represented with normal zoning ubiquitous and oscillatory only weakly developed, but revealing originally euhedral cores.

2. Hawaiites with numerous macrophenocrysts

Only 1 flow, identical to the olivine + plagioclase + magnetite microporphyritic hawaiites, carrying several volume percent of large feldspar phenocrysts has been found in west central Skye. This flow, Sk7634, capping the sequence exposed in the cliffs at Rubha Gruinn to the north side of Talisker Bay (c.305310) is markedly porphyritic, containing up to 5 percent plagioclase macrophenocrysts up to 2 centimetres long or across, set in a relatively fine-grained groundmass. The larger phenocrysts are rare enough to escape incorporation in thin section but rather grade into abundant (approx. 20%) microphenocrysts over 1.5 millimetres long, showing combinations of carlsbad albite, pericline, possibly ala-type twinning and strongly zoned outer margins (Plate 58). The larger phenocrysts are compositionally zoned with a narrow zone of reversely zoned plagioclase followed outwards by a normally zoned margin containing minute granules of olivine, magnetite and clinopyroxene at the interface. In this respect, the flow is similar to the composite hawaiite of Dun Ard an t-Sabhail and may possibly represent a lateral equivalent or its lateral

PLATE 58

Photomicrograph of a Loch Dubh-type plagioclase macro-porphyritic hawaiite Sk7634 showing good flow alignment of ~~the~~ groundmass constituents. The plagioclase micro-phenocrysts are typically stumpy crystals showing com-binations of carlsbad, albite and possibly ala twinning laws. Large plagioclase macrophenocrysts are present to some degree in this flow although none appear in this section. Many hawaiites and mugearites possess rare, scattered macrophenocrysts but are not generally termed porphyritic in this study. Harker (1904) describes several examples of such rocks (he considered them as sills) from west-central Skye and terms them quasi-porphyritic dolerites.



continuation although the latter is mainly exposed over 2.5 kilometres to the north-east. In detail however the two flows are petrographically distinct, Sk7634 showing features similar to the feldspathic rocks of the Loch Dubh Group. Finer-grained patches within this flow are characterised by microporphyritic, occasionally glomero-porphyritic plagioclase, olivine and magnetite, irregular resorbed, untwinned but strongly zoned macroporphyritic plagioclase and opaque-charged groundmass plagioclase laths. Of the microphenocrysts, the olivine and magnetite may be partly enclosed along the margins of the feldspars indicating the later growth of the plagioclase with respect to them, but the majority of euhedral magnetites are not incorporated and possibly crystallised last. Similar features have been noticed in the olivine + plagioclase porphyritic basaltic lavas with the olivine being either the earliest phase to crystallise or with it having a more rapid growth rate relative to the plagioclase initially but with subsequent growth of the plagioclase continuing after the olivine had ceased to crystallise; the result being a partially enclosed olivine microphenocryst. The titaniferous magnetite forms cruciform skeletal crystals as well as a more euhedral phase similar in size; a feature not unique to this rock-type. It may also form small embayed partially reacted, crystals. The clinopyroxene is most commonly found as small subophitic plates in this rock but where the grainsize is smaller, it exists as innumerable intergranular crystals.

3. Hawaiites of Mugearitic Affinities containing scattered Macrophenocrysts

The third type of plagioclase macroporphyritic hawaiite is represented by the remnants of a flow capping Beinn nan Dubh Lochan (312324). This flow, Sk740311, has been found to have no lateral equivalents within the Arnaval Group to the south and east and is unique in the area. It is tentatively assigned, along with the feldspar-rich hawaiites to the north and south-west, to the Loch Dubh Group. The Differentiation Index of this rock (44.8) places it as a hawaiite but in detail, its mineralogy indicates the mugearitic affinities of the groundmass. In hand specimen, the rock is extremely fissile and consequently weathered deeply along joint surfaces. The plagioclase macrophenocrysts weather to a glassy-yellow colour and are reasonably abundant (up to 8%).

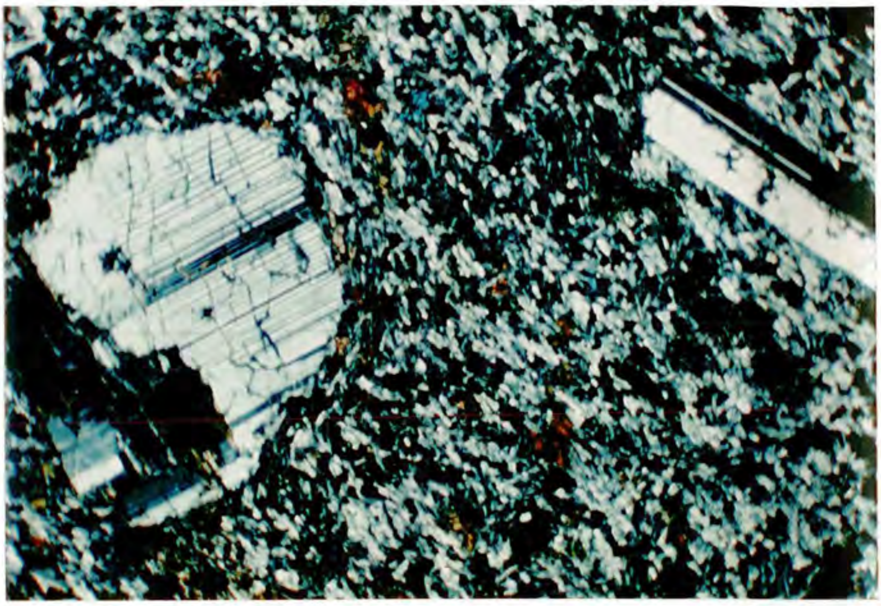
In thin section (Plate 59) it is not evidently intermediate in composition, unlike the other hawaiites, as many of its petrographic features especially the coarser grainsize are more commonly seen in the basaltic lava types. The groundmass consists of 0.5-0.7 millimetre diameter, ophitic, brown to purplish-grey pleochroic titaniferous clinopyroxene and randomly oriented to

PLATE 59

Photomicrograph of the plagioclase macroporphyritic hawaiite Sk740311 from the summit of Beinn nan Dubh Lochan showing the large corroded and peripherally zoned plagioclases in a flow textured groundmass of augite, titaniferous magnetite, olivine and accessory apatite, biotite and hornblende.

PLATE 60

Photomicrograph close-up of the groundmass of Sk740311 revealing the presence of beautifully euhedral basaltic hornbelnde (lamprobolite) and apatite needles in the interstices. Titaniferous magnetite occurs as subhedral octahedra and is confined to the groundmass.



subtrachytic 0.2-0.25 millimetre long oligoclase laths with core compositions around $An_{26}Ab_{72}Or_2$ quickly zoning outwards to $An_{18}Ab_{79}Or_3$ with more highly potassic margins. Plagioclases of this composition are more characteristic of mugearites (Muir and Tilley, 1961a). Granular olivine and subophitic to interstitial titaniferous magnetite are also present. Very rare, large olivine microphenocrysts 0.25-1.0 millimetres across are now represented by green-yellow bowlingsitic or green micaceous pseudomorphs. Titaniferous magnetite is also an infrequent microphenocryst phase.

The plagioclase phenocrysts (An_{58-60}) vary in size from 3 millimetres to 1.5 centimetres long, possess Carlsbad, Carlsbad-Albite and Albite-Pericline twinning and are commonly subhedral with rounded, resorbed margins. Normal zoning is only weakly developed towards the margins (e.g. An_{55}) but the margins themselves are strongly zoned ($An_{35}Ab_{63}Or_2$) and strongly potassic at the extremes.

An interesting feature of this relatively coarse-grained rock is the presence of euhedral biotite and basaltic hornblende. The biotite is present as deep red-brown pleochroic anhedral plates and flakes while the basaltic hornblende may be 0.3 millimetres long and euhedral (Plate 60) or present as small subophitic interstitial plates. The amphibole is also markedly pleochroic with - α -colourless to pale brown,- β - brown and - γ - dark reddish brown. These hydrous phases are restricted to the larger interstitial areas associated with strongly zoned alkali-rich plagioclase, alkali feldspar and rare euhedral apatite and analcite.

7.1ii)F <u>The Composite Hawaiite of Dun Ard an t-Sabhail</u>

The close association in the field of porphyritic and nearly aphyric members of the intermediate suite is well known. Such composite bodies have long been recognised among the lava sequences of Mull (Ben More), Hawaii (Mauna Kea), Australia (Nandewar) and Northern Skye (Druim na Criche, Roineval) and are also noted from intrusions in the Midland Valley of Scotland and some of the pre-Cambrian dykes of south-west Greenland. The flow under discussion here crops out at Dun Ard an t-Sabhail, south-south-west of Fiskavaig Bay (318333) within the Arnaval - Loch Dubh Group lavas. It can be traced for a small distance westwards, and southwards extends towards Huisgill. Related rocks may be present at Loch Dubh (Sk750103) and at Talisker Bay (Sk7634), although due to poor exposure and faulting, the correlation is only tentative. The best exposures are at the 'Dun' itself (Plate 31) and show some 7-8 metres of highly plagioclase macroporphyritic hawaiite (Sk760703) overlying and apparently grading, over about 1 metre, into 3-5 metres of a more sparsely porphyritic rock (Sk760702).

There is a detectable, albeit small, increase in plagioclase phenocryst content towards the base of the upper unit. Harker (1904) noted that this flow was more basic, and had a different phenocryst distribution to the composites of Druim na Criche and Roineval and that the contacts between the units on the latter were much sharper. Recently, a number of composite bodies belonging to the alkali-olivine basalt-trachyte suite, including those from the Skye lava-field were studied by Boyd (1974) adding to the earlier studies of composite lavas by Kennedy (1931).

1. <u>The Upper Unit</u>

Taken as a whole, the upper flow unit at Dun Ard an t-Sabhail contains the phenocryst-xenocryst assemblage:

Plagioclase + Olivine + Titaniferous Magnetite
+ Spinel + Orthopyroxene

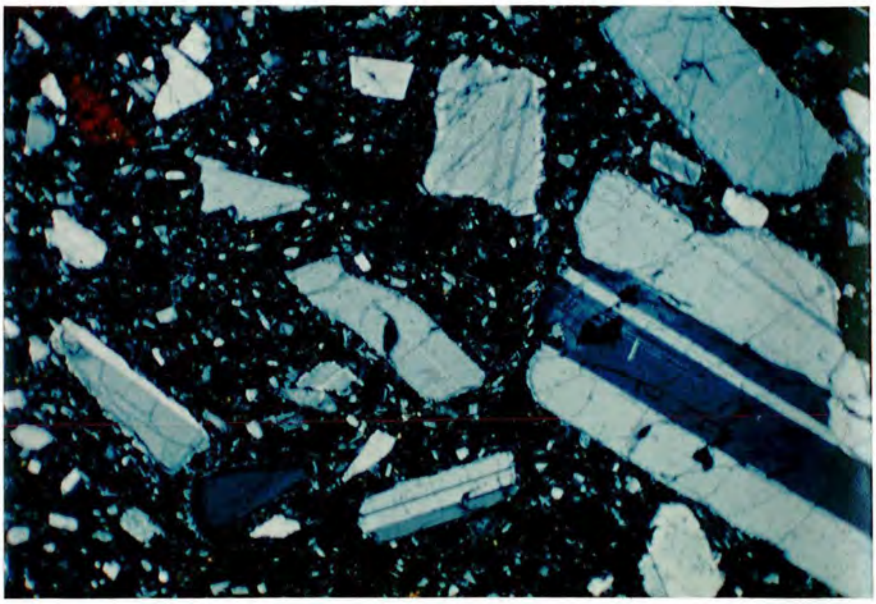
Plagioclase feldspars with apparently homogeneous cores of An_{52} (Boyd, 1974) ranging in size from 5 millimetres to 4 centimetres form on average around 20 percent of the rock (Plate 61). These appear as subhedral to ovoid, twinned crystals with more euhedral but untwinned margins. The margins are normally zoned (An_{45}-An_{34}) but the phenocrysts exhibit a zone of reverse zoning internal to this (An_{60}). The junction with the outer rim is marked by lines of inclusions which appear to be clinopyroxene,

PLATE 61

Photomicrograph of the upper porphyritic unit of the composite hawaiite of Dun ard an t-Sabhail showing rare olivine and magnetite microphenocrysts dominated by plagioclase phenocrysts. The plagioclase phenocrysts are of two distinct types, only the common subhedral to anhedral, zoned and corroded type with associated zones of olivine + magnetite + clinopyroxene inclusions is shown here. The other more sodic type is much corroded, ovoid and essentially unzoned, they are rare in comparison.

PLATE 62

The upper unit of the composite flow also contains a small percentage of hercynitic spinels + orthopyroxene xenocrysts in addition to plagioclase, magnetite and olivine. This photograph shows a typical example of an hercynitic spinel as found on the weathered surface of the flow.



olivine and some which, from studies on other porphyritic rocks, including the large allivalite dykes of northern Skye (Anderson and Dunham, 1966), by Donaldson (1975,1977) may possibly be subcalcic augite or an intergrowth of subcalcic augite and amphibole. Among these large phenocrysts Boyd also noted the existence of a second plagioclase with a composition of $An_{32}Ab_{64}Or_4$, which lacked twinning or zoning and inclusions but which had occasionally well-developed sieve textures and embayed margins. They make up less than 1 percent of the total phenocryst content and are present as traces in specimens Sk741004 and Sk760703. Plagioclase similar in appearance to the larger phenocrysts also forms a microphenocryst phase some 0.5-2.0 millimetres long. Hence there are two populations of macro-phenocrysts and the more common type has a bimodal distribution in terms of size.

As with the common hawaiite-type, the flow also carries rare (0.5-1.0 percent) microphenocrysts of olivine (Fo_{55-59}) and titaniferous magnetite. The olivines are small 0.4 millimetre subhedral and only rarely 0.7 millimetres across while the titanomagnetite is smaller but more euhedral.

Boyd also noted the occurrence of scarce phenocrysts of a hercynite spinel in this flow, distinguishing it, along with the presence of a second population of feldspar phenocryst, from the composite flows of Druim na Criche and Roineval several kilometres to the east. They are not easily found but on the weathered surfaces of the flow commonly they protrude from the surface, being apparently more resistant to weathering than the rest of the rock (Plate 62). They vary in size from 1-8 millimetres, are anhedral, often embayed and jacketed by a thin rim of titanomagnetite. Some are also found as 0.2-0.3 millimetre inclusions in some of the larger feldspars and in specimen Sk741004, aggregated masses of corroded and embayed crystals are present.

The present study also finds extremely rare, 1-4 millimetre diameter, phenocrysts of a dark brown but pink to green pleochroic, optically negative orthopyroxene ($Wo_3En_{70}Fs_{27}$). This is probably hypersthene. Found and collected in a similar manner to the spinels, they were initially identified as orthopyroxene using X-ray Diffraction and optical techniques. Only one example of this mineral has been tentatively identified in thin section Sk760703.

The groundmass is essentially that of the normal olivine + magnetite + spinel microphyric hawaiites possessing a subtrachytic to disoriented texture of andesine laths (An_{45-34}) zoning outwards to oligoclase and anorthoclase ($An_5Ab_{73}Or_{22}$) (Boyd 1974) , and including granular to subophitic, brown to neutral coloured clinopyroxene, small olivines and magnetite.

The interstitial areas are often rich in apatite needles, analcite with accessory rare amphibole and ilmenite, and zeolites, chlorite is also abundant. Some of the larger clinopyroxene plates, although possessing subophitic margins, appear to have roughly subhedral outlines and may have been early microphenocryst phases. This texture is noted among many of the basaltic lavas. Supporting evidence for the primary crystallisation of clinopyroxene or the presence of xenocrysts comes from the discovery of several clinopyroxene - spinel - serpentine - chlorite, irregular intergrowths up to 2 millimetres long (Plate 63). It is possible that this clinopyroxene, the hercynite spinel, the orthopyroxene and the second generation of plagioclase crystals are not true phenocrysts but cognate or accidental xenocrysts. The significance of this is discussed later.

2. <u>The Junction of the two units</u>

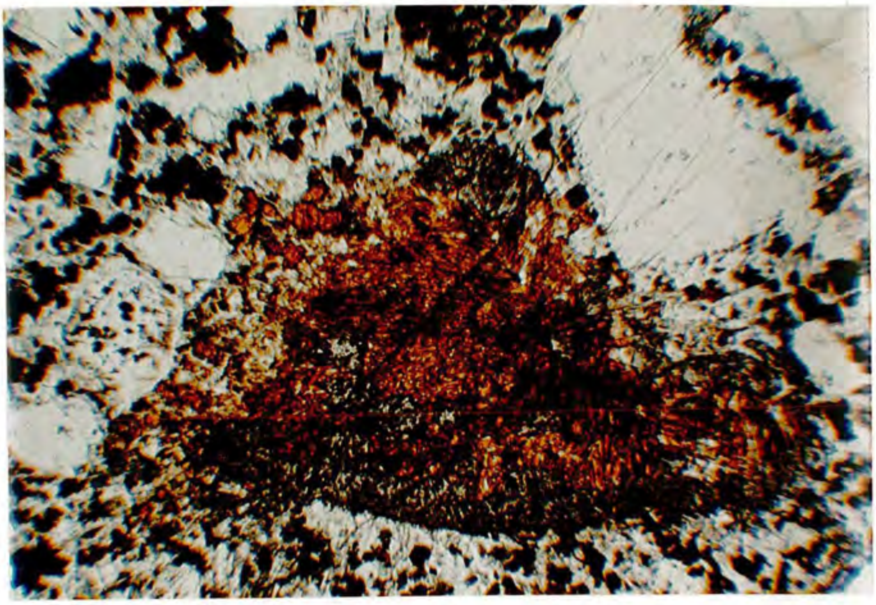
The junction between the porphyritic and sparsely porphyritic units is not well exposed but tends to indicate that a non-chilled, non-brecciated, diffuse gradational contact is present. The base of the upper unit has a distinct flow banding due to trachytic textures in the groundmass and fewer macrophenocrysts are present. The rest of the groundmass is considerably fine-grained and consists of minute granules of clinopyroxene, olivine

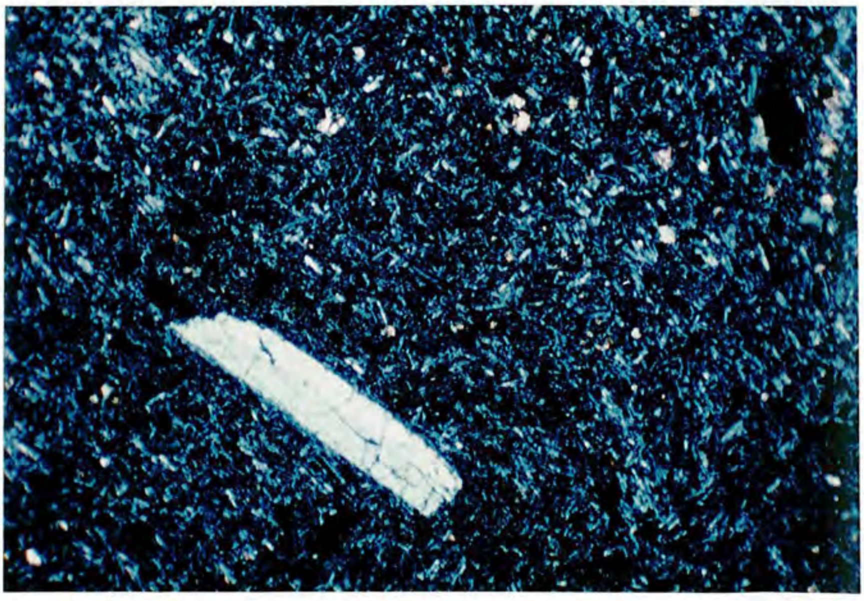
PLATE 63

Photomicrograph of problemmatic clinopyroxene + serpentine + magnetite? intergrowths in the upper unit of the Dun Ard an t-Sabhail composite hawaiite flow.

PLATE 64

Photomicrograph of the aphyric (trace amounts of plagioclase + titaniferous magnetite microphenocrysts) lower unit of the Dun Ard an t'Sabhail composite hawaiite, showing general texture.





and titaniferous magnetite. Chlorite is abundant and locally, rare brown amphibole and biotite are developed.

3. The Lower Unit

Below the junction between the two units, a marked decrease in the volume percent phenocrysts, takes place. Only scattered rounded and resorbed feldspar phenocrysts (1-2%), and rare olivine and magnetite microphenocrysts are present in a progressively finer-grained groundmass equivalent to, but finer-grained than, the base of the upper unit (Plate 64). The resultant rock is a fine-grained hawaiite with olivine and magnetite as minor microphenocrysts and some plagioclase phenocrysts varying from 1-3.5 millimetres long. Locally, the groundmass has concentrations of minute opaque granules and interstitial calcite.

7.1iii) Mugearites

Mugearites, (Differentiation Index 45-65, Normative Feldspar An_{15}-An_{30}) named after the type locality of Drium na Criche near Mugeary, 5-6 kilometres south-west of Portree, are locally abundant within the Skye lava outcrop. They are commonly associated with the hawaiites and are especially characteristic of the Arnaval Group forming the higher levels of the stratigraphic succession.

In the field, they form characteristic bold escarpments often with a covering of grey lichen on a rusty-brown to yellowish weathering surface, possess a distinctive close-set, sub-horizontal platey jointing or fissility and are dark, dense, finely-crystalline rocks mostly without obvious phenocrysts. In handspecimen, the horizontal jointing is seen to be concordant with the strong trachytic texture developed by the groundmass plagioclase laths while a secondary, wider spaced jointing, mentioned previously in Chapter 5.liii), and also found in some hawaiites, often corresponds directly to a second alignment direction at high angles to the primary flow structures. This may represent sealed joints formed during the solidification of the lava.

The following petrographic types are distinguished, and as with the lavas of preceeding sections, all are necessarily intergradational and not usually completely separable on geochemical criteria:

A. Olivine + Plagioclase + Magnetite Microporphyritic Mugearites.

B. Coarse-grained Mugearites.

C. Olivine + Magnetite Microporphyritic Mugearites.

D. Aphyric Mugearites.

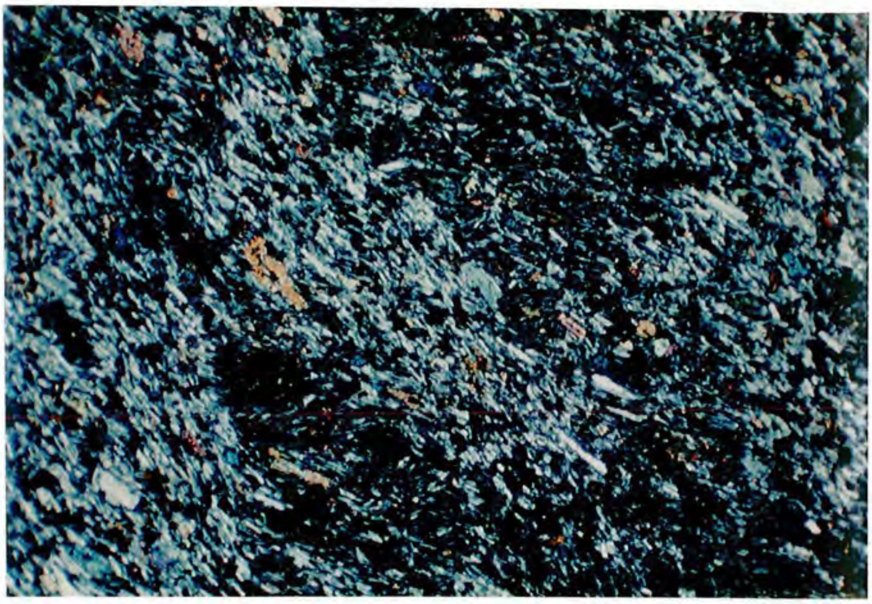
E. Plagioclase Macroporphyritic Mugearites.

The full chemical range of Mugearites (Differentiation Index 45-65) was not sampled, the most evolved lava being Sk751801 from Carbost Burn (373310) with a Differentiation Index of 59. The majority of mugearites sampled come from the Gleann Oraid region and have chemistries and mineralogies gradational with the hawaiites with which they are closely associated in the field.

7.1iii)A Olivine + Plagioclase + Magnetite Microporphyritic Mugearites

Mugearites carrying the same microphenocryst phases as the commoner hawaiites, but possessing a considerably less mafic, more alkali-rich groundmass are most commonly encountered (Sk7624)(Plate 65). The moderately iron-rich olivines (e.g. Fo_{55}-Fo_{42}) form small, often skeletal, pale yellow to colourless subhedra with rhombic or tabular outlines with the long axis, the X crystallographic axis (Muir and Tilley 1961a), usually oriented parallel to the primary flow structures of the rock. In size they vary from 0.25 to over 1 millimetre, have apparently near homogeneous cores but often strongly zoned margins and constitute between 1-4 percent of the rock. A cleavage parallel to the length is also noted.

Plagioclase feldspar forms a modally variable phenocryst and may be present from only scattered subhedral laths up to 1.5 millimetres long (e.g. Sk740510) or locally more abundant as in specimens Sk740401, Sk740513 and Sk7602 which are very fine-grained possibly chilled rocks. In these, the olivines and plagioclases are often skeletal and enclose numerous euhedral opaque inclusions. The feldspar microphenocrysts are slender, simply twinned, zoned



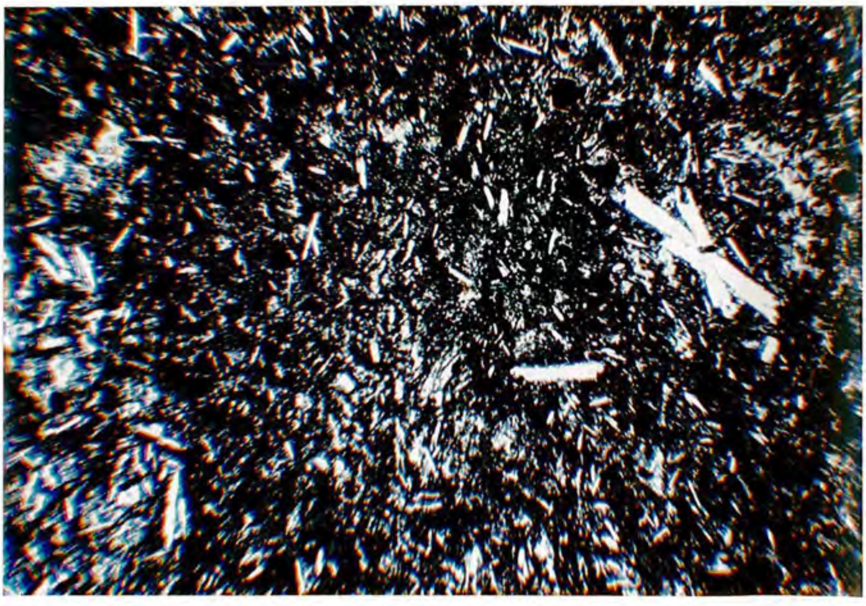


PLATE 65

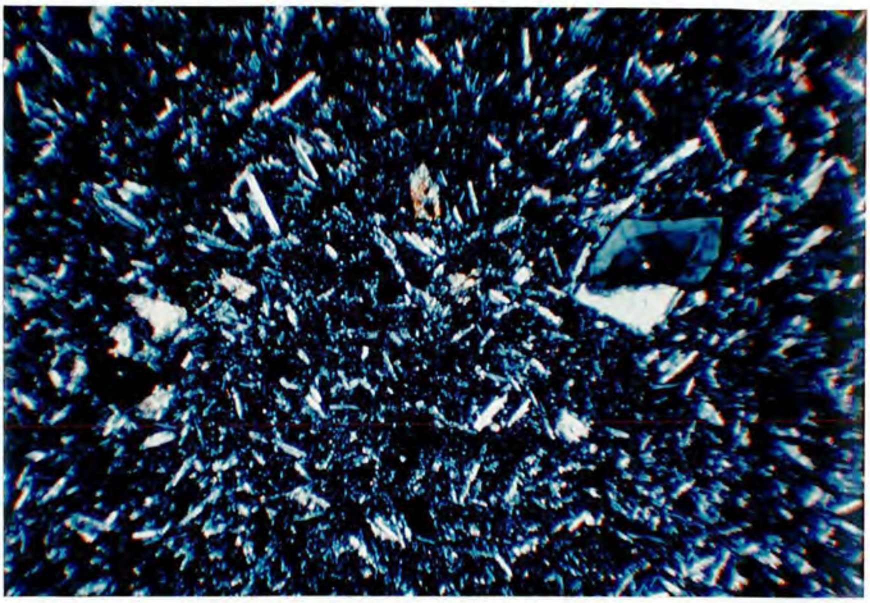
Photomicrograph of an olivine + titaniferous magnetite + plagioclase microporphyritic mugearite Sk7624 from the summit of the Stockval Ridge high in the Arnaval Group. This rock type differs little in general appearance from equivalent hawaiites.

PLATE 66

Photomicrograph of a fine-grained almost glassy mugearite Sk7602 from near the summit of Arnaval, high in the Arnaval Group showing stellate plagioclase microphenocryst aggregates and titaniferous magnetite octahedra. The groundmass owes its melanocratic nature to myriads of minute titaniferous magnetite octahedra. This phase can be concentrated in layers by flow banding producing a distinctly banded rock. Irregular 'dusty' patches are also common near the base of many mugearite flows and may represent quenched autoliths within the main flow.

($An_{45}Ab_{53.5}Or_{1.5}$ to around $An_{36.5}Ab_{61}Or_{2.5}$ in Sk740701), subhedral needle-like laths up to 1 millimetre long and often forming stellate aggregates (e.g. Sk7602) (Plate 66). Occasionally they may show euhedral outlines and exhibit well-developed oscillatory zoning (e.g. Sk740401)(Plate 67).

Homogeneous titaniferous magnetite, with only very rare ilmenite exsolution lamellae, forms as two distinct types of microphenocryst phase, both often occurring within a single specimen. In the first instance, the mineral is euhedral octahedral in habit and 0.2-0.5 millimetres in diameter (e.g. Sk740513, Sk740701) while the second type, although retaining a subhedral outline appears to be embayed and partially skeletal acting in a subophitic manner to the groundmass (e.g. Sk740401, Sk740510 and Sk7602). This latter condition perhaps indicates a continuation of growth subsequent to the beginning of groundmass crystallisation, as clinopyroxene where rarely present as subophitic oriented plates encloses the magnetite microphenocrysts (e.g. Sk740302). In specimen Sk740401 the olivine and magnetite are occasionally partially glomeroporphyritic with the olivines frequently enclosing the opaque phase indicating an earlier period of magnetite formation. Consequently, as noted in some of the hawaiitic lavas, three distinct generations of magnetite may exist, - euhedral microphenocrysts of early crystallisation, skeletal microphenocrysts with a long crystallisation



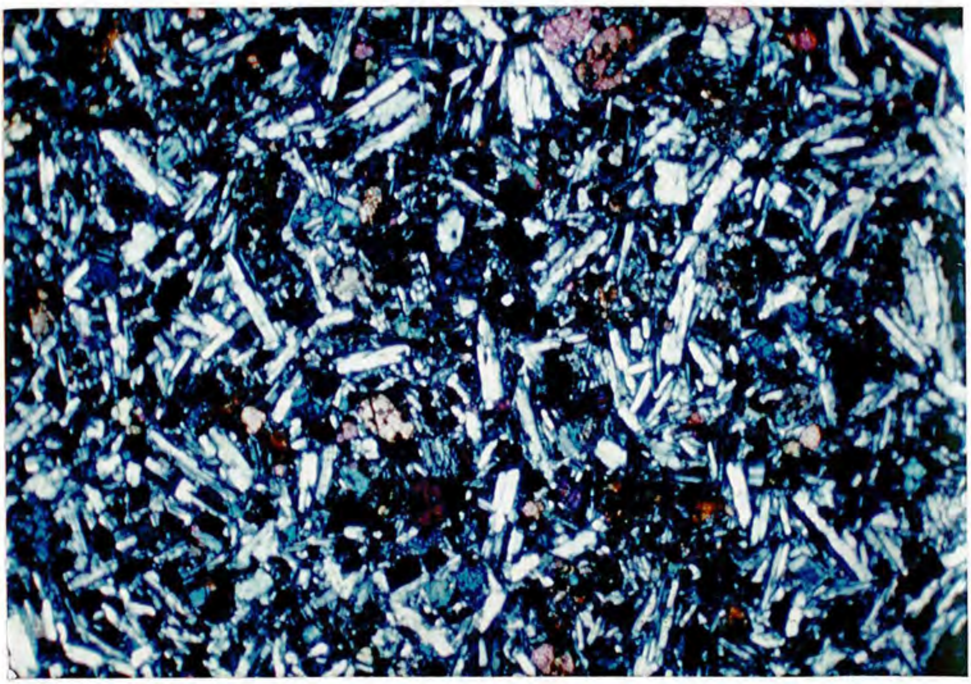


PLATE 67

Photomicrograph of the fine-grained mugearite Sk740401 with minute olivine + plagioclase + titaniferous magnetite microphenocrysts. The plagioclase is oscillatory zoned and there is no flow orientation of these or the groundmass constituents despite its extreme development in the same flow 0.5 kilometres south at Macfarlane's Rocks.

PLATE 68

Photomicrograph of a coarse-grained mugearite Sk740810 from Stockval. There is little parallelism of constituent minerals in flows such as this.

period and the groundmass. Large, anhedral corroded microphenocrysts are rare but may be present (e.g. Sk760301). This example from Cnoc na Moine (374284) is a titaniferous magnetite with rare ilmenite lamellae and is flanked by chlorite and granular clinopyroxene and visibly deflects the flow structures of the groundmass.

The major constituent of the mugearitic groundmass is a strongly fluxioned and relatively alkali-rich, zoned ($An_{33}Ab_{64}Or_3$ through $An_{18}Ab_{75}Or_6$ to $An_7Ab_{83}Or_{10}$ which also represents the interstitial phase) sodic andesine or oligoclase with anorthoclase overgrowths. These laths have a parallel-near-parallel extinction, carlsbad and also some faint fine-scale polysynthetic twinned cores but untwinned rims, and vary from slender microlitic needles in the extremely fine-grained lavas to ragged, short laths 0.2 millimetres long. In the finer-grained examples, especially the specimens previously quoted, they are charged with dust-like opaque oxide and consequently the rock is distinctly dense and melanocratic. In many cases the trachytic texture is developed in an irregular fashion and there is a partial breakdown of this texture due mainly to the equidimensional tendency of the plagioclase. Groundmass magnetite is present in varying amounts and is most obvious in the finer-grained examples, where it forms minute euhedral octahedra, local concentrations of which may impart a diffuse banding to the rock parallel as in Sk7602 to a slight grainsize layering. The clinopyroxene phase in these rocks is very subordinate to the other mafic phases and is almost always found as small, rounded, weakly pleochroic brown to yellowish-brown granules. In general, a decrease in the percentage of clinopyroxene and a change in its habit from poikilitic through ophitic and subophitic to intergranular, is noted for the transition basalt-hawaiite-mugearite. Commonly the interstices of these mugearites are of anhedral zoned alkali feldspar ($An_7Ab_{82}Or_{11}$) and analcime, accounting for the nepheline normative character of these rocks. Apatite needles, notably pleochroic light brown to reddish brown biotite and possibly amphibole are common accessories. Thompson et al. (1972) describe very rare microphenocryst apatite and amphibole as occurring in some of the northern Skye examples but these phases were not detected as phenocrysts in any of the examples dealt with here. Muir and Tilley (1961) report that both chalcopyrites and pyrites occur as small grains in these mugearites.

The common deuteric alteration products are encountered in these rocks but often the rock is surprisingly fresh and this may be, in part attributable to its more compact structure and more finely crystalline nature. Hydrothermal alteration and weathering are the main sources of alteration, especially along the horizontal joint planes and olivines are altered to bowlingsitic or dark chloritic pseudomorphs with rims of a yellow-green acicular chlorite. Pale amphibole may replace the clinopyroxene while sericitic mica coats both clinopyroxene and feldspars. Biotite may be associated with either the olivine pseudomorphs or primary magnetite.

7.liii)B Coarse-grained Mugearites

The commonest type of coarse-grained mugearite is one in which the essential mineralogy of the type A Mugearite is retained but due to coarser crystallisation, these phases may partially be obscured by the groundmass. Good examples of such rocks are found in Gleann Oraid on the lower slopes of Arnaval (e.g. Sk740204 and Sk740205). The strongly zoned plagioclase microphenocryst phase apparently grades in size into the trachytic plagioclase of the groundmass but can often be distinguished by its having more complex twinning laws and rarely, oscillatory zoning around subhedral cores. Interstitial areas of alkali feldspar are usually better developed than in their finer-grained counterparts and the accessory minerals are more evident. The clinopyroxene is generally found as elongated prismatic granules (Sk740204) but may occur as greyish purple to brown pleochroic subophitic plates or as discrete plates with subophitic or intersertal margins (Sk740205).

Near the summit of Stockval (Sk740810)(351296) another type of coarse-grained mugearite crops out. This rock is a true feldspathic dolerite texturally characterised by abundant normally and often oscillatory zoned aligned tabulate plagioclase feldspars ($An_{56}Ab_{43}Or_1$ to $An_8Ab_{82}Or_{10}$) and a subophitic to pseudomicroporphyritic grey-neutral-pink weakly pleochroic clinopyroxene which may reach 0.75 millimetres in length (Plate 68). The above feldspars are microphenocrysts up to 1.5 millimetres long and constitute between 15 and 20 percent of the rock. They are surrounded trachytically by slender oligoclase-andesine laths ($An_{32}Ab_{65}Or_3$) with more alkalic margins. Olivine appears as 0.5-1.0 millimetre subhedra (Fo_{58-59}) showing little zoning and also a smaller granules associated with a granular clino-pyroxene(?) in the groundmass. Euhedral titaniferous magnetite is also present as a concealed microphenocryst phase and may have some ilmenite exsolution lamellae. In common with type A mugearites, this example also contains large rounded, reacted phenocrysts of titaniferous magnetite. They are not compositionally homogeneous but show evidence for reaction with the groundmass and are surrounded by chloritic rims.

7.1iii)C <u>Olivine + Magnetite Microporphyritic Mugearites</u>

Mugearitic rocks containing only olivine and a titaniferous magnetite as microphenocryst phases tend to be more evolved than those with plagioclase included in the assemblage. If present at all, plagioclase microphenocrysts are small and only trace amounts which may escape detection in thin section. In handspecimen they are indistinguishable from other mugearites and are commonly banded with two obvious directions of fluxion textures.

A typical example (Sk750204, Sk751801) carries small, less than 0.5 millimetre microphenocrysts of olivine and magnetite with the later usually euhedral and the former showing indications of some resorption. The olivine is relatively iron rich ($Fo_{35.8}$) and may be weakly pleochroic from a transparent yellow to colourless-neutral. The groundmass is constituted by flow aligned potassic oligoclase laths ($An_{26}Ab_{70}Or_4$) showing some degree of textural disruption ie. there is a partial breakdown in the flow structures; the feldspars prescribing various lines of flow and small fold structures. The interstitial feldspar is an alkali feldspar similar to that common in the previously mentioned mugearites, and is accompanied by myriads of small apatite needles. The clinopyroxene is relatively rare but may comprise small subophitic but more commonly intergranular masses with a slight grey-brown to greenish pleochroism. Groundmass euhedral titanomagnetite and accessories are as for the other types of mugearite.

7.1iii)D <u>Aphyric Mugearites</u>

The least common mugearite type is one in which obvious microphenocrysts are lacking or extremely rare. Again, in handspecimen the type is indistinguishable from types A and C. Only some 2-3 examples are recorded and all come from Gleann Oraid relatively high within the Arnaval Group. In thin section, the rock is more or less identical to the groundmass of the commoner types but in specimen Sk750917 below Preshal More, the distinctive trachytic texture is lacking and only trace amounts of resorbed microphenocrysts are present accompanied by considerable interstitial alkali feldspar, apatite and fine-grained reddish-brown biotite flakes. The clino-pyroxene is intergranular and colourless and there is considerable euhedral magnetite.

7.1iii)E <u>Plagioclase Macroporphyritic Mugearites</u>

Within the lava succession of west-central Skye and especially the upper parts of the Arnaval Group exposed on Biod Mor (c.370273), above Glen Eynort, mugearitic lavas containing sporadic plagioclase macrophenocrysts are locally important. Here, and elsewhere in Skye, Harker (1904 , pp.250-251) noted these porphyritic rocks but consistent with his interpretation of them as sills, grouped them with his 'Great Group' rather than with the lavas. Their extrusive nature here is confirmed as in every case a pinkish-grey weathered top, with or without the presence of bole, was located in the thin, rather irregular upper amygdaloids.

In thin section the Biod Mor examples (Sk750607, Sk750608 and Sk750609) and others from below Preshal More (Sk750923) and on the Stockval Ridge (Sk750407), have a groundmass essentially similar to the fine-grained near aphyric types with granular olivine, subophitic clino-pyroxene, euhedral magnetite and trachytic plagioclase. Small microphenocrysts of plagioclase are also present in the majority of examples studied. The large phenocrysts (up to 1.5 centimetres across) are invariably rounded and resorbed with zoned, inclusion filled margins, and compositionally are probably andesines (Optical Determination), although labradorite may also be present. They constitute only a trace phenocryst phase and may escape incorporation in the making of the thin sections.

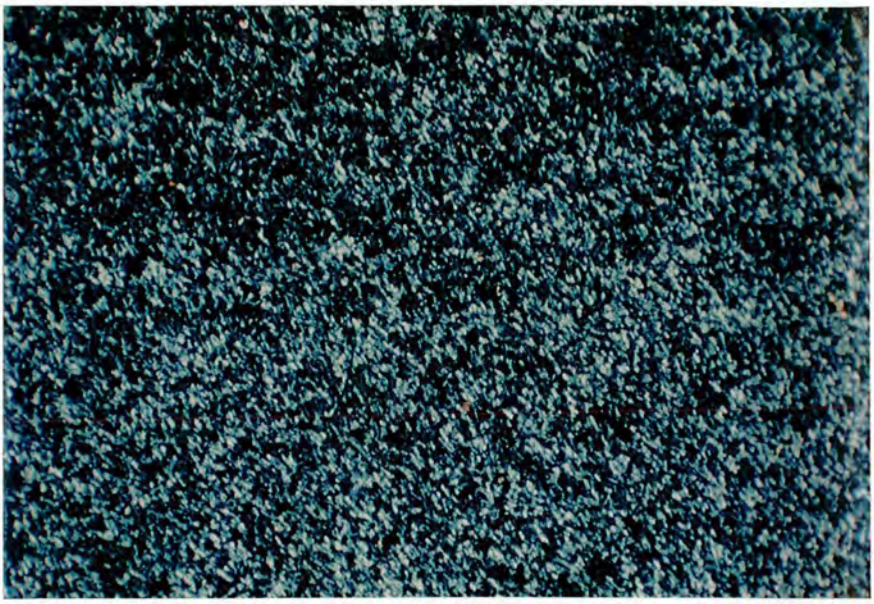
7.liv) <u>Benmoreites</u>

At Cnoc Glas Heilla (c.349344) near Portnalong, a substantially thick flow of fine-grained, melanocractic, very nearly aphyric mugearite-benmoreite (Differentiation Index around 65) crops out. This is the only example of this rock type discovered in the area and seems to be associated with the basal hawaiites and mugearites of the Arnaval Group. In handspecimen it is identical to these rocks.

Petrographically the rock varies according to the sampling position within the flow. Specimen Sk77010 was collected from the columnar zone and Sk77011 from near the upper surface. In thin section, yellowish anhedral olivines (Fo_{32}) and granular subhedral 0.1-0.2 millimetre diameter titaniferous magnetite associated with small euhedral 0.05 millimetres long apatite needles, are set in a moderately finer-grained groundmass composed largely of subtrachytic to disoriented plagioclase laths ($An_{38}Ab_{56}Or_{6}$), interstitial alkali feldspar, analcime and chlorite with relatively common, largish 0.25-0.3 millimetre diameter, reddish-brown to colourless pleochroic, poikilitic biotite plates (Sk77010) (Plate 69). Trace amounts of brown interstitial amphibole and a greenish pyroxene(?) may also be present. In detail there is some degree of grainsize layering or matrix banding present, parallel to the flow jointing.

7.1v) <u>Trachytes</u>

Lavas more differentiated than the mugearite-benmoreite of Portnalong are rare in west-central Skye in marked contrast to the area immediately to the north and north-east across Lochs Harport and Bracadale where an alternating series of mugearites, benmoreites, trachytes, big-feldspar mugearites and subordinate basalts forms a relatively narrow north-west to south-east trending outcrop. These lavas form the Bracadale Group of the Northern Skye



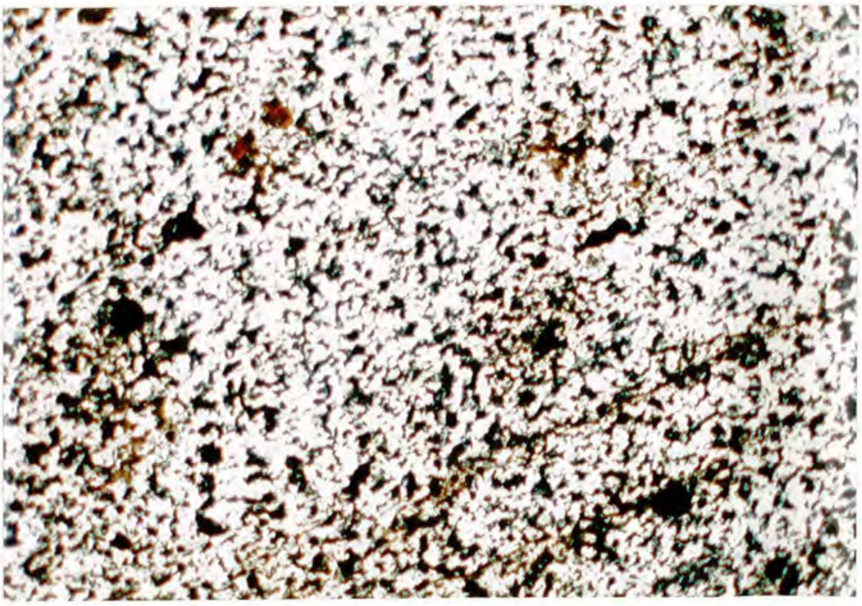


PLATE 69-A and 69-B

Photomicrographs of the essentially aphyric benmoreite of Portnalong Sk77011 showing in 69-A small olivines and magnetites in association with minute plagioclase laths and in 69-B the presence of interstitial biotite in a felt-like feldspathic groundmass. Considerable apatite is also present but is not easily made-out due to the fine-grain size of this rock.

Memoir (1966) and occupy a position roughly central to the lava field (Fig.15) and are locally succeeded upwards by the Osdale Group although they were probably in-part contemporaneous with it. In the area under study, only two occurrences of such evolved rocks are recorded. Both strongly contrasted in their chemistry and petrography, they appear to be the only supporting evidence for the two distinct lineages within the Skye lavas reported by Thompson et al. (1972), and this is dealt with more fully in the succeeding chapters. Both occurrences are considered separately.

Occurrence 1. Sleadale: Iron-Poor Transitional Trachyte or Trachy-Andesite (NG 326285, Specimens Sk750804 to 0806, Sk7625 and Sk7705).

The trachyte of Sleadale crops out as a substantial terraced feature directly below the northern agglomerates of Preshal Beg and in the north-flowing tributary of Sleadale Burn immediately to the north. It is distinctly leucocratic with a greyish yellow tint and flow jointed with large ovoid flattened vesicles below Preshal Beg (e.g. Sk750804 to 0806) but to the north is more melanocratic, much finer-grained and lacking in substantial vesicles (e.g. Sk7625 and Sk7705). This latter exposure, if connected to the main flow appears to be a small irregular tongue of the trachyte which possibly flowed to the north. It is here faulted against basalts and hawaiites to the east. Both in handspecimen and thin-section, the lava is notably porphyritic although only sporadically so with the larger tabular feldspars, up to 1 centimetre by 3 millimetres in size, lying sub-parallel to the flow jointing. The average Differentiation Index is 76.

In thin section, the rock is seen to carry the phenocryst assemblage (Plate 70):

Plagioclase + Alkali Feldspar + Magnetite +
Clinopyroxene + Apatite

The dominant phenocryst phase is a subhedral plagioclase feldspar (cores around $An_{32}Ab_{64}Or_{4}$) averaging 0.5-0.75 millimetres in length with fine-scale polysynthetic, pericline or carlsbad twinning and a distinct normal and rarer oscillatory zoning (e.g. Sk7625). This is accompanied by scarce, mostly anhedral alkali feldspar with faint but characteristic crosshatch anorthoclase-type twinning. In total, feldspar forms around 3 percent phenocrysts.

Titaniferous magnetite is a notable microphenocryst phase forming beautifully euhedral crystals 0.2-0.5 millimetres across and occasionally sporting some ilmenite exsolution lamellae. Microprobe analyses of this phase also detected discrete grains of ilmenite and the elongate-

PLATE 70

Photomicrograph of the Sleadale sub-alkalic trachyte Sk7705 showing the typical phenocryst assemblage of titaniferous magnetite + alkali feldspar + plagioclase + apatite ± clinopyroxene and a small xenolithic mass. The groundmass is very fine-grained and consists of plagioclase (oligoclase) laths with some development of secondary quartz.

bladed opaques, found sparingly in specimen Sk7625 may be this mineral.

Accompanying the feldspars and opaque oxide in glomeroporphyritic aggregates is an euhedral to occasionally subhedral-rounded, colourless to yellowish-green pleochroic clinopyroxene ($Wo_{39}En_{46}Fs_{15}$) up to 1 millimetre diameter but everaging less than 0.5 millimetres. Almost invariably this phase shows simple twinning on 001 and may have a thin outer rim of minute magnetite grains (Plate 71). Strongly pleochroic blue-grey to pink euhedra of apatite are fairly commonly associated with these aggregates and may reach 0.25 millimetres in length. Lines of minute inclusions, parallel to the main cleavage traces, are common (e.g. Sk7625) and the crystals may also develop a more densely coloured outer rim (Plate 72). Rare anhedral magnetite and quartz are also identified in these aggregates and the total phenocryst content probably varies between 4 and 7 percent.

The groundmass is always very fine-grained being composed almost entirely of small, subtrachytic, irregular felt-like masses of alkali feldspar which is zoned from potassic oligoclase ($An_{20}Ab_{70}Or_{10}$) in rare cases, to anorthoclase ($An_{6}Ab_{67}Or_{27}$ to $An_{9}Ab_{53}Or_{38}$). In all cases studied the alkali feldspar is very much dominant over plagioclase. Small granules of a colourless or perhaps pale-greenish clinopyroxene are scattered throughout the

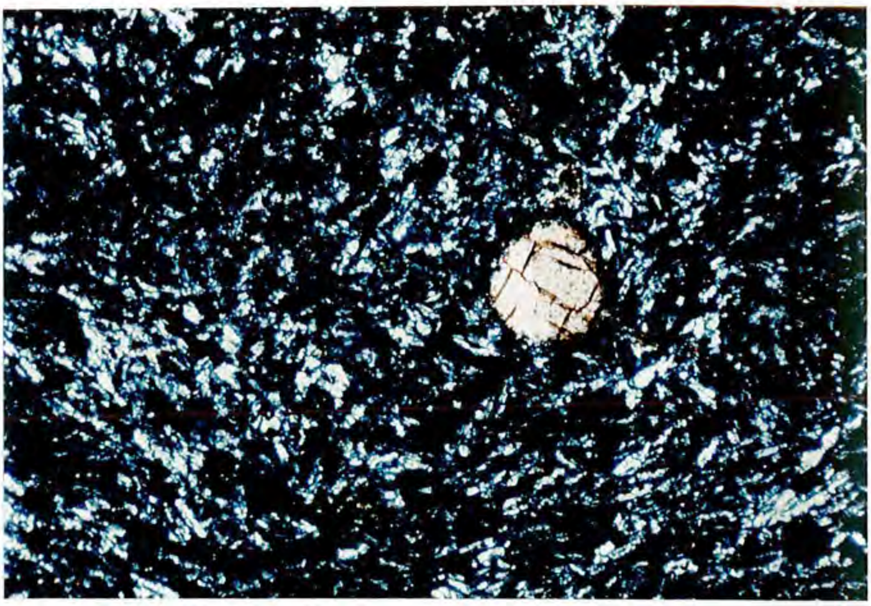


PLATE 71

Photomicrograph of the feldspathic groundmass of the Sleadale trachyte Sk750805 showing a small round, twinned clinopyroxene microphenocryst. These are especially common in the flow close to Preshal Beg in association with glomeroporphyritic aggregates of plagioclase + titaniferous magnetite.

PLATE 72

Photomicrograph of the feldspathic groundmass of the Sleadale trachyte Sk7625 showing well developed diachroic apatites with magnetite inclusions and rims. Also present is a small rounded crystal of quartz which is probably secondary.

rock but only constitute a very minor phase. A diffuse banding, due to grainsize differences within the groundmass (matrix banding?) and local concentrations of dusty opaque oxide, is frequently developed in the finer-grained 'chilled' examples and detached masses of dark, glassy autolithic material are also encountered (e.g. Sk7705) with the partially breaking-down flow-banding visibly being displaced around them.

Sericitic mica is a common replacement of the feldspar phenocryst while the ferromagnesian phases are replaced, often irregularly by an iddingsitic-like material especially around the margins. Pseudomorphs after pyroxene(?) are relatively common in Sk7705.

Occurrence 2. Cnoc Scarall: Alkali Trachyte

(NG. c.390284, Specimens Sk7603, Sk7604 and Sk7605).

The most differentiated rock recorded from west-central Skye is an alkali trachyte and crops out immediately to the east of Glen Eynort on the twin hills of Cnoc Carall. Structurally it appears to have occupied a small amphitheatre being surrounded by escarpments of mugearites and basalts which rise well above the base of the flow itself (Fig.19). In the field it has the characteristics of a mugearite but in handspecimen is notably coarser-grained and may weather in a style more

FIGURE 19

Cross-sections across the Cnoc Scarall region of west-central Skye showing the position of the Cnoc Scarall trachyte in relation to the lavas of the Arnaval/Tusdale Groups.

B	Basalt
H	Hawaiite
M	Mugearite
Tr	Trachyte

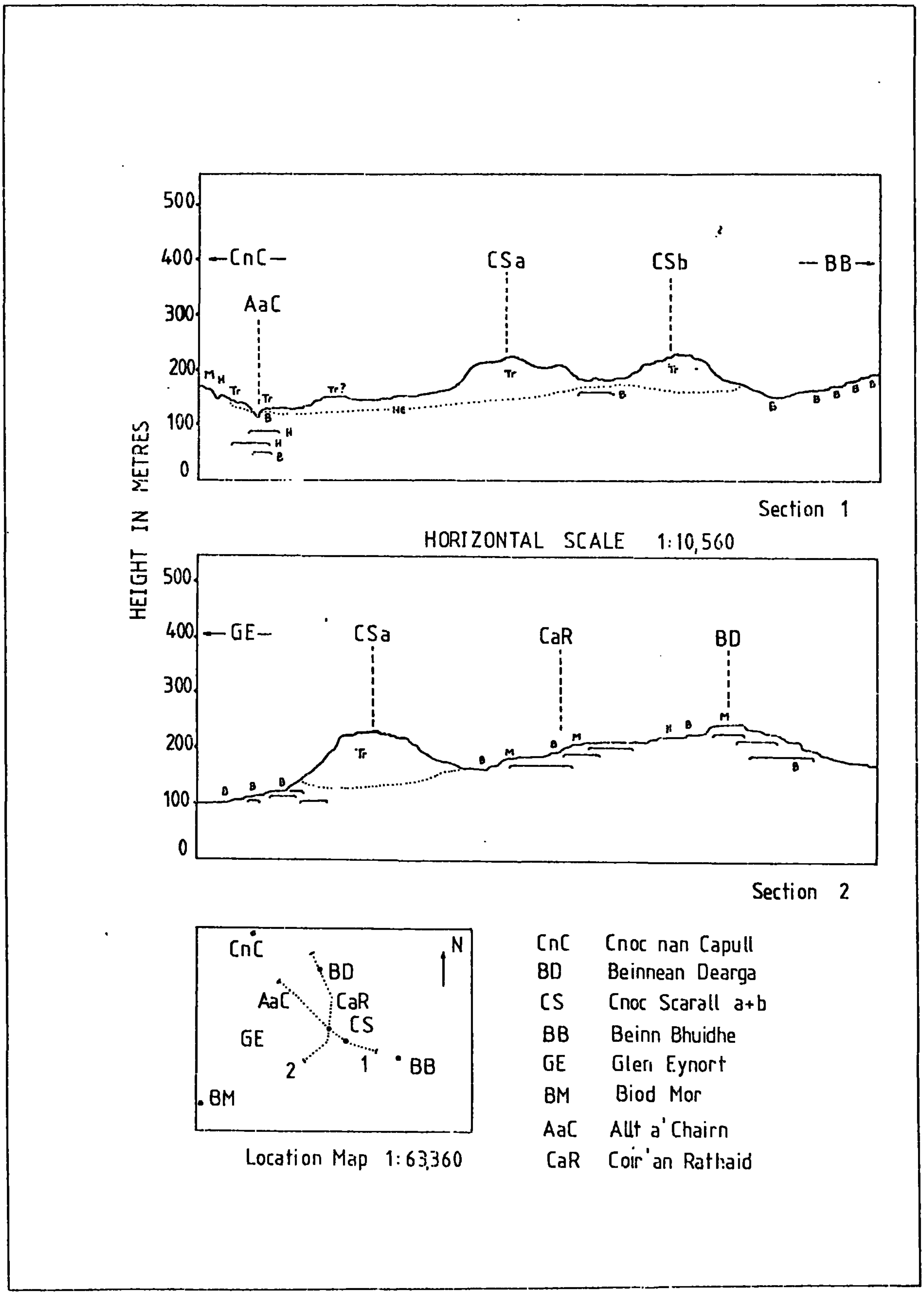

HEIGHT IN METRES
500
400
300
200
100
0
—CnC—
AaC
CSa
CSb
—BB—
Tr
Tr?
Section 1
HORIZONTAL SCALE 1:10,560
—GE—
CSa
CaR
BD
Section 2
CnC
BD
AaC
CaR
CS
GE
2
1
BB
BM
N
Location Map 1:63,360
CnC Cnoc nan Capull
BD Beinnean Dearga
CS Cnoc Scarall a+b
BB Beinn Bhuidhe
GE Glen Eynort
BM Biod Mor
AaC Allt a'Chairn
CaR Coir'an Rathaid

Figure 19

characteristic of the basaltic lavas. Its strongly flow aligned feldspar microporphyritic nature is quite evident and scattered 'opaque' microphenocrysts are visible in fine-grained specimens.

In thin section, the rock is strikingly feldspathic, containing the phenocryst assemblage:

Alkali Feldspar + Magnetite + Olivine +
Apatite + Amphibole

An alkalic plagioclase or sodic alkali feldspar forms microphenocrysts which constitute the bulk of the rock (Plate 73). They are equant, tabular 0.5-1.5 millimetre laths, strongly zoned ($An_{20}Ab_{70}Or_{10}$ through $An_{17}Ab_{67}Or_{16}$ to $An_9Ab_{59}Or_{32}$) with fine-scale albite twinning and combined albite-carlsbad twinning. Faint crosshatch twinning may also be distinguished. They also possess a marked trachytic texture and contain abundant mafic inclusions. Larger anorthoclase phenocrysts, with an identical composition ($An_{19}Ab_{70}Or_{11}$) form euhedral tabular crystals up to 2.5 millimetres across and displaying well-developed cross-hatch twinning, a fine-scale polysynthetic twinning and some oscillatory zoning are frequently encountered (e.g. Sk7604)(Plate 74). A normally zoned margin of composition $An_2Ab_{64}Or_{34}$ and some incipient albitisation may be prominent.

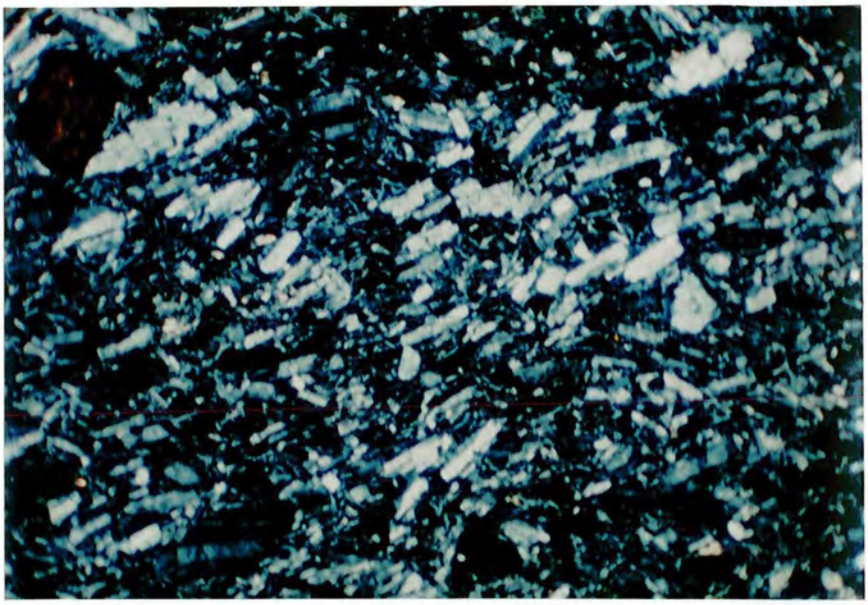
The mafic phenocrysts are not abundant in the rock

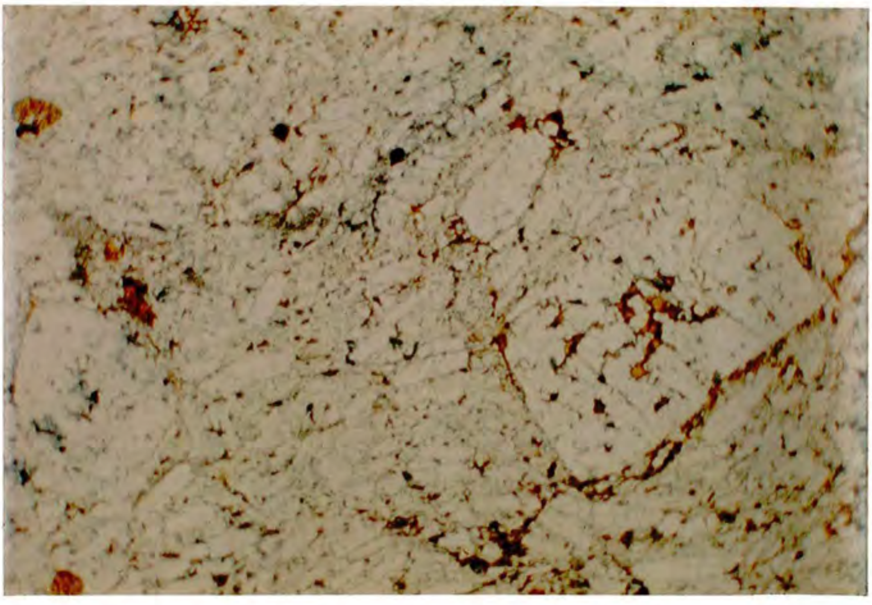
PLATE 73

Photomicrograph of the Alkali Trachyte of Cnoc Scarall Sk7604 showing the general texture and mafic (amphibole) phenocrysts rimmed by and full of inclusions of titaniferous magnetite. Virtually the whole rock is made of felsic constituents.

PLATE 74

Photomicrograph of large anorthoclase phenocrysts in the alkali trachyte of Cnoc Scarall Sk7605 visibly deflecting flow aligned groundmass oligoclase-albite laths. The photograph also shows small octahedra of titaniferous magnetite and amphibole ? pseudomorphs. A greenish-blue pyroxene, apatite and yellowish olivines are also present in small amounts.





and are subordinate to the feldspar which constitutes between 40 and 50 percent. A distinctly yellow-coloured fayalitic olivine (Fo_{22-23}) is the common phase, forming subhedral crystals up to 0.25 millimetres in diameter which are readily replaced by bright red iddingsite or a greenish-brown mineraloid. Also present in trace amounts are relicts of an amphibole-phenocryst phase. The crystals which are euhedral and 0.2-.5 millimetres across are now partially, and in some instances completely replaced by a multitude of minute magnetite octahedra nucleating along cleavage traces (Plate 73). Microprobe analysis of this distinctly pleochroic, from colourless to reddish brown, phase indicates an amphibole of the basaltic hornblende or lamprobolite type but with considerable contamination from the opaques and also some included feldspar(?). The opaque phase occurs as distinct 0.2-0.5 millimetre subhedral titaniferous magnetite microphenocrysts often with rounded, resorbed margins.

Due to the relatively high percentage of feldspar microphenocrysts the groundmass is necessarily less distinct than in the other lavas but reveals a mass of 0.1 millimetre, trachytic textured alkali feldspar laths ($An_2Ab_{67}Or_{31}$). A more calcic core is present but alkali feldspar is dominant with accompanying euhedral titaniferous magnetite and rare subophitic, partially bladed, yellow-green to brownish-orange pleochroic ferroaugitic clinopyroxenes. Within the groundmass, but constituting a microphenocryst phase are beautiful blue-grey apatite euhedra occasionally forming aggregates up to 2 millimetres long and with lines of small rounded opaque inclusions.

Apart from the serpentinous-bowlingsitic alteration of the olivines, the main alteration products appear to be deep brown to red biotite flakes associated with the magnetite and perhaps representing a late magmatic stage. A pale amphibole may also be present and considerable greyish-pink sericitic mica has developed on the feldspars.

7.2 Petrography of the Intrusive Igneous Rocks

The intrusive igneous rocks associated with the volcanics, encompass a wide range of both compositional and petrographic types ranging from the major gabbroic and ultrabasic intrusions along the margins of the Central Complex to the minor acid sills and dykes. They are divided as follows:

i) Dykes

ii) Inclined Basic Sheets

iii) Larger Basic-Intermediate Sills

iv) The Glen Brittle Felsite sheet and late-Granophyre Veins

v) The Marginal Gabbros and Ultrabasics (including minor plugs and intrusion breccias)

7.21) Dykes

The dykes encountered during the course of this study include a fairly wide range of compositions and the limited numbers sampled are considered to be representative of the region in general. The following types are recognised and within each, varying petrographic subtypes may be discernable:

A. Ultrabasic and Picritic Dykes

B. Alkali-Transitional Alkali and Low-Alkali Tholeiite Basaltic Dykes

C. Hawaiitic and Mugearitic Intermediate Dykes

D. Acid-Intermediate Dykes

Further details on the dykes are given by Harker (1904), Anderson and Dunham (1966) and Mattey et al. (1977), with broader considerations being dealt with by Speight (1972).

7.21)A Ultrabasic and Picritic Dykes

Three examples of ultrabasic dykes were sampled, all from the Rubh'an Dunain peninsula south-west of the Central Complex. They consist of the following:

	Specimen Number	Rock Type	Grid Reference
1.	Sk7708	Xenolithic Dunite-wehrlite	441170
	+Sk7709	+Allivalite Xenolith	"
2.	DY010	Feldspathic Peridotite	394169
3.	Sk7620	Picrite	438191

1. Dunite-wehrlite

The dunite-wehrlite forms a shallow, westwards dipping dyke or sheet-like body intruding pre-Tertiary strata and the early lavas of the Meacnaish Group, immediately to the east of An Leac. It is a coarse-textured, orange-weathering xenolithic (allivalite, gabbro, basalt and quartzite) 2-3 metres wide, radial intrusion with respect to the Cuillin gabbros (Plate 10, fig.4).

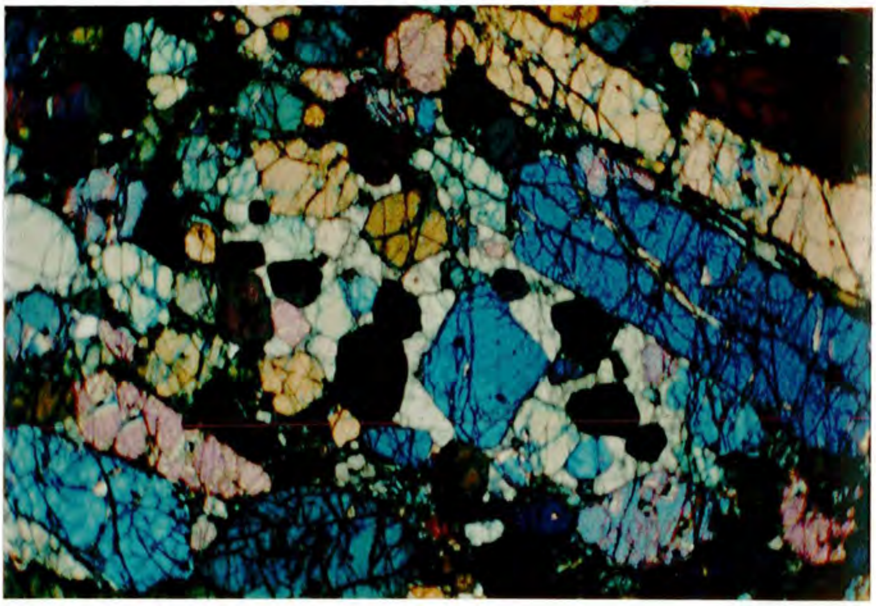
In thin section, the rock is dominantly (> 85%) composed of what, had the form and size of the intrusion been different, might have been termed 'cumulus', densely-packed, 0.2 to 6 millimetres long, often aligned, elongated and frequently strained or showing dislocation lamellae, forsteritic olivines (Plate 75). It was probably intruded, largely as a 'crystal-mush', the olivines being derived via the accumulation of crystals within some magma chamber, as it is difficult to envisage the formation and intrusion of such a compact, olivine-rich rock as a liquid crystallising in situ as a dyke. However, abnormally olivine-rich picrites and associated rocks forming sills and dykes elsewhere in Skye (Sligachan, Coire Lagan) and Soay were considered by Drever and Johnston (1958) not to have derived by the gravitative settling of olivine but rather, perhaps by direct precipitation from picritic or

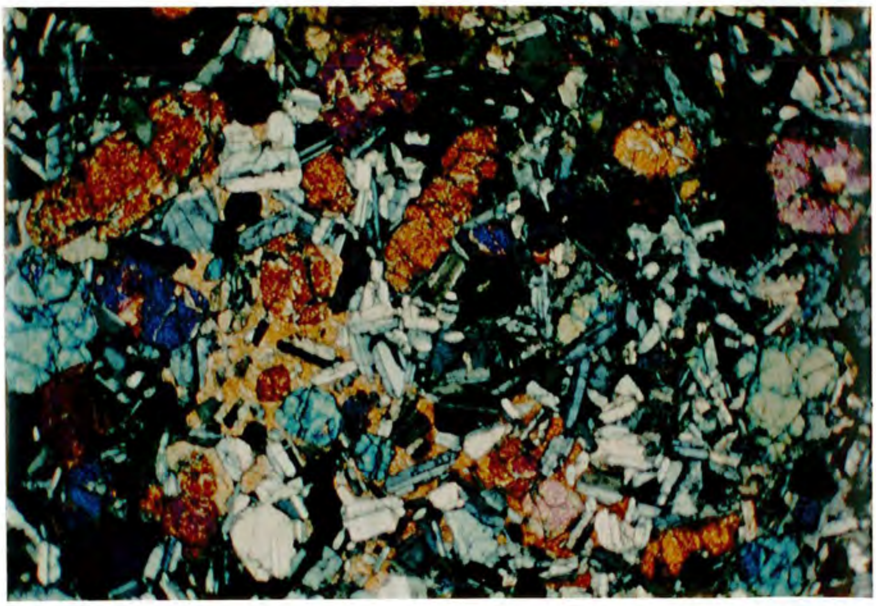
PLATE 75

Photomicrograph of dunite-wehrlite-peridotite dyke Sk7708 from An Leac showing a marked parallelism of the larger olivines and an interstitial mass of clinopyroxene. Chrome-spinel is also common.

PLATE 76

Photomicrograph of one of the allivalitic-gabbro xenoliths Sk7709 within the ultrabasic dyke Sk7708 from An Leac.





even ultrabasic magmas 'sweated' from existing ultra-basics. Associated with the olivines are scattered euhedra of chrome-spinel and relatively rare 'intercumulus' clinopyroxene and very rare plagioclase. Serpentinous and blue-green chloritic veins and irregular patches are common. Related rock types are also found as more major intrusives within the Central Complex while minor intrusions are found scattered around the Complex.

The majority of xenoliths are tenuously banded in the field but in thin section appear to be more or less homogeneous, medium-grained allivalitic rocks with larger 'phenocrysts' or again 'cumulus' phases of olivine and plagioclase, and poikilitic or intercumulus clinopyroxene (Plate 76). Of the phenocryst phases, olivine is the largest, forming up to 2.5 millimetres in diameter, subhedra often enclosing euhedral plagioclase crystals or small (0.05 to 0.2 millimetres) inclusions which appear to consist of spinel, chlorite, biotite and possibly pyroxene. The plagioclase is a subhedral bytownite with zoned margins and dominates the rock. A modal analysis gave Plagioclase 60-70%, Olivine 25-35%, Clinopyroxene 2-4% and accessories between 2-3%.

Thermal metamorphism of the allivalite due to incorporation in the dunite, has resulted in thin reactions rims around the xenoliths which have rounded outlines and petrographically, the olivines appear ragged and, like the poikilitic clinopyroxene, show a tendency towards a recrystallisation to minute granules along the borders. Secondary alteration in the form of serpentine attackes the olivines while the feldspars are partially clouded around the edges with opaque-oxides and usually develop a dusting of sericitic mica.

2. Feldspathic Peridotite

The pertinent field relations of the Carn Mor feldspathic peridotite have been described previously in Chapter 4.

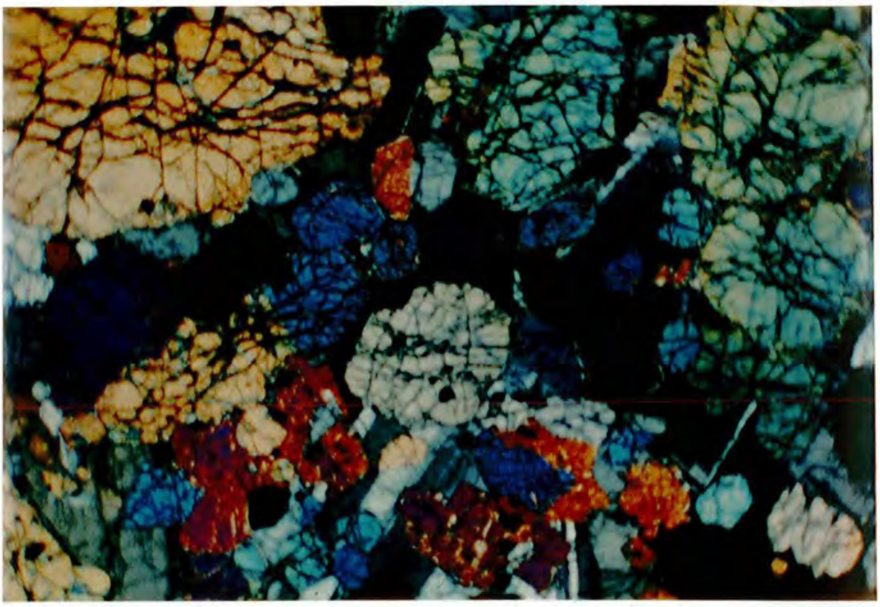
Petrographically, the rock contains abundant euhedral, 2-5 millimetre, magnesium-rich olivines associated with euhedral to subhedral, brown, translucent chrome-spinels usually occurring as primary inclusions within the olivines. There is substantial intercumulus or interstitial brown to neutral clinopyroxene and zoned plagioclase (Plate 77). Small rounded olivines occur as inclusions within some of the feldspars. The latest feldspar to crystallise is anhedral with a pronounced zoning and in some of the secondary cavities and interstices may be associated with fibrous zeolite, prehnite, mica and amphibole developing as secondary products. Serpentinous alteration is common and the olivines and pyroxenes may be jacketed by thin rims of a pale-green

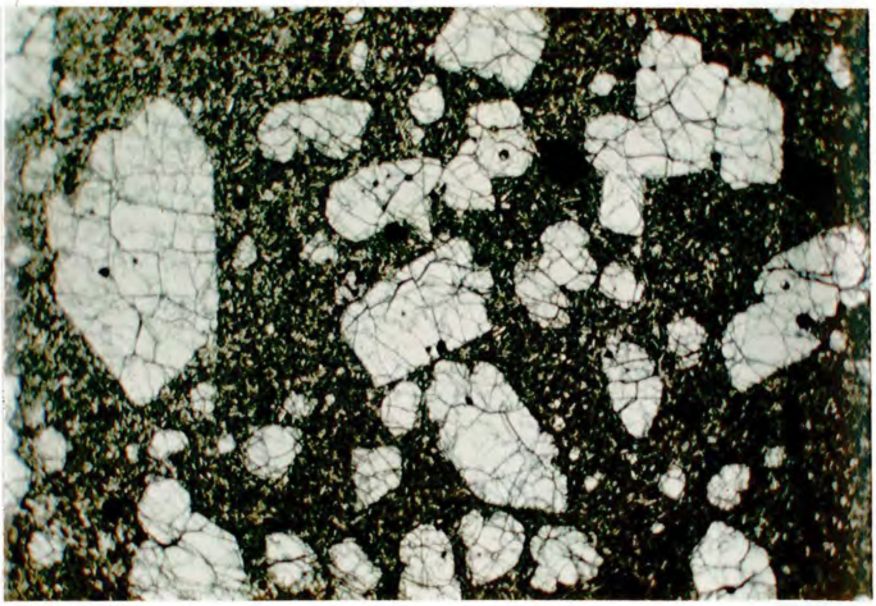
PLATE 77

Photomicrograph of the feldspathic peridotite dyke Dy010 of Carn Mor showing olivines enclosing numerous chrome-spinels and interstitial clinopyroxene and ophitic plagioclase.

PLATE 78

Photomicrograph of the olivine + chrome spinel porphyritic picrite dyke Sk7620 emplaced within metamorphosed lavas at An Sguman. The olivines are very fresh and the chrome-spinels are beautifully euhedral and unreacted with the groundmass of the rock.





to yellow chlorite or fibrous green amphibole. A modal analysis gave the following: Olivine 42%, Plagioclase 36%, Clinopyroxene 19% and Accessories including Spinel 3%.

3. Picrite

A small, 0.5 metres wide, radial dyke of picritic basalt intrudes the metalavas north of An Sguman within the inner zone of the thermal aureole around the Central Complex. In thin section, it is a notably porphyritic rock containing up to 3 millimetres in diameter, euhedral to subhedral, rarely embayed, frequently strained magnesian olivines and deep-reddish brown translucent chrome-spinels set in a relatively fine-grained, typically basaltic groundmass of small, colourless, subophitic clinopyroxene, scattered granular olivines, widely distributed magnetite octahedra and weakly flow-aligned (around the phenocrysts) plagioclase laths (Plate 78). The spinels range in size from 0.02 to 0.5 millimetres in diameter and occur as inclusions, within, along the margins of or outwith the olivine phenocrysts. They are characteristically mantled by opaque rims when not enclosed by the olivines; a feature also noted from the spinels of the Olivine + Spinel porphyritic lavas in the area and from some of the lavas and minor intrusions of the island of Rhum (C.H. Emeleus and R.M. Forster, Person.Commun). A number of similar dykes are reported as intrusive into the outer gabbros of Coire Lagan by Drever and Johnston (1958) and examples are also quoted by Harker (1904) and Bowen (1928).

7.2i)B Basaltic Dykes

The basaltic dykes described here fall into the categories 'alkali basalt' or 'olivine tholeiite', although in some instances, especially those of alkalic affinities are perhaps more correctly termed 'transitional basalts'. The tholeiites are chemically comparable to the olivine tholeiite of Talisker and probably represent the Preshal More and Fairy Bridge Type tholeiites of Mattey et al. (1977). They are also petrographically similar in some instances to the lava flow of Talisker and constitute the majority of dykes examined.

1. Alkali-Transitional Alkali Basalt Dykes

These dykes are comparatively rare, only a few of the sampled specimens conforming to compositions similar to the lavas they traverse. In part, this apparent lack of alkalic dykes is due to inadequacies in the sampling and, assuming that dykes may have fed the lavas, does not represent their true abundance or distribution. Petrographically they are coarse-grained dolerites with well-formed ophitic to poikilitic, deep purple to pinkish mauve, up to 2 millimetres in diameter, titaniferous augites and randomly oriented labradorite laths (e.g. DY009, DY013 and Sk7726). Partially or wholly pseudomorphed olivines, to 1 millimetre across, are common and the opaque phase is usually an euhedral, frequently skeletal titaniferous magnetite. The groundmass is coarse enough to hide the microphenocrysts and contains substantial anhedral, zoned interstitial plagioclase, with accessory zeolite and analcime. Primary analcime in rocks of teschenitic or crinanitic affinities is recorded from some dykes in northern Skye (Anderson and Dunham 1966) as well as the larger sills.

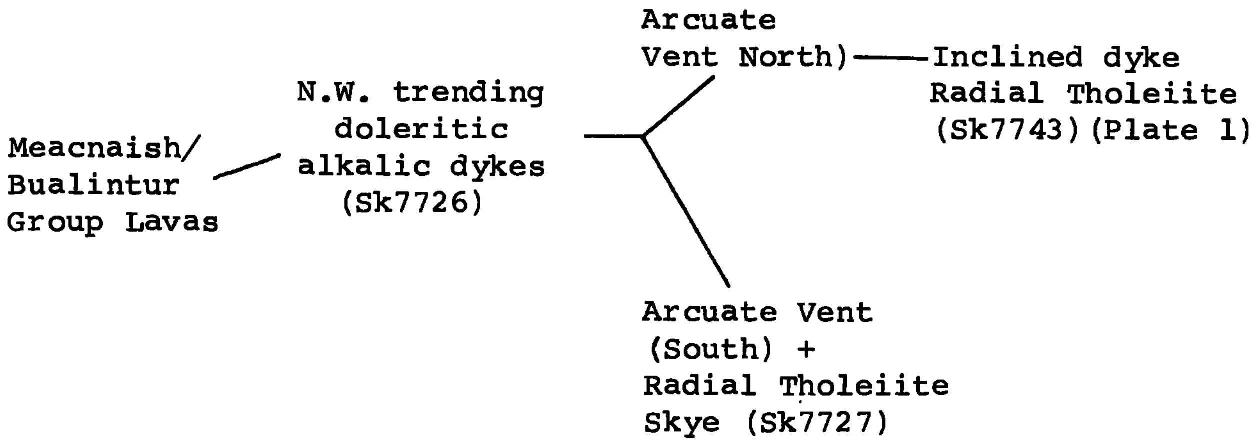
2. Olivine Tholeiite Basaltic Dykes

Chemically distinct from the alkalic lavas and dykes (Chapter 9), olivine tholeiite dykes are found throughout the region, but are especially abundant to the east near the central axis to the swarm (Mattey *et al*. 1977 , and Fig.4). Petrographically, two distinct types are recognised. The first type appear essentially identical to the alkalic dykes described above but may contain scattered or abundant (e.g. DY015, DY016) bytownitic-labradoritic plagioclase macrophenocrysts with anhedral cores and euhedral outlines. The finer-grained examples are characterised by a gentle flow orientation of the groundmass feldspars and scattered olivine and plagioclase microphenocrysts. A doleritic example from Fiskavaig (Sk7638) carries numerous subangular xenoliths of gabbro ranging in size from 1-15 centimetres (Plate 11). The xenoliths are of a fairly olivine-rich gabbro with a predominance of strongly zoned and inclusion filled labradorite plagioclase.

The second type of tholeiite has a petrography akin to that of the olivine tholeiite of Talisker and the feature common to them all is the presence of a fine-grained groundmass of granular, intersertal or ragged, perhaps partially microphenocrystic brown-neutral clinopyroxene, intersertal magnetite and disoriented plagioclase laths. They also frequently contain large (to 5 millimetres), zoned, euhedral bytownite-anorthite plagioclase phenocrysts occurring individually or in stellate (DY006) or glomeroporphyritic (DY006, DY008) aggregates. Often associated with these aggregates are large talc or green-pink pleochroic mucaceous pseudomorphs after olivine.

The phenocryst content of individual samples is largely dependent upon the sampling position within the particular dyke examined, as it was found that, in the majority of cases examined, the phenocrysts when present were distributed somewhat unevenly throughout the intrusion. Also in a few examples they occupy the central part of the dyke and are flanked by partially amygdaloidal, partially tachylitic borders.

It is of interest here to mention the relative ages of the alkali-transitional alkali basalt dykes and the tholeiites. A relationship, thought to be representative of these intrusions in general, is observable above low water mark, south-east of Glen Brittle beach. Here, cross-cutting relationships suggest the following sequence of events:



7.2i)C Intermediate Dykes

The few dykes with Differentiation Indices greater than 32, fall into two main categories:

1. Nepheline Normative Transitional
   Alkalic Rocks

2. Hypersthene Normative Olivine and
   Quartz Tholeiites

The transitional alkalic rocks (DY001, DY020) are mugearitic in composition and carry rare plagioclase microphenocrysts in a groundmass of granular clinopyroxene, small pseudomorphed olivines, euhedral titanomagnetite and faintly-aligned andesitic-oligoclase laths, while those with more tholeiitic affinities, broadly speaking, are similar to the tholeiitic basalts, ranging from aphyric (DY005), through dolerites (DY003) to plagioclase macroporphyritic (DY004). All contain the characteristic granular-intersertal brown clinopyroxene. Specimen DY004 is of particular interest in that it is the only apparently quartz-normative tholeiite recorded. It contains scattered 0.5 millimetre clinopyroxene and plagioclase phenocrysts. The clinopyroxene is subordinate to the plagioclase and forms the usual pseudophenocrysts. The dyke also contains what may be cognate xenoliths of a tachylitic, variolitic basalt with quench-textured opaques, feldspar microlites and minute clinopyroxene phenocrysts.

All are vesicular and contain interstitial glass to some degree. Secondary minerals include calcite, analcime and a range of fibrous zeolites. No quartz was found.

The more extensive mugearite and trachyte dykes mapped by Harker (1904) and also by Anderson and Dunham (1966), along the north-eastern margins of the area, were not sampled although as previously mentioned in Chapter 4, they were examined along the Vikisgill Burn and also in the extensive roadside cuttings above Drynoch. The distribution of these types sampled here is in accord with a position close to the axis of the swarm but it is more than likely that they are more especially associated with the intermediate lavas which characterise the Arnaval (this study), Osdale and Bracadale (Anderson and Dunham, 1966a) Lava Groups.

7.2i)D Acid-Intermediate Dykes

Apart from the late-stage granophyric veining associated with the inner hornfels zone of the Cuillin aureole at An Sguman, the only discrete acid dyke encountered is the thin, irregular but planar mass of deeply weathered greenish-grey porphyritic pitchstone (DY007) which intrudes the indurated lavas south-east of Glen Brittle beach.

In handspecimen, small pink feldspars and small, dark greenish-brown pyroxenes are easily seen as phenocrysts in a flow-banded groundmass. In thin section, the feldspars are 0.5-1.5 millimetres across, tabular, euhedral plagioclases with broad albite lamellae and simple carlsbad twinning. Rare orthoclase, showing extremely faint microcline-type cross-hatch twinning may also be present. The feldspars are usually slightly albitised and badly altered to sericite. They form glomeroporphyritic aggregates, up to 1 centimetre in diameter, along with faintly-green to colourless pleochroic, 0.5 millimetre subhedral augite and numerous euhedral magnetite octahedra and subsidiary apatite (Plate 79). In this respect they are reminiscent of some of the Inninmoreite-pitchstones of Mull (Bailey et al., 1924) and Ardnamurchan (Richey et al., 1930) although apparently lacking in orthopyroxene as a major phase.

They also resemble some of the augite-andesites or andesitic-pitchstones described by Harker (1904 ., pp. 399-410) from the Eastern Guillins and Red Hills. The phenocryst assemblage is also similar to that of the Intermediate-Trachyte of Sleadale (Chapter 7.1) and to the subacid-trachyte sheet described from the south coast of Soay by Harker (1904 , p.395). The latter carries orthoclase, oligoclase and augite phenocrysts with substantial magnetite in a groundmass composed of feldspar microlites. The Glen Brittle pitchstone is hence very probably of intermediate composition.

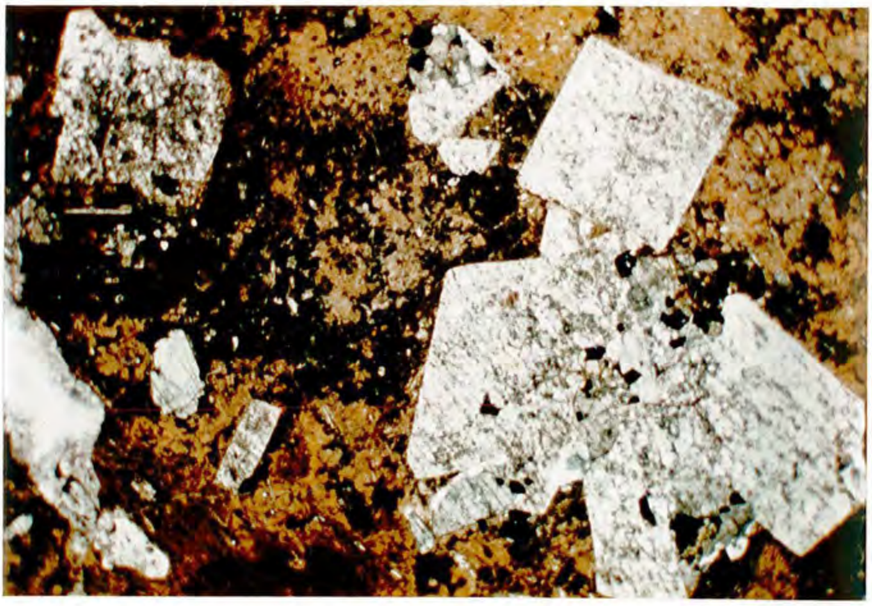
Texturally, the clinopyroxene may enclose euhedral magnetite and itself be partially enclosed by feldspar and more subhedral magnetite indicating a complex crystallisation history, with substantial overlaps in the periods of growth of the phases involved. The groundmass is formed by a brownish-red to orange-yellow, devitrified, partially spherulitic, partly flow-banded, occasionally perlitic acid glass. Associated with this is widely disseminated yellow pleochroic epidote and vein quartz. The quartz forms small veins and amygdale-like lenses which are undoubtedly of secondary origin as they visibly cut across shattered and broken feldspar phenocrysts. Green chlorite and serpentine are common pseudomorphs after the clinopyroxenes.

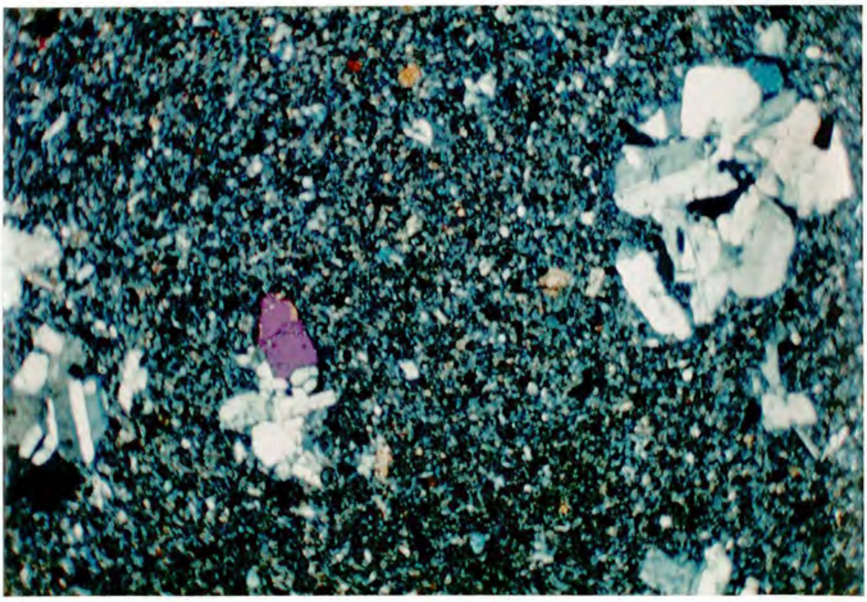
PLATE 79

Photomicrograph of the partially devitrified sub-spherulitic pitchstone/felsite dyke Dy007 from the eastern shores of Loch Brittle, with glomeroporphyritic aggregates of tabular feldspars, titaniferous magnetite and greenish clinopyroxenes.

PLATE 80

Photomicrograph of a typical low-alkali tholeiite inclined sheet Sk750701 from Clachan Gorma near Biod Mor with well developed glomeroporphyritic aggregates of plagioclase and olivine in a fine-grained granular groundmass typical of the tholeiites in west-central Skye.





7.2ii) Inclined Basic Sheets

Low inclination dykes, and sills throughout the area and cone-sheets associated with the Central Complex, form a series of minor tholeiitic intrusions referred here to as 'inclined sheets'. Both main sets are similar petrographically and although tholeiites, contain no hypersthene or pigeonite orthopyroxene.

Generally orange-brown weathering with a distinct perpendicular cross-jointing and frequently porphyritic, they average around 1 metre in thickness although substantially thicker, notably columnar examples (eg. Sk750701) are recorded. In thin section, they are all readily recognisable as olivine tholeiites by comparison with the olivine tholeiite dykes and lavas, in that the majority carry glomeroporphyritic olivine and plagioclase. The 2-5 millimetre long plagioclase, usually either bytownite or anorthite (An_{70}-An_{92}, Anderson and Dunham, 1966), is always dominant over the olivines which may attain 1 millimetre in diameter. The composition of the plagioclases compares well with that of the Talisker tholeiite. The size of these aggregates varies from around 4 millimetres to about 1.5 centimetres in diameter, the larger ones resembling cognate gabbroic xenoliths similar to some of the gabbroic-anorthosite dykes of Northern Skye (Anderson and Dunham 1966 ., and Donaldson, 1975,1977)In most, they are widely scattered (e.g. Sk750507, Sk750511, and Sk760802) but may be relatively abundant in others (e.g. Sk750701, NG 359268) (Plate 80). The generally fine-grained groundmass is characterised by subophitic (Sk741105, Sk750511) or granular to microporphyritic-intersertal (Sk750507, Sk7703) brownish-neutral to colourless clinopyroxene, varying amounts of granular olivine and interstitial subhedral or skeletal titaniferous magnetite. The groundmass feldspars only rarely show a tendency towards trachytic texturing (e.g. Sk750507) and opaque-charged borwn glass may be present in the interstices of a few examples. A banding, due to groundmass textural changes similar to those described in the low-alkali olivine tholeiite lava on Preshal More is also present in the sheet intruding and overlying the agglomerates at the summit of Beinn Bhreac (Sk750511). In most sheets encountered, a thin, glassy, chilled contact is present and may be partially devitrified with euhedral plagioclase and rare olivine microphenocrysts (e.g. Sk760801).

7.2iii) Large Basic-Intermediate Sills

Although the large numbers of major sills, described by Harker as intruding the basaltic lavas, do not exist, sill-like bodies larger than the inclined sheets and dykes are encountered. Three contrasting occurrences were discovered. The northernmost is described first and the most southerly last.

The first sill (Sk7615) forms the five metres high wave-cut platform at Creagan Dubh and is a plagioclase macroporphyritic (20-25% modal) tholeiite. The mostly euhedral but occasionally subhedral feldspars have weakly zoned cores of bytownite with more sodic rims and reach a maximum of 5-6 millimetres in length. Thorough resorption is rare but some crystals possess rounded outlines and inner, inclusion filled rims. There are very rare olivines and a zoned, granular, neutral-coloured clinopyroxene but perhaps the most distinctive feature of the groundmass is the beautifully poikilitic titaniferous magnetite (Plate 81).

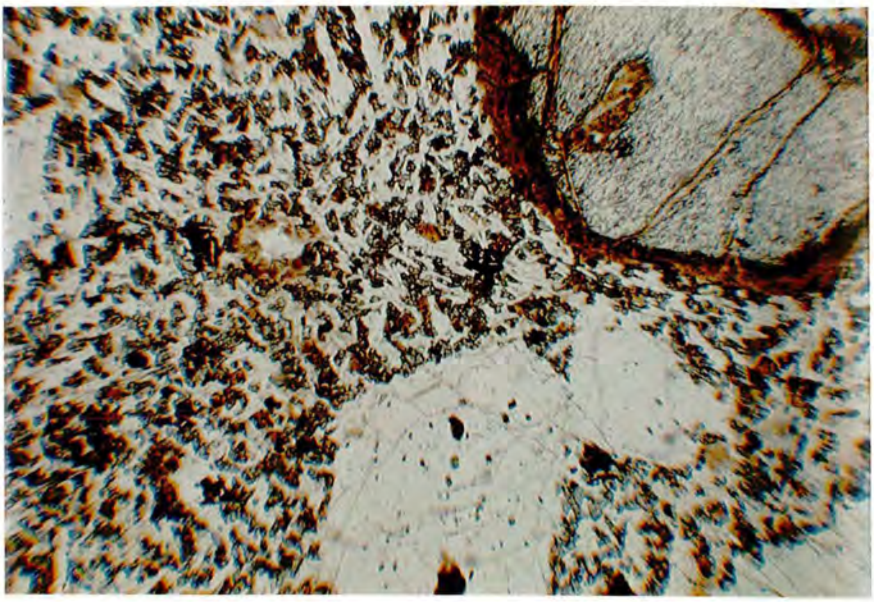
The sill which intrudes above the conglomerates at Geodh'a'Ghamhna and also on the Allt Gearraidh Dhroighinn is a more differentiated version of the Creagan Dubh sill (Differentiation Index = 40-41). It carries variable amounts of macroporphyritic plagioclase of labradoritic composition (An_{65-68}), for example specimens Sk7626 from the latter locality and Sk7629 from the former contain about 10% and 4% respectively. In both cases the phenocrysts are much resorbed and exhibit a patchy development of a more sodic plagioclase (An_{36}). In some, there may be a very irregular, anhedral core surrounded by a euhedral, zoned rim in turn

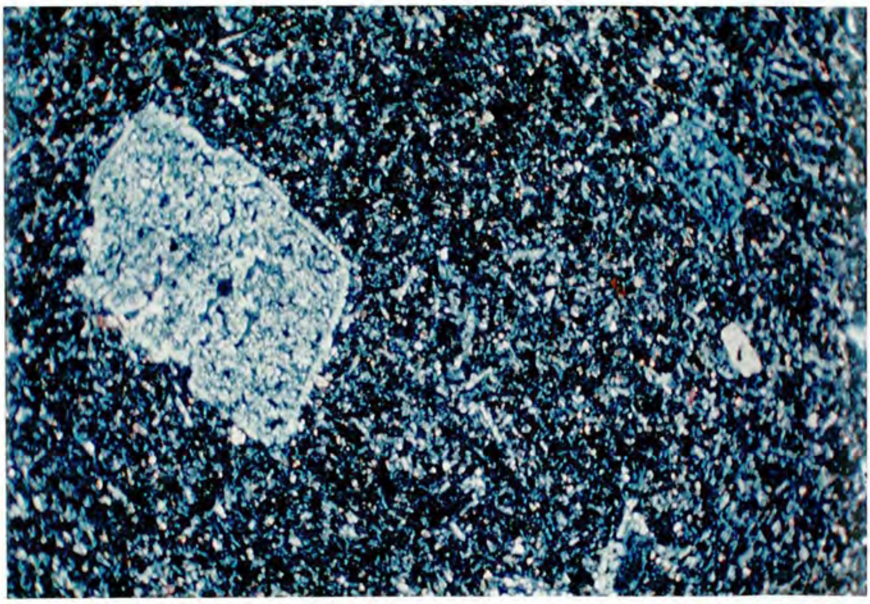
PLATE 81

Photomicrograph of the tholeiitic Creagan Dubh sill Sk7615 with conspicuous macrophenocrysts of plagioclase and olivine in a fine-grained groundmass characterised by granular clinopyroxene, disoriented plagioclase laths and subophitic titaniferous magnetite.

PLATE 82

Photomicrograph of the andesitic Bualintur sill Sk7626 showing altered and partially corroded feldspar phenocrysts. The plagioclase feldspar is now composed of a random mosaic composed of aggregates of labradorite and potassic andesine. Small clinopyroxene microphenocrysts are also present.





surrounded by a rounded subhedral margin (Plate 82, Sk7626). The polysynthetic twinning visibly continues out into the outer zone. The larger feldspars are commonly embayed and partially replaced by zeolites, sericite and calcite. The calcite may form large (5 millimetre) poikilitic crystals. A small percentage of rounded, inclusion-filled clinopyroxene microphenocrysts ($Wo_{37}En_{40}Fs_{22}$) up to 1 millimetre long, may also be present but mainly the clinopyroxene is a granular, colourless, highly birefringent variety similar to that of the tholeiitic inclined sheets. The groundmass plagioclase is an andesine with ragged outlines, faint albite twinning and sodic overgrowths.

The final sill described here intrudes and transgresses up through the pre-Tertiary strata west of An Leac, is best observed at the sea-cave, and for a small distance to the east lies between the lavas and Mesozoic sediments. It eventually intrudes the lowest aphyric lava of the Meacnaish Group (Sk760510) at An Leac but transgresses no higher in the volcanic succession. In this respect it is similar to the larger sills of the Trotternish peninsula which may intrude along the plane of the unconformity but seldom cut through the volcanics. Petrographically, it (Sk760509) bears no resemblance to the other sills cited and carries abundant trachytic textured microporphyritic plagioclases and pseudomorphed olivines. The groundmass clinopyroxene is distinctly brown to yellowish brown in colour and forms intergranular aggregates and small subophitic plates. The rock is deeply weathered with much bright green chlorite and fibrous amphibole developed, especially surrounding the olivine pseudomorphs of mica and magnetite and the common vesicles. It visibly truncates some of the dykes near the sea-cave but is cut by others to the east, thus occupying an intermediate position in the early intrusive history of the area.

7.2iv) Felsites and Granophyres

1. Felsites of Glen Brittle

Along the western margins of the outer gabbros and their contacts with the lavas in Glen Brittle, occur several elongated, disconnected, sheet-like masses of porphyritic felsite. Harker (1904) considered them intrusions earlier than the adjacent gabbros but due to the poor degree of exposure and the sheared nature of many of the associated rocks, the present survey was unable to confirm this. Being apparently transgressive towards the lavas and showing few signs of thermal metamorphism, they are however interpreted as representing intrusive sheets rather than acid-intermediate lava flows.

In hand specimen, the rock (Sk7716) is light grey in colour with numerous large, pinkish-yellow feldspar phenocrysts and a distinct fluxion texture which may impart a prominent jointing. Small brown flakes of biotite are also visible. The phenocrysts are of orthoclase, rare sodic plagioclase and biotite, together constituting between 5 and 15 percent of the rock (Plate 83).

The alkali-feldspars are often rounded but are more frequently tabular euhedral crystals displaying simple carlsbad twinning and are extensively altered to sericite. The rarer plagioclases are more elongated with faint but closely spaced albite twinning and together with the orthoclase, form occasional glomeroporphyritic aggregates up to 4 millimetres in diameter. The biotite is a dark brown - yellowish brown - reddish brown pleochroic variety, found frequently as much altered, ragged 0.2 to 1.0 millimetre flakes or small aggregates, in association with rare subhedral to anhedral 0.2 to 0.5 mm magnetites, apatite euhedra and the feldspars. These are set in a felt-like groundmass of minute trachytic textured alkali plagioclase zoned apparently continuously to true alkali feldspar laths. Quartz veins transect the majority of exposures and individual crystals of later formed quartz may be found in close association with both the biotite and larger altered feldspar phenocrysts.

2. Granophyric Veining

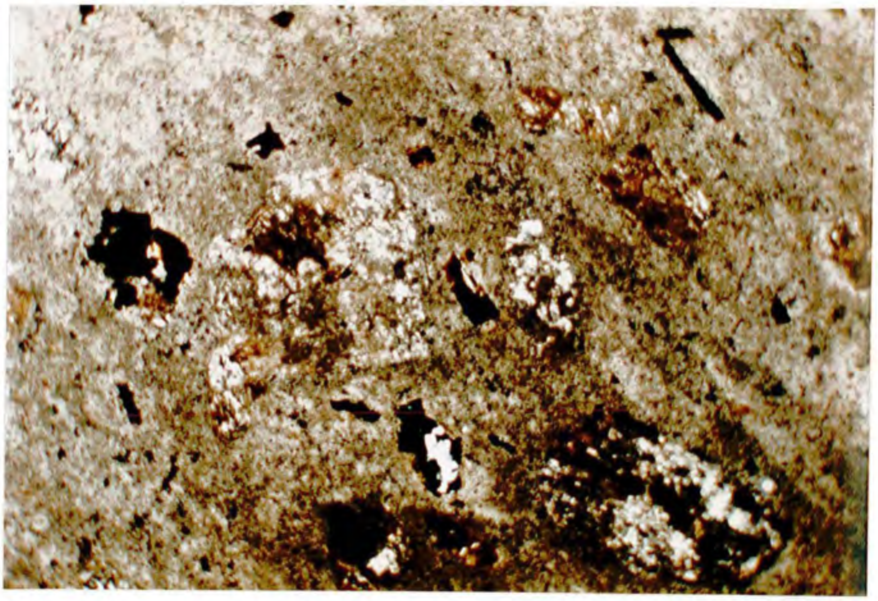
Associated with the marginal gabbros and hornfelsed lavas at An Sguman are numerous anastomasing leucocratic veins.

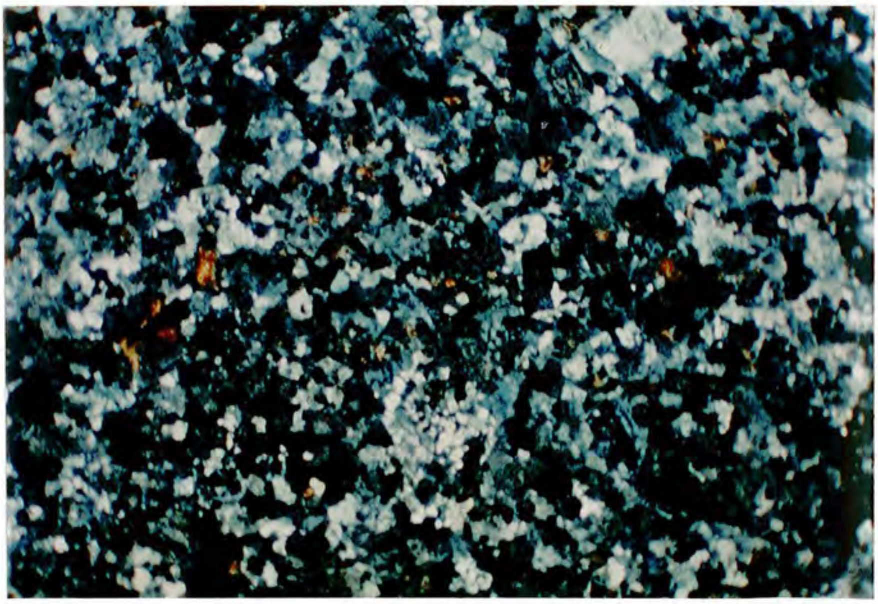
PLATE 83

Photomicrograph of the alkali feldspar + biotite + quartz porphyritic felsite sheet Sk7716 from Upper Glen Brittle at Leachd Thuilm. The large, irregular dark patches are altered biotite and magnetites.

PLATE 84

Photomicrograph of the fine-grained net-veining Sk760816 from the meta-lavas near An Sguman. The veining is an equigranular mosaic of plagioclase, quartz, orthopyroxene and amphibole with some imperfectly developed granophyric intergrowths.





Upon examination the specimens Sk770816 and Sk770817 consist of a fine-grained equigranular non-porphyritic microgranite or granophyre. In thin section, the mafic phase is a green to greenish-yellow to pink mildly pleochroic orthopyroxene associated with considerable, sometimes secondary green amphibole and rarer clinopyroxene. It is possible that the orthopyroxene is a sign indicating a rheomorphic origin for this rock as may be the case with some of the altered granophyres near Harris on the Island of Rhum (C.H. Emeleus, Pers. Comm.). Alkali feldspar and plagioclase are dominant over quartz with granophyric intergrowths reasonably well, albeit patchily developed. Accessories include numerous slender needles of apatite, euhedral opaques, including secondary haematite and rare sphene (Plate 84).

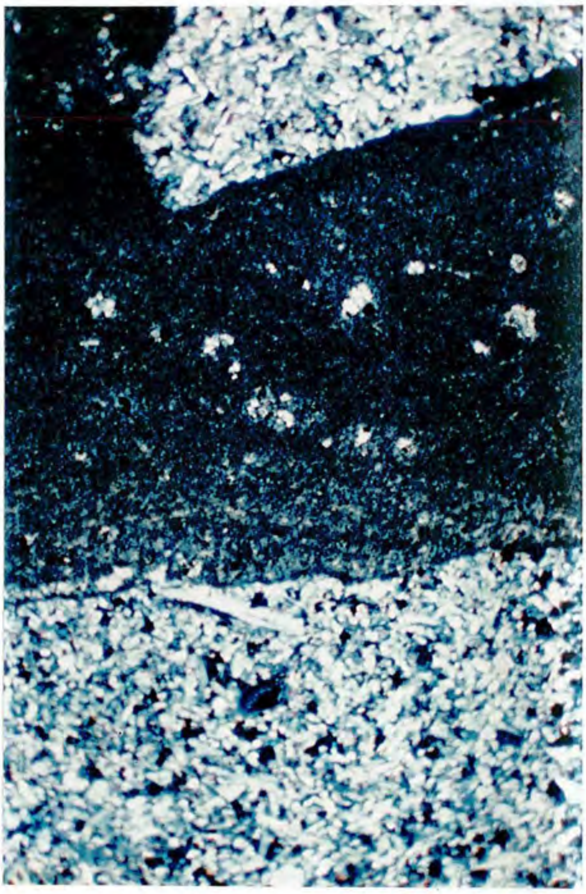
7.2v) Intrusion Breccias, Marginal Gabbros and Peridotites

1. Intrusion Breccias

The intrusion breccia of An Sguman (specimens Sk7728-31) consists of a non-porphyritic ophitic basalt with a partially developed hornfels texture veined by a very fine-grained, often variolitic basalt with traces of olivine and titaniferous magnetite microphenocrysts (Plate 85). The groundmass of the intrusive veins also contains small biotite flakes and dendritic, quenched clinopyroxene microlites upon which minute magnetite octahedra have nucleated. The small feldspar laths

PLATE 85

Photomicrograph of some of the intrusion breccia Sk7729 near An Sguman showing hornfelsed basalt lava fratured and intruded by aphanitic olivine porphyritic basalt. Note the chilling at the edges of the hornfels blocks.



do, in places, possess a crude flow alignment and along with the finer-grained chill developed around many of the angular to sub-rounded lava fragments, prooves the intrusive nature of the veining.

The small agglomerate and breccia-filled vents south-east of Glen Brittle beach are also in places intricately 'net veined' by a basic igneous rock. In this instance it is a distinctly fine-grained, rust-coloured rock which in thin section is almost variolitic but with subophitic to granular clinopyroxene and numerous 0.5 millimetre olivine pseudomorphs. The fragments consist of hydrothermally altered 'Big Feldspar' basalt, olivine porphyritic basalt and aphyric basalt. A fine-grained groundmass with subtantial glass may be developed peripherally to the vent in some areas.

2. The Marginal Gabbros

From the work of Weedon (1961) and Hutchison (1966 and 1968), the gabbro in contact with the lavas of West-central Skye appears to be an arcuate intrusion of 'eucritic' composition. However, this poorly exposed intrusion, at least in the vicinity of the lava contacts in Glen Brittle itself, is highly variable both texturally and in its modal mineralogy. Also, at An Sguman, patches of a gabbro differing fundamentally in its mineralogy from the 'norm' are exposed but their relationship to the coarse-grained, often pegmatitic eucrite is often difficult to assess.

The bulk of the marginal intrusion is a coarse-grained, patchily feldspathic rock e.g. Sk760801, Sk760803, with well developed ophitic textures. The pyroxene is a light brown to colourless augite ophitically enclosing 0.2 to 10 millimetre plagioclase laths exhibiting normal continuous and frequently, oscillatory zoning (Plate 86). Rounded olivine crystals are present in varying amounts; from 2-3 percent in Sk760801 to around 15 percent in the finer-grained equigranular variant Sk7707 occurring along the margins of and within the sheared zone of the An Sguman peridotite. Invariably it is represented by chloritic or micaceous pseudomorphs perhaps with a small core of unaltered olivine. Interstitial titaniferous magnetite with faint ilmenite lamellae is ubiquitous; biotite, amphibole, apatite and extremely rare tourmaline occurring as accessories.

In addition, zoned 3 millimetre long, tabular plagioclases may be considered phenocrysts in another subophitic variant exposed in the small ravine near the road bridge in Glen Brittle (Specimen Sk7713) and large 3-5 centimetre idiomorphic clinopyroxenes are well developed in the deeply weathered, gravel forming, pegmatoids exposed in the Allt a'Coire Ghreadaidh, east of the youth hostel and at Eas Mor on the Allt Coire na Banachdich.

The gabbro associated with the lavas and peridotite on An Sguman is a medium to coarse-grained rock carrying euhedral olvines, granular and subophitic titaniferous clinopyroxene,

PLATE 86

Photomicrograph of the Outer Ring Eucrite Sk760803 showing ophitic clinopyroxene enclosing olivine, plagioclase and magnetite.

PLATE 87

Photomicrograph of the 'noritic' or hypersthene eucrite variant Sk760808 of the Outer Ring Eucrite. The pyroxenes are sub-ophitic towards the other constituents.

well developed cavities composed primarily of prehnite, zoisite, fibrous green amphibole, zeolites and epidote and frequent pegmatitic patches (Plate 87). The main distinguishing feature of some irregular, discrete lenses within this gabbro is the presence of what appears to be hypersthene. No exsolution lamellae of inverted pigeonite were recorded. In these patches (e.g. Sk760808) which may be small or several metres in length, the orthopyroxene is joined by subordinate clinopyroxene and olivine and the rock may be termed a hypersthene gabbro or an olivine-hypersthene-eucrite. Important accessories are biotite and apatite with exceptionally rare sphene.

The eucrite immediately north-east of An Sguman contains elongated doleritic, occasionally amygdaloidal bodies interpreted by Harker (1904) as totally enclosed lava xenoliths, but more recently found, through the detailed mapping of Hutchison (1966) in the Western Cuillins, to belong to a suite of tholeiitic intrusions of a relatively minor nature.

Alteration products include replacement of the plagioclases by sericitic mica calate and epidote, finely divided dusty magnetite and chlorite or fibrous amphibole replacing the pyroxenes and micaceous pseudomorphs and magnetite developing along fractures after olivine.

3. The Gabbro Plug of Loch Brittle

As mentioned in Chapter 4.3iii) this small gabbroic plug consists essentially of a main mafic gabbro (Sk751105-A, Sk7721) with some leucocratic pegmatoid layers (Sk751105-B, Sk7722, Sk7723) developed towards the top. A marginal facies is also recognised (Sk7724).

The majority of the plug consists of a fairly melanocratic gabbro made up of large ophitic 5-6 millimetre brownish, faintly pleochroic clinopyroxenes enclosing 0.5 to 1.5 millimetre strongly zoned laths of labradorite. Small aggregates of fractured olivines represented by serpentinous and iddingsitic pseudomorphs are accompanied by small subhedral magnetite. There is also some interstitial red-brown biotite and amphibole may rim the pyroxenes. The leucocratic layers are by contrast much more feldspathic but the feldspars, up to 3 millimetres in length, are generally shattered and considerably hydrothermally altered and occasionally intergrown with quartz. The clinopyroxene, whilst remaining a faintly pleochroic brown variety, is not ophitic. Rather, it forms up to 2 millimetre long euhedral to subhedral, occasionally twinned crystals with darker brown, possibly zoned margins. Rare olivines are present and along with large patches of titaniferous magnetite may occur in layers parallel to the larger scale 'bedding'. Zeolite and epidote lined cavities always accompany the quartz and feldspar bands (Plate 88).

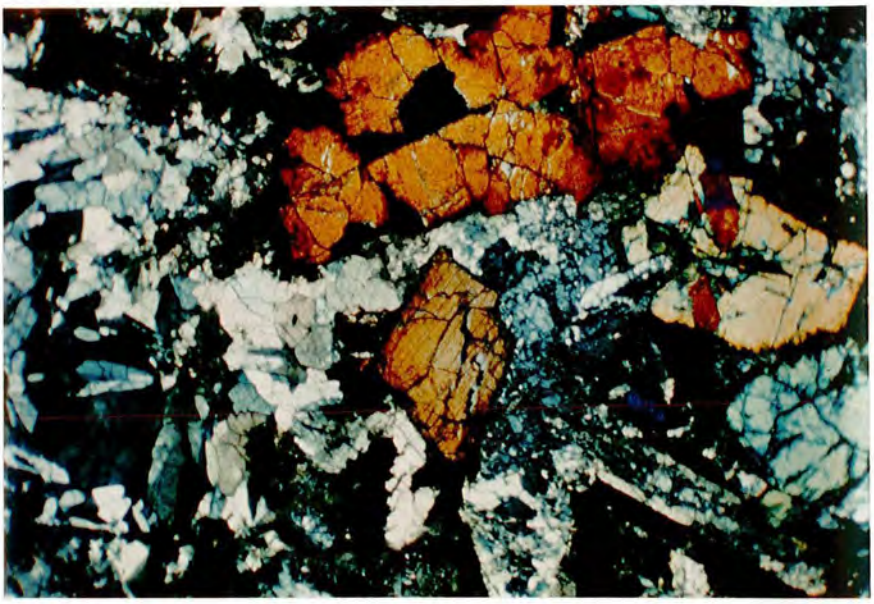
The marginal zone or possibly a peripheral intrusive sheet, is appreciably fine-grained and equigranular but may carry small anhedral plagioclase and clinopyroxene microphenocrysts similar to the clinopyroxene porphyritic lava of

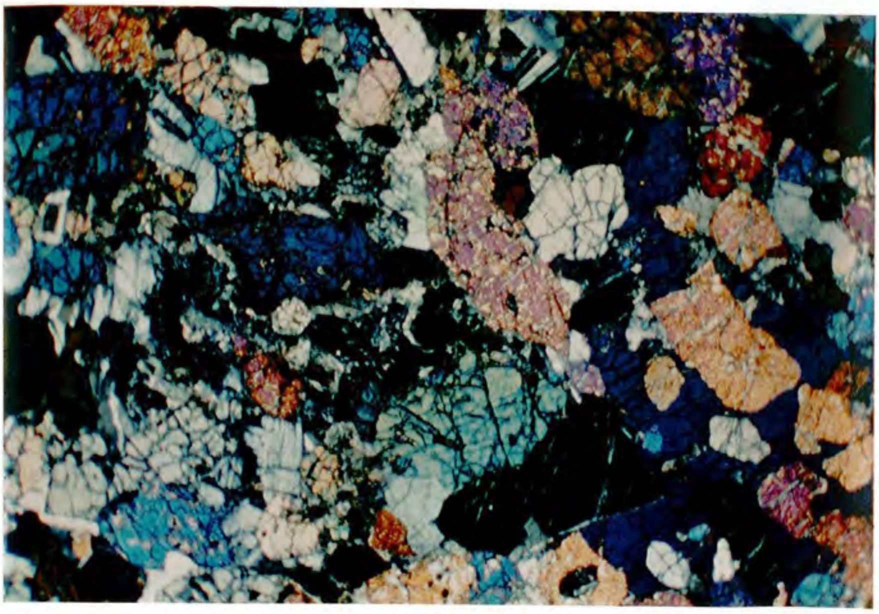
PLATE 88

Photomicrograph of the leucocratic pegmatitic layering Sk7721 in the minor gabbro plug of west Loch Brittle showing large idiomorphic clinopyroxenes in a groundmass of tabular feldspar laths, zeolites and amphibole.

PLATE 89

Photomicrograph of the feldspathic peridotite of An Sguman Sk760809 with a subophitic relationship between clinopyroxene and olivine (+ spinel); both ophitically enclosed in minor plagioclase. The effects of crushing and slight thermal metamorphism are quite apparent in this specimen.





Beinn an Eoin (Sk751218). In general the petrography of the plug broadly duplicates that of the outer gabbros of the Cuillin Complex.

4. The Peridotite of An Sguman

The irregular ultrabasic body exposed at An Sguman along the southern margins of the outer ring eucrite, is a feldspathic peridotite (Sk760806, Sk760809). It is composed dominantly of euhedral, often sheared forsteritic olivines up to 2.5 millimetres in diameter in association with small subhedral chrome-rich spinels, intercumulus poikilitic faintly green clinopyroxene and rare but variable intercumulus plagioclase (Plate 89). The grainsize varies across the intrusion being generally finer-grained, sheared, crudely foliated and xenolithic towards the margins. The percentage of intercumulus plagioclase showing carlsbad, albite and rare pericline twinning laws, is also variable, giving rise to diffuse feldspathic patches and bands which may weather out in prominent hollows and careous ridges. Harker (1904) regarded the intrusion as possessing no visible banding in contrast to the other major peridotite bodies of the Cuillins. A faint form of matrix banding, possibly due to the modal variation in olivine and feldspar, can however be seen in some parts of the intrusion. Brown biotite and hornblende appear to be the main accessories. Alteration minerals are as for the minor ultrabasic intrusions of An Leac and Carn Mor. A modal analysis gave the following results: Olivine 58-60%, Clinopyroxene 23-24%, Plagioclase 12-16%, Spinels 4%, Accessories 3%.

7.3. The Petrography of the Tertiary Sediments and Pyroclastics associated with the Volcanic Series

The various pyroclastic accumulations and sediments associated with the lavas of West-central Skye are described in Chapter 3 and their petrography is summarised below.

7.3i) Pebbles in the Conglomerates and Associated Sandstones

A. Acid Igneous Types

The acid igneous pebbles found within the conglomerates interstratified with the lava succession at various localities (Chapter 3.3) are basically of two types; granophyres and felsites. Variations in these types are also recognised. Their origins are also discussed.

1. Felsites: Specimens Sk760903, Em7707

Porphyritic felsite forms the least common acidic type in these conglomerates. Quartz, the dominant phenocryst phase forms approximately 15% euhedral frequently strained crystals up to 2 millimetres across often with some embayment or rounding of the margins and is associated with a lesser percentage of 0.5 to 2 millimetre tabular, rectangular euhedral microperthitic orthoclase. The groundmass is fine-grained and consists of a mosaic of subangular quartz and equigranular 0.01 to 0.05 millimetre alkali feldspar with subordinate ore and amphibole. Very rare 0.1 millimetre magnetite microphenocrysts are also recorded. Accessory phases appear to be rare but muscovite, epidote, fayalite and some poikilitic opaque are encountered infrequently. In the specimens examined, the groundmass is notably finer-grained around the quartz and feldspar phenocrysts and a thin rim of mafic inclusions and incipient granophyric intergrowths may be developed. Frequently the large feldspars are completely replaced by a mosaic of angular plates of laumontite and stilbite (Plate 90). A rock, bluish-grey and friable in character, regarded as being a completely degraded version of the normal leucocratic felsite, and now composed of sub-angular quartz, fibrous to acicular bluish laumontite and specular clay minerals occur in the lower conglomerate beds at Geodh'a Ghamhna (Table 2).

2. Granophyres Specimens Sk760902-12, 7630, 7703, 751903-A

Biotite and pyroxene-hornblende granophyres are the two common variations noted but there is apparently some degree of overlap. The degree of development of granophyric intergrowth textures and the presence of phenocrysts also serves to subdivide this suite, some rocks exhibiting substantial areas of micrograniti c and porphyritic microgranular textures.

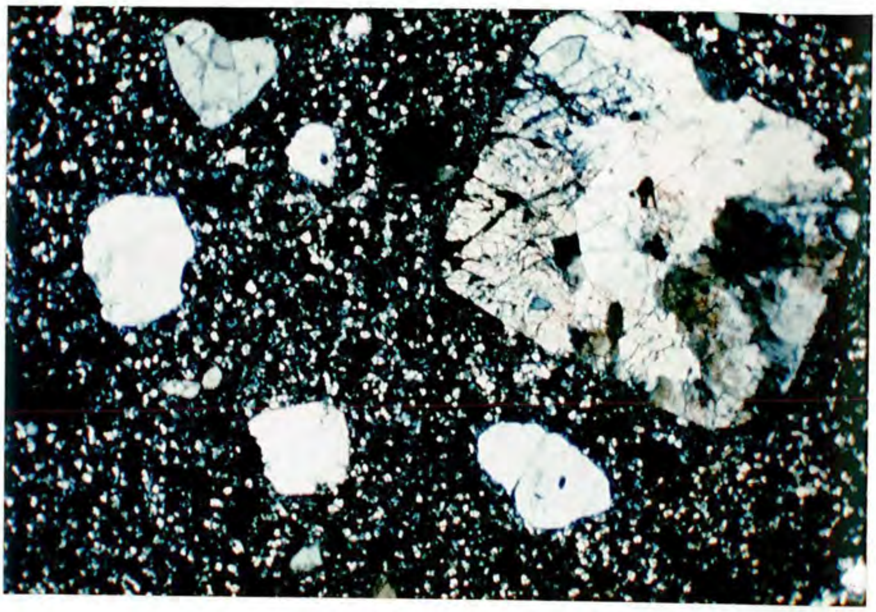
The majority are medium-grained, brownish-red to greenish weathering granophyres in which euhedral, often oscillatory zoned, sodic plagioclase and extremely rare anorthoclase forms a major phenocryst phase up to 3.5 millimetres in length set in a granular groundmass of quartz and alkali feldspar. In nearly all specimens the quartz and alkali feldspar are granophyrically intergrown to some extent and in the porphyritic

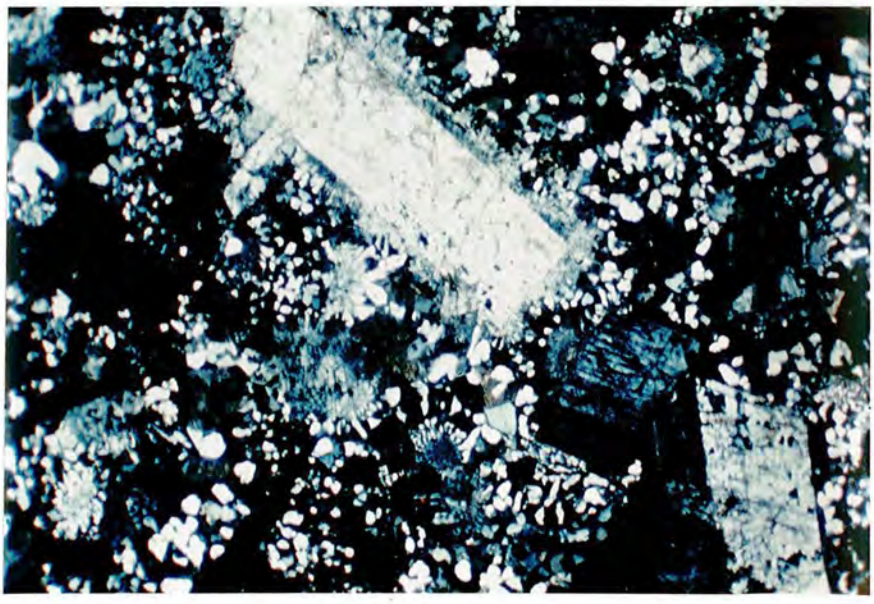
PLATE 90

Photomicrograph of a typical feldspar + quartz porphyritic felsite cobble Sk760903 in the intraformational conglomerates at Geodh'a'Ghamhna. The quartz is often embayed and strained whilst the originally alkali feldspar phenocrysts are represented by aggregates of laumontite and stilbite. There is some chilling and quartz + alkali feldspar intergrowths around the margins of the phenocrysts.

PLATE 91

Photomicrograph of a typical plagioclase feldspar porphyritic granophyre cobble Sk760909 from the intraformational conglomerates at Geodh'a'Ghamhna. Note the nucleation of very fine-scaled quartz + alkali feldspar intergrowths around the phenocrysts. Biotite is the common mafic phase in this rock type.





varieties this intergrowth is often nucleating upon the alkali feldspar mantle around the plagioclase phenocrysts (Plate 91). Similar features with the granophyric intergrowth grading from the radiating fine type, around the individual carlsbad and faintly albite twinned plagioclase feldspar phenocrysts, through an irregular type to an almost granitic texture in the interstitial areas has been reported from some of Rhum granophyres by Hughes (1960). Quartz, not granophyically intergrown, appears to be absent or at least very rare in only a few specimens e.g. Sk760905. Dark brown pleochroic biotite is the only readily identifiable primary ferromagnesian phase in virtually all the pebbles sampled but in others e.g. Sk7630 it occurs only as an accessory to a green augitic or possibly a Na-hedenbergite clinopyroxene and green-brown pleochroic hornblende (Plate 92). The modal percentage of these mafic phases is highly variable, ranging from about 2-12%. The opaque phase encountered is mostly a shapeless magnetite but rarer, bladed ilmenite and reddish haematite may be present.

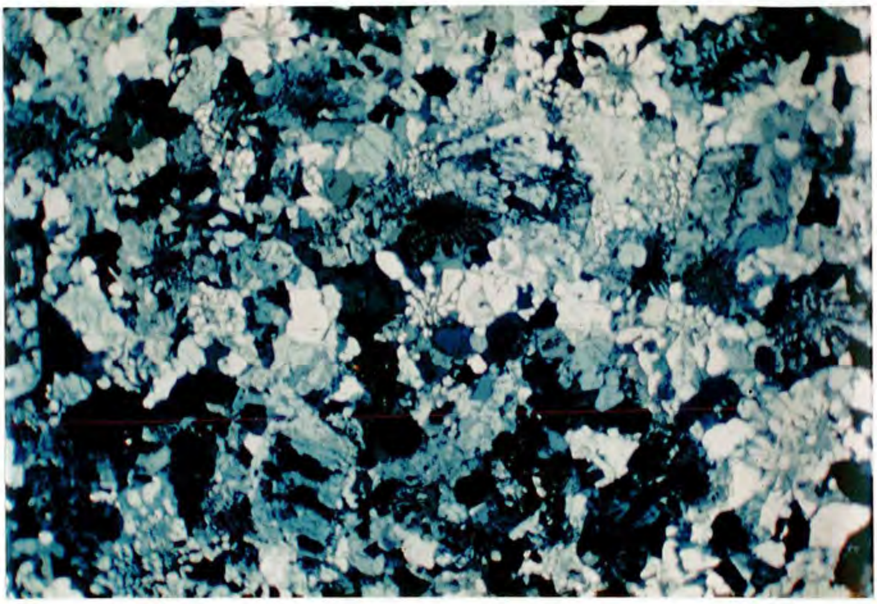
The granophyres in common with many of the later Tertiary intrusions of the Hebridean Tertiary Igneous Province, also frequently contain small drusy cavities of quartz, feldspar, zoisite and zeolites. Tourmaline, epidote, zoisite, apatite, zircon and prehnite are important accessories with minute granules of sphene only tentatively identified. Secondary alterations are well developed mainly in the forms of micaceous

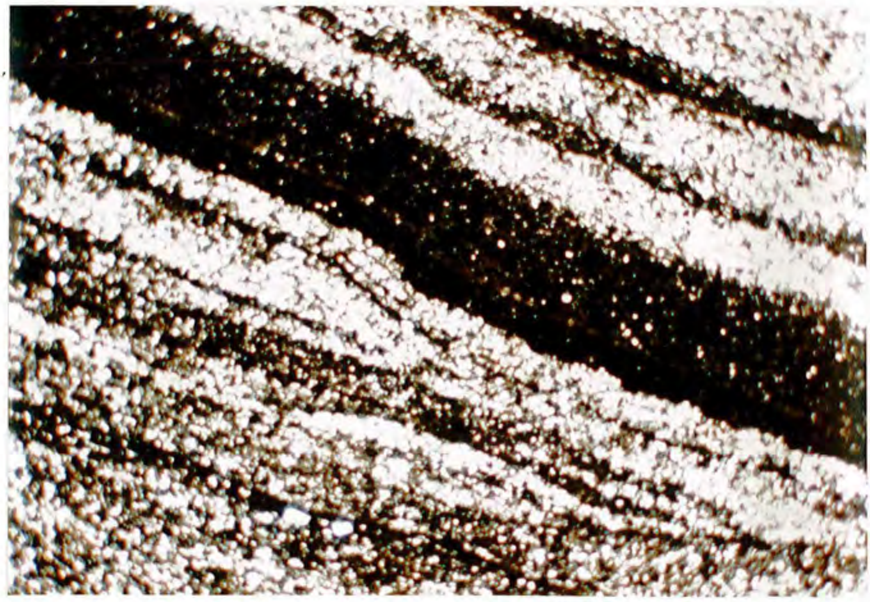
PLATE 92

Photomicrograph of a fine-grained aphyric granophyre cobble Sk7630 in the intraformational conglomerates at Allt Mor. Pyroxene and amphibole may be the mafic phases in this case.

PLATE 93

Photomicrograph of a banded siltstone cobble Em7704 from the intraformational conglomerates at Geodh'a'Ghamhna showing fine-scale possibly graded bedding and cross laminations.





alteration after feldspar, fibrous green amphibole from the biotites and pyroxenes and considerable chlorite, haematite, serpentine and an amorphous brown limonitic-like material.

Petrographically, the granophyres, although considerably altered, in containing an iron-rich biotite and some amphibole as the major ferromagnesian minerals, bear some resemblance to the marginal facies of the Glamaig and Glas Bheinn Mhor epigranites of the Red Hills complexes (Thompson, 1969). The other Tertiary granophyres from Skye are however, rare in biotite by comparison and instead contain substantial amphibole and clinopyroxene with minor amounts of fayalite. Although broadly similar to the Red Hills types, no correlation of the pebble types with them is possible as the plutonic basic complex which cuts and metamorphoses the lavas and inter-stratified conglomerates of west-central Skye, is demonstrably itself truncated by the later Red Hills Centres.

The Western Granophyre of Rhum (Black, 1954) also appears to contain many features akin to those of the pebble-granophyres but again it varies considerably in detail being in places a two-pyroxene granophyre (Emeleus, pers. comm.) not duplicated as yet in the Skye samples. It may be significant to note that the demonstrably pre-central complex granites of Rhum and Arran are biotite-bearing varieties.

The felsites bear some resemblance to the felsitic facies of the Southern Porphyritic Epigranite of the Red Hills but again age relations preclude correlation. They also resemble the porphyritic felsites of Rhum (Hughes 1960; Dunham 1968) and could conceivably derive from them.

It is apparent that petrography alone is sufficient to rule-out correlation between these igneous clasts and the Caledonian granites of the mainland but insufficient to enable correlation with presently exposed Tertiary intrusions. Hence it may be necessary to invoke the existence of a pre-volcanic phase of acid magmatism in the Skye area as presiously mentioned in Chapter 3.3.ii).

B. Sedimentary Types

The commonest sedimentary pebbles are arenaceous types, ranging from fine-grained, quartzose, bedded siltstones to coarse-grained ferriginous arkoses or feldspathic litharenites.

The finer-grained, grey to greenish-grey, obviously bedded and occasionally fissile pebbles are the least common type e.g. Sk751405-B and Em7704. Angular quartz and feldspar grains are generally equally abundant and altho8gh very small, coarser graded units may be characterised by larger grains up to 0.2 millimetres in diameter. A high percentage of brown, ironstained argillaceous matter forms the matrix while biotite and muscovite occur in small amount as accessories defining bedding planes. Epidote and sphene also occur as accessories. Cross laminations are common (Plate 93).

The medium and coarse-grained feldspathic litharenites consist of angular to subangular quartz and feldspar grains varying up to 2 millimetres in diameter with the often strained quartz generally as abundant as or marginally subordinate to the feldspars. The dominant feldspar is an alkali feldspar (orthoclase and/or microcline) but plagioclase may also be common. Rock fragments are well represented in most specimens and consist of varying percentages of granophyre-granite, sandstones, polycrystalline quartz and rare basic igneous fragments e.g. Sk7728. The matrix is mostly formed by clear overgrowths of the quartz grains allied to ferruginous clay minerals, e.g. Sk751408. Some intergrowth between quartz and feldspar is also recorded. Volumetrically, lime-green to yellow pleochroic epidote is the most important accessory, the rocks thus bearing strong resemblances to the Epidotic Grits of the Torridonian. This is joined by sphene, biotite, muscovite, garnet and zircon (Plate 94). The sorting is varied and generally poor as in specimens Sk751408, Sk751403-B and Em7706 but within graded units, the individual grains may be well-rounded and equidimentional e.g. Em7705. A percentage modal analysis of a typical rock, specimen Sk751402 gave the following:

Quartz 27%	Free 76 Polycrystalline 24
Feldspar 26%	Microcline 15 Alkali 77 Plagioclase 8
Rock Fragments 40%	Granites 60 Shales 4 Sandstones 36
Mafics including Accessories 5%	
Cement 2%	
Maturity index Q/F 1.01, Q/F+R 0.54	
Provenance F/R 0.5	

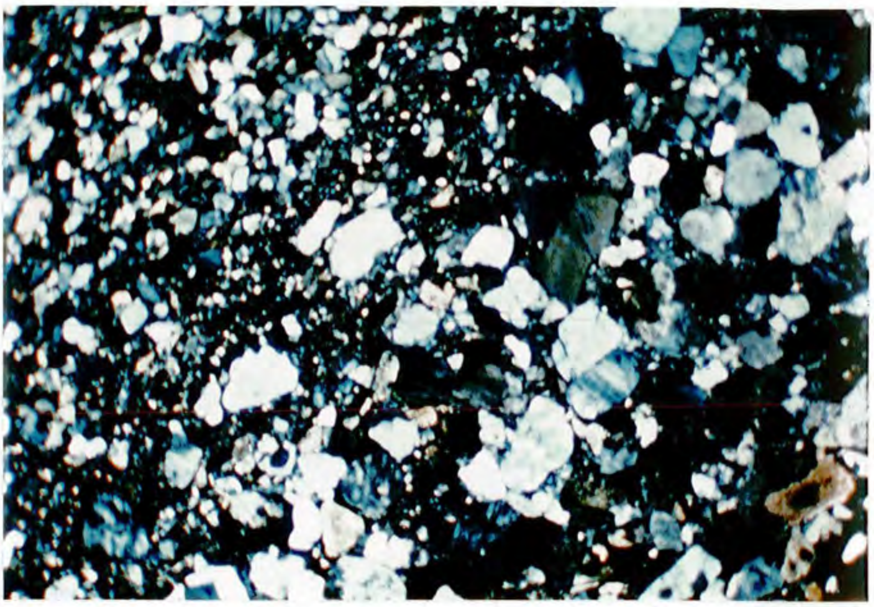
The abundance of rock fragments of the acid-igneous type clearly suggests the presence of a typical suite of granitic

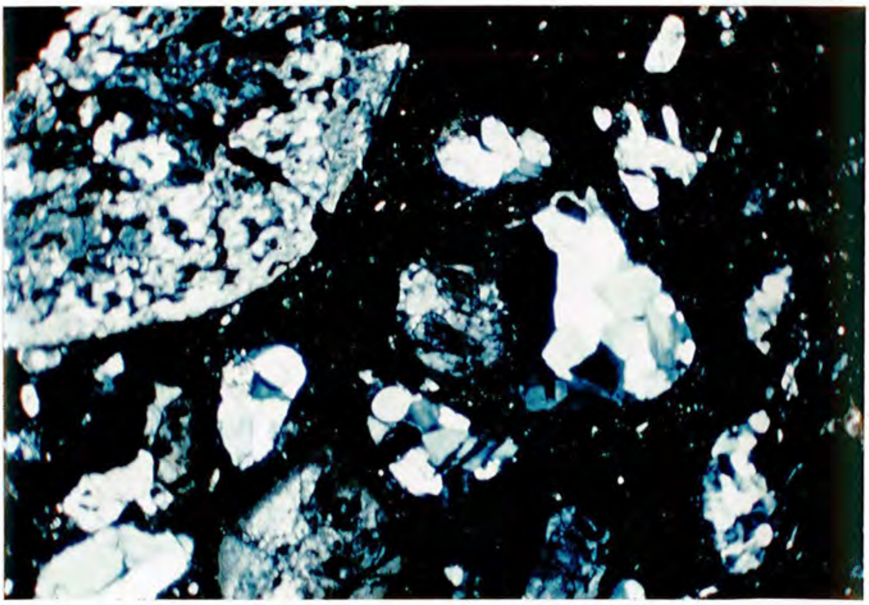
PLATE 94

Photomicrograph of an epidotic arkose or feldspathic litharenite cobble Sk761403-D with graded bedding, from the intraformational conglomerates at Geodh'a'Ghamhna. The presence of substantial epidote, strained quartz and microcline is reminiscent of typical Torridonian sediments as exposed today along Soay Sound, in the Sleat Peninsula and southwards on the island of Rhum. The acid igneous pebbles and cobbles may also derive from the latter (see text).

PLATE 95

Photomicrograph of a completely altered amygdaloidal plagioclase macroporphyritic basalt cobble Sk760901 from the Geodh'a'Ghamhna conglomerates. The feldspars are now severely corroded and replaced by aggregates of laumontite, stilbite, natrolite and sericitic mica; some of which may also occupy adjacent amygdales. Such assemblages appear to be the result of a reaction the reverse to that in zeolite filled cavities near the Intrusive Complex (see Chapter 10).





bodies at source while the microcline and strained polycrystalline aggregates of quartz are more suggestive of a gneissose terrain. In most instances therefore, a Lewisian basement is implied further strengthening the contention that the predominantly red 'grits' are Torridonian in age. The complete absence of fossiliferous shales or limestones within the pebble assemblage reinforces this view and consequently none are regarded as being of Mesozoic age. This has previously been discussed in Chapter 3.3ii).

The matrix of the conglomerates at Allt Mor and Geodh'a' Ghamhna and to a lesser extent those of the Cuillin border series, is a well-washed porous rock comprised almost entirely of quartz-alkali feldspar intergrowths and shattered feldspars derived from the same source as the granophyre pebbles themselves. It is therefore a very immature sediment resembling a sandstone with little 'free quartz' and only very rare accessories. Although obviously of igneous origin, this is a secondary phenomenon and the matrix and separate beds of this 'sandstone' are not the tuffaceous rock described by Harker (1904). Along the margins of the Cuillin Intrusion the conglomerates are much baked and indurated both by their proximity to the major mafic intrusions and the combined effects of numerous cone-sheets. The sandstone matrix is generally green in colour due mainly to the presence of much chloritic material and some beds contain a relatively high percentage of opaque argillaceous matter. In specimens collected within a metre or so of the lava-sediment/Ring

Eucrite contact (Sk751606, Sk751607) these shaley bands pass laterally into feldspathic sandstones. Sediments showing extreme thermal metamorphism are exposed above Glen Brittle cottage to the north of the latter localities, situated south-east of Loch an Fhir-Bhallaich and are possibly undergoing the first stages of rheomorphism.

C. Basic Igneous Types

As previously mentioned, pebbles of the lavas with which the conglomerates are interbedded are extremely rare. Only in the ferriginous red sandstone exposed at the top of the Allt Mor gorge are fragments and pebbles and boulders of lavas encountered. Invariably they are almost completely altered to chloritic and clay rich materials and retain few original petrographic features. An exception to this is the fine-grained basalt boulder measuring a couple of metres in diameter found in the waterfall at this locality. At Geodh'a' Ghamhna, to the south-east a few scattered amygdaloidal basalts are preserved but the main type appears to be a much altered, barely recognisable feldspar macroporphyritic basalt. The specimens recorded e.g. Sk760901 and Sk760908 are light brown to yellowish in handspecimen with numerous tabular 'feldspars' and amygdales.In thin section the 'feldspars' are found to consist of aggregates of stilbite, laumontite and natrolite with rarer heulandite and to retain the euhedral form of the presumably plagioclase feldspar (Plate 95). The phenocrysts, up to 0.5 centimetres long, comprise upwards of

10 percent of the rock and may possess a sub-parallel alignment. The groundmass is a fine-grained network of feldspar laths, minute subhedral magnetites and altered, amphibolitised clinopyroxene. A few olivine pseudomorphs may also be present.

7.3ii) Tuffaceous Interlava Horizons

Apart from the fine-grained bedded and frequently graded basic tuffs and ashes associated with the major agglomerate blankets (Chapter 3.2), rock derived from the weathering of tuffaceous rocks and the decomposition of air-borne basaltic glass and ash, appear to be widely distributed and are in most instances indistinguishable in the field from well developed boles e.g. Sk750302, Sk750305.

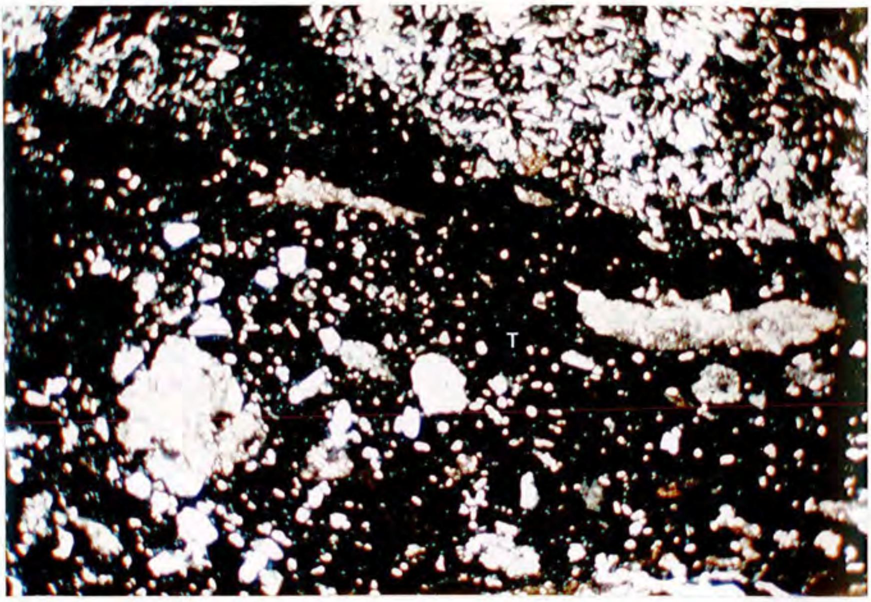
Crystal-vitric tuffs with subsidiary vitric-lithic material are however somewhat rare. The only recorded occurrence is found on the slopes of Cnoc Leathan in close association with an irregular surface belonging to a sub-aerially weathered olivine porphyritic basalt. This tuff (Specimen Sk750515) (Plate 96) is fine-grained and brownish-red in handspecimen with small, 4 millimetre or less, rounded and elongated basaltic and apparently fluxion textured glassy fragments of hawaiite. In thin section, olivine pseudomorphs, rare clinopyroxene and broken, clouded 0.1 to 0.5 millimetre plagioclases are incorporated in the groundmass which resembles a dark brown opaque-charged, flow banded glass and ash with an indication perhaps of some flattening and streaking out of the

PLATE 96

Photomicrograph of the banded crystal-vitric tuff Sk760515 from the Meacnaish Group above An Leac. The fluxion arrangement of tuff and crystals (T) is visibly deflected around the remnants of the underlying reddened olivine porphyritic basalt (B).

PLATE 97

Photomicrograph of a well developed bole (Stage F) Sk750302 showing only a dark amorphous mass of iron oxides with some mica and various clay minerals. Little can be done with such rocks microscopically.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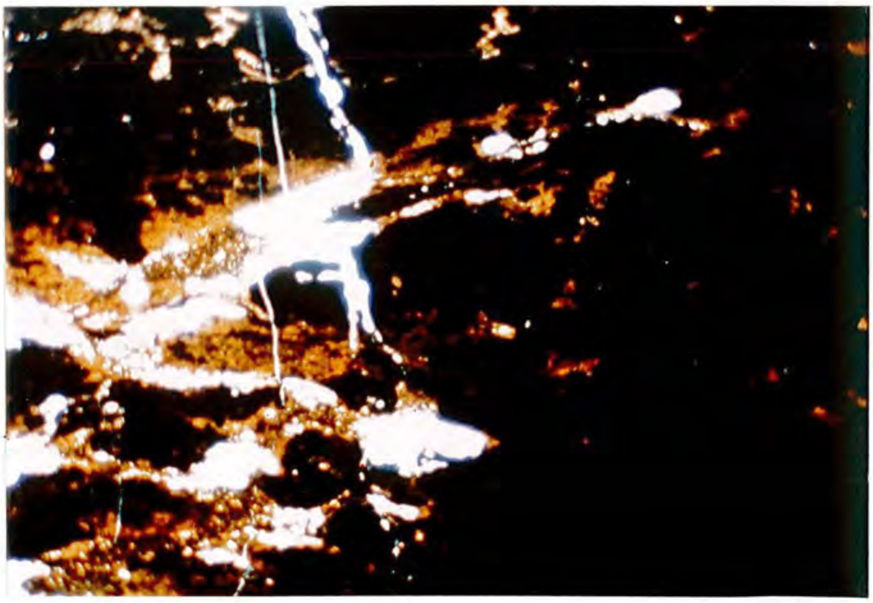
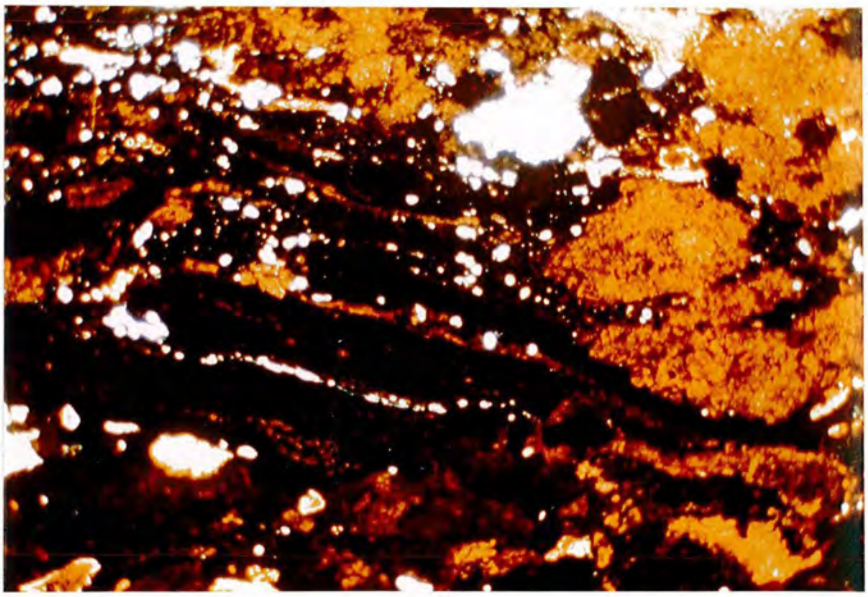


PLATE 98

Photomicrograph of the laminated iron-rich mudstones of Ben Scaalan Sk750308 showing aggregates of limonite, goethite and haematite and various clay minerals with some cellular (possibly plant debris) and banded material. Crystals of plagioclase (often sanidine) are infrequently found in these sediments possibly indicating that they are derived from tuffaceous rocks. The rock is generally traversed by irregular strings and patches of zeolites.



fragments lying roughly parallel to the contact with the reddened upper surface of the underlying basalt. The bed of tuff is only about 0.5 metres thick but it and its associated lava top can be traced for over 200 metres along the base of a small escarpment.

7.3iii) Boles and Fine-grained Sediments

The in situ formation of bole from fresh basic lavas by the contemporaneous subaerial weathering of the scoria associated with the lavas is best represented by the following sequence of specimens taken from various localities throughout the region. The finer-grained ironstones and orange-grey, ashy mudstones often found associated with the better developed boles are described also.

1. Boles

All grades of subaerial weathering are recorded, from unaltered basalt,hawaiite or mugearite to dense iron-rich clays derived perhaps partly from volcanic dust or from rain-wash transport of the lateritic soils themselves.

Stage A: Specimen Sk740601 Mugearite

In hand specimen this rock is distinctly pinkish-grey in colour but retains the obvious flow alighment of plagioclase microphenocrysts and the fissile jointing characteristic of the rock type. The colouration is developed to a thickness of about 1 metre but is irregular, often 'pinching and swelling' as the flow follows the irregular upper surface topography of the flow beneath. In thin section haematite staining and clouding of the plagioclase laths is the main feature, the majority of mafics remaining fresh (see Chapter 7).

Stage B: Specimen Sk760515 Olivine Porphyritic Basalt

A distinctly reddened flow top overlain by a flow-banded crystal vitric tuff with zenoliths of this flow within it. In thin section (Plate 96) it shows many of the features shown by Stage A but the haematite staining and clouding of the feldspars is more advanced and there is a lack of fresh mafic material. Olivines are always pseudomorphed firstly by iddingsite then amorphous haematite and magnetite. The overall basaltic texture is however retained.

Stage C: Specimen Sk750306 Aphyric Basalt

A much more obviously weathered flow top than the preceeding examples but it remains compact and amygdaloidal. Again in thin section it is mostly a haematitic staining which is responsible for the colouration. No fresh mafics are present, the feldspars are undergoing alteration to sericite and calcite, fibrous interstitial chlorite, amphibole and zeolites are common and the original texture of the rock is becoming less distinct. There are some geopetal structures present.

Stage D: Specimen Sk750820 Plagioclase Porphyritic Basalt

This is a stage, in which the matrix/groundmass is very fine-grained and now completely degraded to iron alumino-silicates and haematite, limonite and various finely divided clay minerals. No original texture is seen in the majority of the slices examined apart from the obvious porphyritic feldspars, themselves largely replaced by sericite and calcite.

Stage E: Specimen Sk750305 Aphyric Basalt

In handspecimen, aphyric basalt fragments from the flow below are enclosed in a deep red, compact bole showing little internal structure. In part this bole is 'transport' derived as it carries, in addition, scattered quartz grains. Darker 'bolar' fragments are also present in elongate masses in a crudely pisolitic, bright red bole veined by zeolites and haematite rich bands. Considerable isotropic, yellowish-clear matter is present, its origins and constitution uncertain. It may represent a form of 'gel' now lithified.

Stage F: Specimen Sk74 Bole 1/750310-B Unknown constitution

A completely non-structured rock with a complete lack of original minerals. Haematite, spinel and various alumino-silicates are all that remains.

Many boles in West-Central Skye have achieved this stage and most are hand, compact and lithified but occasionally a more clay-like rock is found. However, this state is interpreted mainly as a weathering effect as adjacent boles may grade from the clay and be baked in contact with the overlying flow.

Boles have been recognised as the subaerial products of weathering of basic igneous rocks since the days of Ami Boue in the early nineteenth century. They have a tendency to filter down into cracks within the underlying lavas, and to have formed both from in situ weathering and degradation of ashes and tuffs. The shaley-boles of North Talisker Bay are presumed to have formed by water transport (probably rainfall) of the finer clay material into pockets on the scoriaceous lava surfaces. At Talisker all variations in colour from brown to bright red are present and small-scale folding, grading and loading are sedimentary structures observed infrequently. Little can be said about the petrography of such rocks e.g. Specimen Sk750302 as a thin section generally only shows an amorphous mass of ferriginous clay minerals (Plate 97).

2. Fine-grained Sediments

Often associated with localities where boles are well developed, extremely fine-grained, often carbonaceous yellow-grey to orange mudstones and indurated ironstones showing close-set laminations and contorted bedding are developed also. They appear to be most prominent within the Tusdale and Arnaval lava groups in the Talisker and Ben Scaalan areas (Chapter 3.4).

In thin sections (e.g. Specimens Sk750308 Plate 98, 750310-A, 760603, 760604) they consist almost wholly of limonite and goethite with only subsidiary haematite in small grains. Veins and cavities of zeolites commonly transect these sediments and occasionally broken sanidine crystals, devitrified basaltic and trachybasalt fragments may be present suggesting a derivation from basaltic and trachytic tuffs not now exposed. Rounded, spheroidal structures, and nodules are common but their origin is thought to be diagenetic rather than primary. The ironstones are almost completely amorphous and fine-grained and occasionally contain obscure, cellular plant debris.

Laminated grey mudstones are often associated with these yellow sediments and apart from containing more compact goethite intermixed with clay minerals and haematite appear essentially similar. In a number of cases they have a tuffaceous aspect and are extensively leached. The harder, indurated ironstone bands possibly represent true laterite horizons or iron pans due to the passage both in and out of the surrounding sediments of rainwater, and groundwaters even after burial, containing both Fe and Al oxides. Upon drying, these horizons would form beds of irreversible hardness, as indeed appears to have happened here.

CHAPTER 8

THE MINERALOGY OF THE TERTIARY LAVAS

In this chapter, the results of some 180 probe analyses of the major phases of the Skye lavas and one differentiated 'andesite' sill are presented and where possible compared with those of volcanic rocks of similar and contrasted setting. The principal minerals are dealt with consecutively.

8.1 Olivines

Olivine is present to varying degrees in nearly all the porphyritic lava types as classified in Chapters 7 and 9. In the few more transitional, near aphyric lavas they are apparently lacking as a major phase and there appears to be no petrographic evidence for their having been present and subsequently being reacted-out in these rocks. Microphenocrystic or minute subhedral plates of colourless to brown clinopyroxene apparently take the place of phenocrystic olivine in some of these rocks.

As phenocrysts, the olivines are almost invariably normally-zoned, this being detected initially by a decrease in birefringence from core to margin, although in some instances the effect is limited. Table 7 summarises the variation in terms of forsterite content.

TABLE 7

Summary of microprobe analyses of olivines from the Tertiary lavas of west central Skye.

Rock Type	Division	Olivine Composition	Specimen and Details
1. Basalt	Ol + sp	Fo_{89-90}	Sk751212 skeletal unzoned phenocrysts
		Fo_{83-88}	Sk751212 " " Sk7616 euhedral zoned phenocrysts
		Fo_{81-90}	Sk751212/Sk7616/Sk740607 Range
	Ol	Fo_{81-87}	Sk750602 Phenocryst
	Ol + Pl	Fo_{68-66}	Sk740801 Phenocryst
		Fo_{60}	" Groundmass
		$Fo_{85-83-77}$	Sk751001 Euhedral zoned phenocryst
		Fo_{67}	" Groundmass
	Ol. Tholeiite	$Fo_{81-67-66}$	Sk750907 Zoned phenocryst
		Fo_{64}	Sk750808 Groundmass
		Fo_{91-55}	Range by Esson et al. 1975 zoned phenocryst
2. Hawaiite	Ol + Pl + Mt	Fo_{66-58}	Sk740301 Euhedral zoned phenocryst
3. Mugearite	Ol + Pl ± Mt	Fo_{52-47}	Sk740701 Phenocryst
	Coarse Ol+Pl+Mt	Fo_{59-57}	Sk740810 Groundmass?
	Ol+Mt+Pl	Fo_{57-56}	Sk740905 Phenocryst
		Fo_{48-42}	Sk741101 "
	Ol+Mt±Pl	Fo_{36}	Sk751801 Phenocryst?
4. Benmoreite		Fo_{30-32}	Sk77010 Groundmass?
5. Alkali Trachyte		Fo_{21-23}	Sk7605 Groundmass?

From a cursory glance at this table and figure 20 it may be noted that the rock types used, may in most instances be characterised by certain olivine compositions or compositional ranges in which considerable overlap may nevertheless be present.

8.1.i) Basaltic Olivines

The range of compositions for the basaltic olivines is the largest noted and appears to reflect the surprising variety of petrographically distinguishable types present within the mildly alkaline series. Not surprisingly, for such a relatively straight-forward mineral, the range is in general agreement with that of olivines from various other volcanic sequences.

An important feature of the phenocrystic olivines of the olivine + spinel porphyritic basalts is their high average forsterite content of Fo_{87} and the significantly high levels of NiO (0.3 to 0.34 wt.%). In this respect they are closely comparable to the picritic basalts of the Deccan Series (Kristamurthy and Cox 1977) and also the olivines of igneous cumulates e.g. Rhum. These olivines, as distinct from the groundmass generation which is usually less Fo-rich, eg. Fo_{62} (Thompson 1974 a) may also contain up to 0.03 wt.% Cr_2O_3 in the analysis. Such low levels, barely above the detection limits are nevertheless significant and are probably explained by the presence of minute quantities of exsolved chrome-spinel distinct from the translucent spinel inclusions and microphenocrysts. The most magnesian olivines eg. Fo_{90} in specimen Sk751212 from An Cruachan are high temperature skeletal forms suspended in a basaltic liquid. They resemble the compositions of olivine from peridotites and dunite nodules (Ross et al. 1954, Kuno and Aoki 1970) but are quite different in form. The high modal percentage of olivine here suggests accumulation subsequent to crystallisation and their form suggests extremely rapid growth with no observed crystal-liquid reaction or marked zonation. The magnesian olivines in Sk751212 are even more magnesium rich than those of the magnesium-rich alkali basalt used in experimental studies by Thompson (1974) and the possibility of the glomeroporphyritic aggregates of these olivines being xenocrystic and texturally distinct from the other magnesian olivines should not be overlooked.

The olivines of the olivine porphyritic lavas, contrasted with those of the olivine + spinel porphyritic basalts are distinctly less magnesium rich and usually show marked compositional zoning. A marked zoning is also found within the olivines of the olivine + plagioclase basalts which tend to be more Fe-rich and slightly more 'evolved' than the other basaltic types. In many cases although olivine can be shown to have been the first crystallising phase, some degree of overlapping crystallisation with the plagioclase feldspar is present.

The low-alkali, high-calcium olivine tholeiite of Talisker contains both olivine and plagioclase feldspar phenocrysts. The olivines in this flow are the most strongly zoned basaltic olivines found, ranging from cores of Fo_{91} to margins of Fo_{55} (Esson et al. 1975) and have characteristic minor element contents which frequently distinguish them from those of the alkalic series eg. figure 20 E & F. The environment of crystallisation as well as the chemistry of the flow is responsible for these features.

Thompson (1974) reports olivines of Fo_{67} zoned to Fo_{49} from a trnasitional basalt (Fairey Bridge Magma Type of Mattey et al. 1977). No olivines were detected and subsequently probed in the west-central Skye examples that appear to be broadly similar types.

8.1.ii) Intermediate Lava Olivines

In general terms the olivines of the intermediate alkali lavas (hawaiite to benmoreite and trachyte) appear to be slightly more magnesium-rich than those in the corresponding rock-types from other alkalic provinces such as Aden (Cox et al. 1970), Dunedin (Price and Chappell 1975) and Otago (Muir and Tilley 1961). This is likely to be related to the existence of co-precipitating clinopyroxene in the latter and not the former. Titaniferous magnetite is as important as or even potentially more important than the olivine microphenocrysts in both.

The few analyses made of the microphenocrystic olivines from these rocks in Skye indicates that both hawaiites and mugearites have a wide range with considerable overlap with the groundmass olivine compositions of the basaltic rocks.

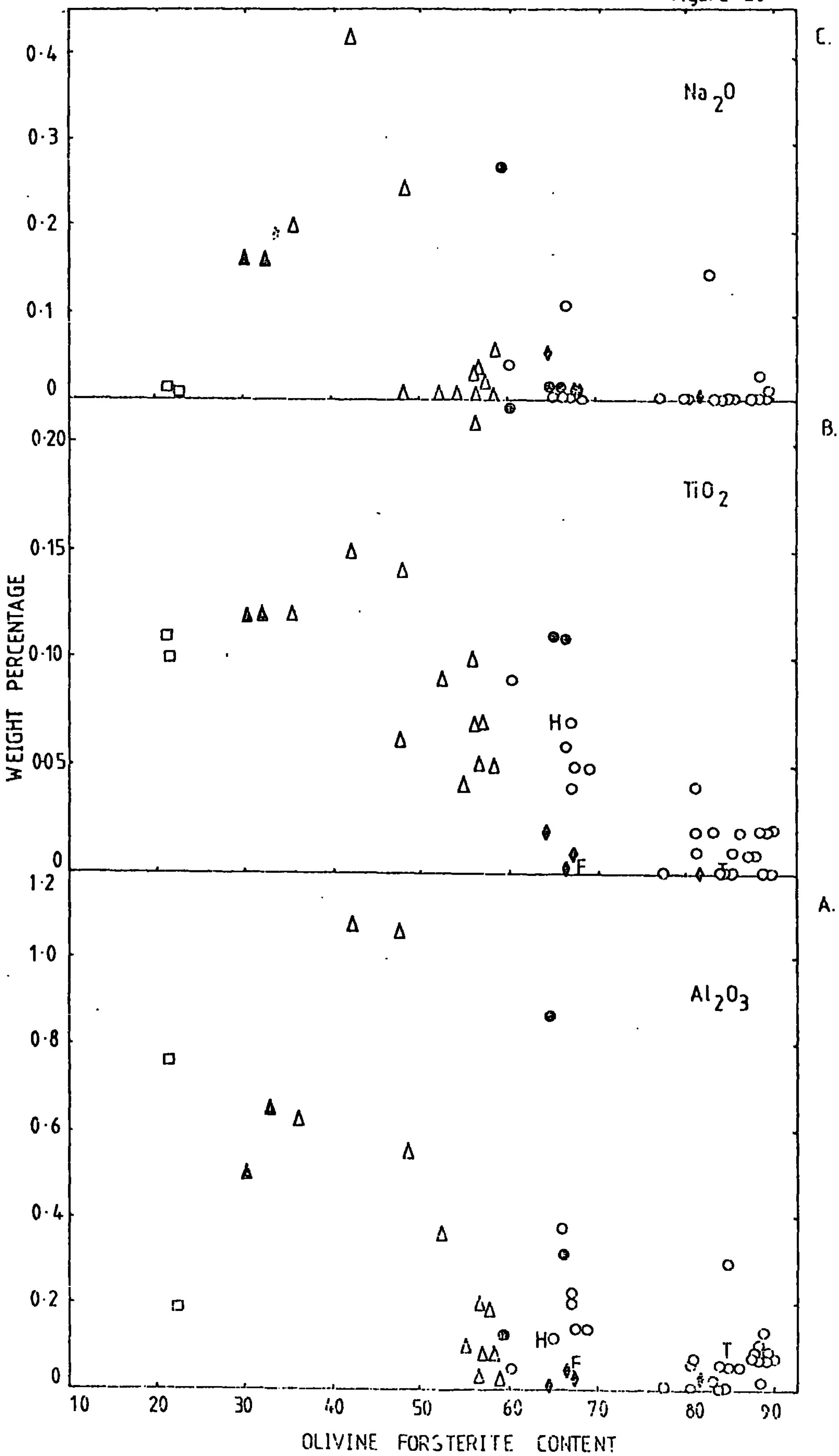
As the Mg/Fe+Mg ratio undergoes a continuous decrease in the series from basalt to mugearite and trachyte, this is necessarily reflected in the compositions of the olivines. Although progressively relegated to a more minor role as scattered small microphenocrysts in the more evolved rocks the olivines conform as expected. The most Fe-rich olivines are found as small, yellow,weakly pleochroic crystals, possibly microphenocrysts, within the alkali-trachyte of Cnoc Scarall and have compositions of Fo_{22-23}. Thus the olivines in the Skye lavas show a complete series from forsterite through crysolite, hyalosiderite and hortonolite to ferrohortonolite.

FIGURE 20

Minor element variation in olivines. The elements Al_2O_3, TiO_2, Na_2O, MnO, NiO and CaO plotted against Forsterite content (Mg x 100/Mg + Fe), for the Skye lavas.

O	Basalt (≡ S.M.L.S)	H	Basaltic Hornfels
●	Hawaiite	♦	Low-alkali olivine tholeiite
Δ	Mugearite		
▲	Benmoreite		
□	Trachyte		
D	Picritic basalts from the Deccan Traps (Krishnamurthy and Cox, 1977)		
T	Skye data (Thompson, 1974)		
F	Fairey Bridge magma type or Transitional basalt (Mattey et al., 1977)		
----1.	Skye data based on the data of Simkin and Smith (1970)		

Figure 20


C.
Na$_2$O
B.
TiO$_2$
A.
Al$_2$O$_3$
WEIGHT PERCENTAGE
OLIVINE FORSTERITE CONTENT
0·4
0·3
0·2
0·1
0
0·20
0·15
0·10
0·05
0
1·2
1·0
0·8
0·6
0·4
0·2
0
10
20
30
40
50
60
70
80
90
H
F
T

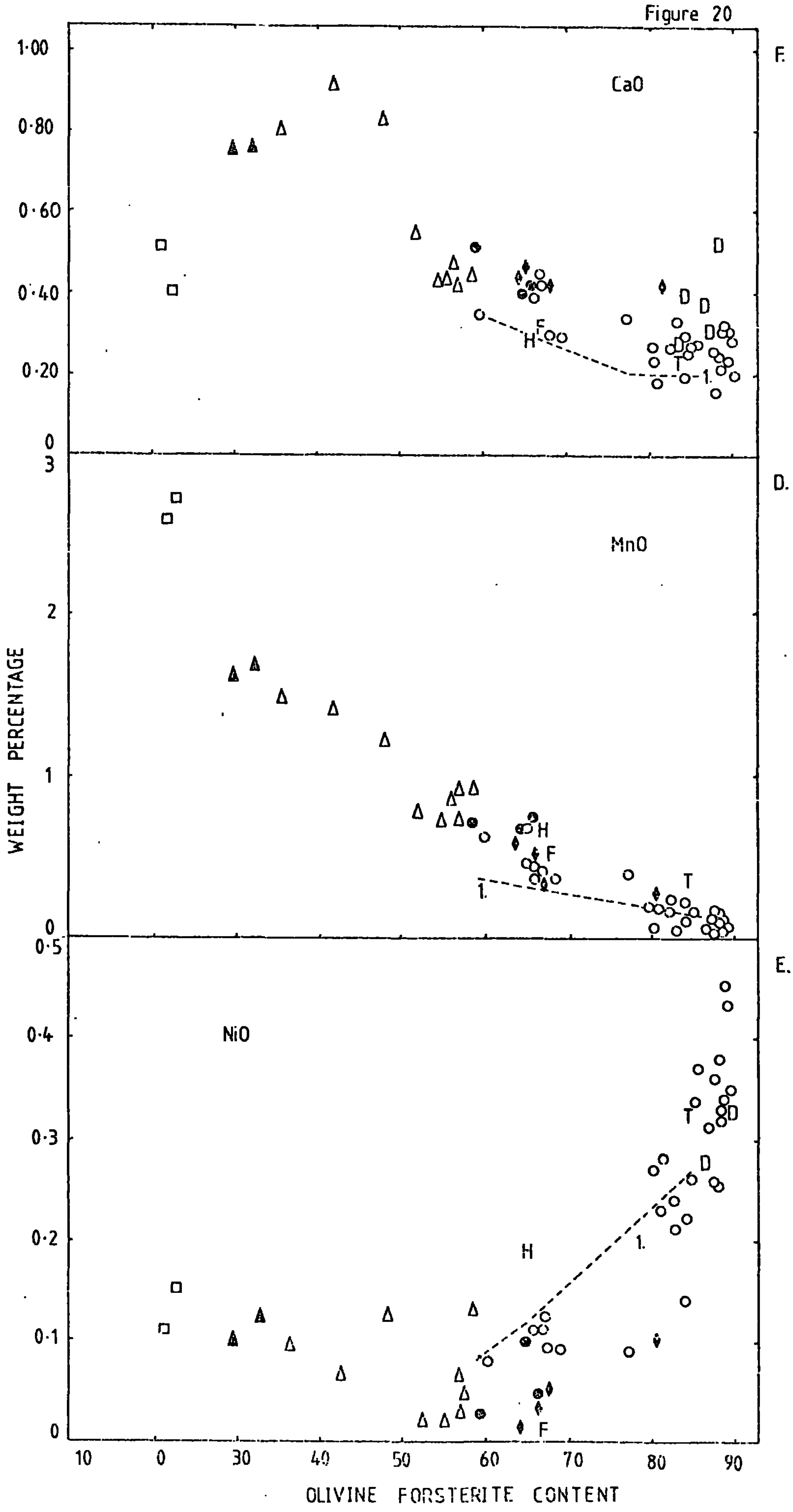


Figure 20
CaO
F.
MnO
D.
NiO
E.
WEIGHT PERCENTAGE
1·00
0·80
0·60
0·40
0·20
0
3
2
1
0
0·5
0·4
0·3
0·2
0·1
0
10
0
30
40
50
60
70
80
90
OLIVINE FORSTERITE CONTENT

8.1.iii) Minor Element Variation within the Olivine Series

In normal basaltic rocks and their evolved derivatives the elements Al_2O_3, TiO_2, Na_2O, MgO, NiO and CaO are considered to be present only to small degrees within the olivine structure. The behaviour of some of these minor constituents with differentiation was investigated in part by Simkin and Smith (1970) as part of a study of the olivines of igneous rocks from different crystallisation environments and their findings for some Skye rocks are compared throughout this section. Trace data on volcanic olivines is of variable quality throughout the available geological literature and is mostly confined to basaltic rocks where it is virtually identical to the Skye lava data presented here and by Donaldson (1977).

8.1.iii)A. Al_2O_3

Aluminium variation within the olivines is highly erratic but there is a suggestion of a positive correlation with decreasing forsterite content from basalt to trachyte. The limit of detection lies at about 0.2 wt.% and most of the analyses of basaltic olivines fall below it and much of the scatter of the data is undoubtedly due to experimental error and contamination. That contamination may have been extremely important in producing much of the observed variation is shown by the analyses of olivines from basalts in which feldspar is a co-existing phenocryst phase. However, the more evolved rocks of the series do contain significantly more Al_2O_3 than the basalts suggesting the feature to be a real one rather than derived. For a given forsterite content the low-alkali tholeiitic olivines appear to have levels of Al_2O_3 below the equivalent olivine + plagioclase porphyritic alkalic basalts but they are only just within the detection limits (figure 20A).

8.1.iii) <u>TiO_2</u>

Titanium shows a definite and pronounced positive correlation with falling forsterite content and there is a suggestion that it falls or levels off from mugearite to trachyte. The detection limit and experimental error lie in the region of 0.02 and $\pm$ 0.01 respectively. This feature is reflected in other forsterite to fayalite analyses (cf. Deer, Howie and Zussman 1966 Table 1, page 4) and is comparable to the behaviour of TiO_2 in the whole rock analyses. Consequently, the trend is undoubtedly influenced by contamination to a small extent as well as by exsolved magnetite. The hawaiitic olivines are exceptionally high in TiO_2 and on average lie above the trend. Apart from the dominance of titaniferous magnetite microphenocrysts in these rocks it is difficult to explain why this should be so. The olivines from the low-alkali tholeiite show very low levels of TiO_2 compared to those of the alkalic basalts and lie just on the limits of detection if experimental errors are taken into account (figure 20B).

8.1.iii)C Na_2O

As is seen in figure 20C the variation in Na_2O is highly erratic. Most of the analyses lie within the detection limits of around 0.02% and indeed many apparently have no Na_2O at all. Contamination due to beam wandering and other spurious errors is taken to account for the wide scatter observed in figure 20c. However an increase with differentiation may be present, decreasing again towards trachyte. Olivines from the alkalic series basalts and the low-alkali tholeiite are indistinguishable. Considerable error, up to $\pm$ 0.25 wt.% may be expected in probe analyses of Na_2O due to problems of easy volatilisation etc., and so the variation of figure 20c is patternless in all probability.

8.1.iii)D MnO

A positively correlated linear relationship between MnO and falling forsterite content exists; MnO increasing with differentiation (figure 20D). The gradient is steeper than that reported for the Skye lavas by Simkin and Smith and appears to steepen between the olivines of the mugearites and the alkali-trachyte of Cnoc Scarall. A continuous increase in MnO is recorded from other provinces and the analyses of the mugearites and trachytes from the alkalic series of Skye fall on the established trend within the ternary diagram of forsterite-fayalite-tephroite of rocks from the Qoroq Centre of the Igaliko Complex in Southern Greenland (figure 21) (Stephenson 1973). Thus as well as Fe/Mg increasing the ratio Mn/Fe also increases with differentiation and also within the analyses of zoned olivines from core to margin as expected. The olivines of the low-alkali tholeiite cannot be distinguished from the main alkalic basalts. The MnO results carry a slight experimental error of around $\pm$ 0.05 wt.% but at the levels present in the analysed olivines this is negligible and the variation is recorded with a fair degree of confidence.

8.1.iii)E NiO

With increasing Fe/Mg ratio, the NiO content of the olivines for the Skye alkalic lavas falls away rapidly from 0.45 wt.% in the most magnesian olivines to 0.15 wt.% in the olivine + plagioclase porphyritic basalts. This

FIGURE 21

Olivines from the 'Alkali' trachyte of Cnoc Scarall plotted in the system Fayalite (Fe) - Forsterite (Mg) - Tephroite (Mn) compared with those of some syenites from East Greenland (after Stephenson, 1973).

□ Alkali trachyte Skye lava

SY Syenite

RSY Recrystallised syenite

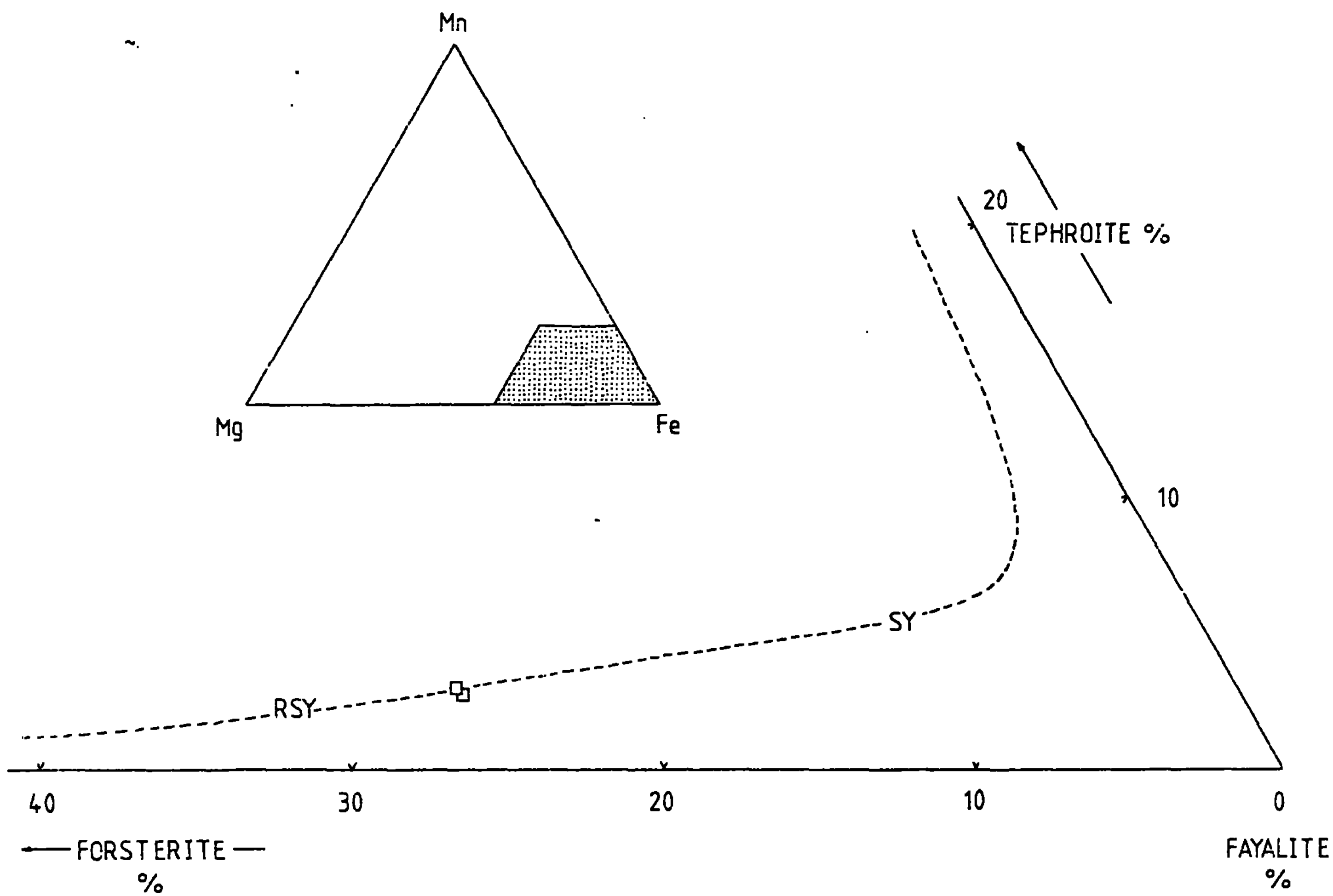

Mn
Mg
Fe
20
TEPHROITE %
10
SY
RSY
40
30
20
10
0
FORSTERITE
%
FAYALITE
%

Figure 21.

general feature of decreasing NiO content has long been a recognised feature of volcanic olivines. Within the magnesian olivines, NiO shows considerable variation whereas MnO is much more restricted. Both, according to Simkin and Smith are dominantly related to major element fractionation. From around Fo_{50} (mugearites) to Fo_{20} (trachyte) there appears to be a slight increase in NiO but since the error on the results is in the order of $\pm$ 0.05 to 0.08 wt.% this cannot be confirmed; the analyses lying near the limits of detection by the micro-probe. However, the constancy of the increase may indicate it to be a real feature. Due to loss of major phenocrystic olivines in these rocks and the fractionation of other phases which would tend to discriminate against nickel, namely alkali feldspar, it might be expected to marginally increase in the olivines of the differentiated rocks, given that little or no non-silicates, in particular sulphides, were present to any degree.

The spread of analyses (figure 20E) agrees closely with that from Simkin and Smith and comparable olivine + spinel porphyritic basalts from Deccan. The low-alkali tholeiite, in reflection of its depletion in many trace elements, shows characteristically low NiO contents in its olivines, which are thus easily distinguished from the main alkalic lava series.

8.1.iii)F CaO

The variation of CaO with increasing Fe/Mg ratio follows a somewhat unusual pattern (figure 20F). It correlates positively with increasing fayalite content in the lavas from basalt to mugearite but subsequently drops back to relatively low levels in the trachyte. The basaltic olivines show a considerable range from about 0.2 to 0.35 wt.% but generally appear more CaO-rich than those reported by Simkin and Smith also for Skye. According to these authors CaO shows a very clear dependence upon the pressure, temperature and cooling rate ie. the crystallisation environment. In consequence a comparison of olivine compositions from volcanic, hypabyssal and plutonic rocks is not valid. However, the olivines from hypabyssal and plutonic rocks from the Tertiary Igneous Province (eg. Dykes from Northern Ireland, Akiman 1971; Igneous Cumulates on Rhum, Brown 1956, McClurg (pers. comm.) etc.) show either comparable or wider ranges of CaO. Other volcanic rocks show equally variable amounts. Ridley (1973) reports a few olivine analyses from basalts from Eigg with a range of 0.35 to 0.4 wt.% CaO which is notably higher than the Skye lavas but broadly comparable to the average Deccan basalt (Kristamurthy and Cox, 1977). The Skye analyses are similar to some from Madiera (Hughes and Brown 1972). The olivines of slowly cooled lavas e.g. lava lakes, and plutonic rocks are relatively depleted in CaO as diffusion takes place with time. Thus one would expect the low-alkali olivine tholeiite from Talisker to contain olivines depleted in CaO relative to the main alkali lava series. Surprisingly, the reverse is found with the olivines being more CaO-rich compared to equivalent olivines of the alkalic lavas. In this case, the peculiar chemistry of the flow, despite the unequivocable field and petrographic evidence for a slow cooling environment may be the dominant factor ie. the high calcium content of the rock is due to and reflected by the high CaO values in the phenocryst phases vis. olivine (0.4 to 0.45 wt.%) and plagioclase feldspar (compositions to An_{90}).

Trace data for more intermediate lavas from other areas is sparse but broadly comparable e.g. hawaiites from Rhum (Ridley 1973).

The sudden drop in CaO content from mugearite through benmoreite to trachyte may possibly be due to the CaO being preferentially removed from the liquid by apatite, which is fast becoming a major phenocryst phase in these rocks.

8.2. Pyroxenes

Groundmass clinopyroxene is a ubiquitous component of all the mildly alkaline lavas, the transitional and tholeiitic lavas and the tholeiitic minor intrusions of west-central Skye. It may also form as a microphenocryst phase in some of the more transitional rocks. Associated with equally ubiquitous groundmass plagioclase feldspar and iron-titanium oxides, it ranges from beautifully ophitic or poikilitic plates in the majority of basaltic rocks, especially where there is ample evidence of slow cooling eg. the Talisker tholeiite, to intergranular aggregates and only scattered sub-ophitic platelettes in the intermediate rocks. Mostly it appears to be a late crystallising phase. However, its texture in some basic lavas suggests that although it mostly follows plagioclase in order of crystallisation it may begin as a microphenocryst with important implications for the petrogenesis of the rocks in question. In the more evolved mugearites and trachytes clinopyroxene is relegated to a very minor phase in the groundmass and is modally subordinate to almost all other minerals. It occurs as colourless-yellowish granules, some of which may have well-formed crystal faces. In the alkali basalts it is usually a mauve to purplish-pink weakly pleochroic titanaugite but is either colourless or pale-brown in the more transitional and tholeiitic rocks.

8.2.i) Major Element Variation

Although the relative positions of pyroxene analyses in the traditional An-Fs-Hd-Di pyroxene quadrilateral are much distorted by the presence of significant Al_2O_3, TiO_2, MnO and Na_2O in the analyses, it remains an invaluable diagram for comparative purposes. The trends developed are internationally known and depend largely upon the SiO_2 content of the magma and the physical conditions under which it crystallised, particularly pH_2O and fO_2.

8.2.i)A Basalts

Figure 22 summarises the range of analyses of the Skye lava clinopyroxenes - both groundmass and phenocrysts. The groundmass trend for the alkalic series is in broad agreement with that of Muir and Tilley (1961). The basaltic end of the trend has a wider scatter but the basaltic analyses lie within the more calcic-augite field towards salite and diopside. The analyses plot with a relatively flat to slightly calcium enriched pattern, falling between the alkaline trends of the Shonkin Sag soda-syenite laccolith (Nash and Wilkinson 1970) and the most recently published data on the

FIGURE 22

Pyroxenes from west-central Skye plotted in the sub-calcic quadrilateral compared with previously established trends and analyses from other sources.

Symbols for basalts, hawaiites, mugearites and the alkali trachyte of Cnoc Scarall are as in figure 20.

In addition:

■	Sleadale Intermediate trachyte
+	Transitional Suite basalt
P	Phenocrysts in olivine + plagioclase + clinopyroxene porphyritic basalt of An Sguman
S	Phenocrysts in andesitic sill
x	Data for Skye from Muir and Tilley (1962)
Bm	Benmoreite from Easter Island (Baker et al., 1974)
Z	Orthopyroxene xenocrysts in the composite hawaiite of Dun Ard an t-Sabhail

Trends:

1. Dippin Sill - Arran (Gibb and Henderson, 1978)
2. Shiant Isles (Gibb, 1973)
3. Skaergaard
4. Shonkin Sag soda-trachyte sill (Nash and Wilkinson, 1970)
5. Small Isles (Ridley, 1973)

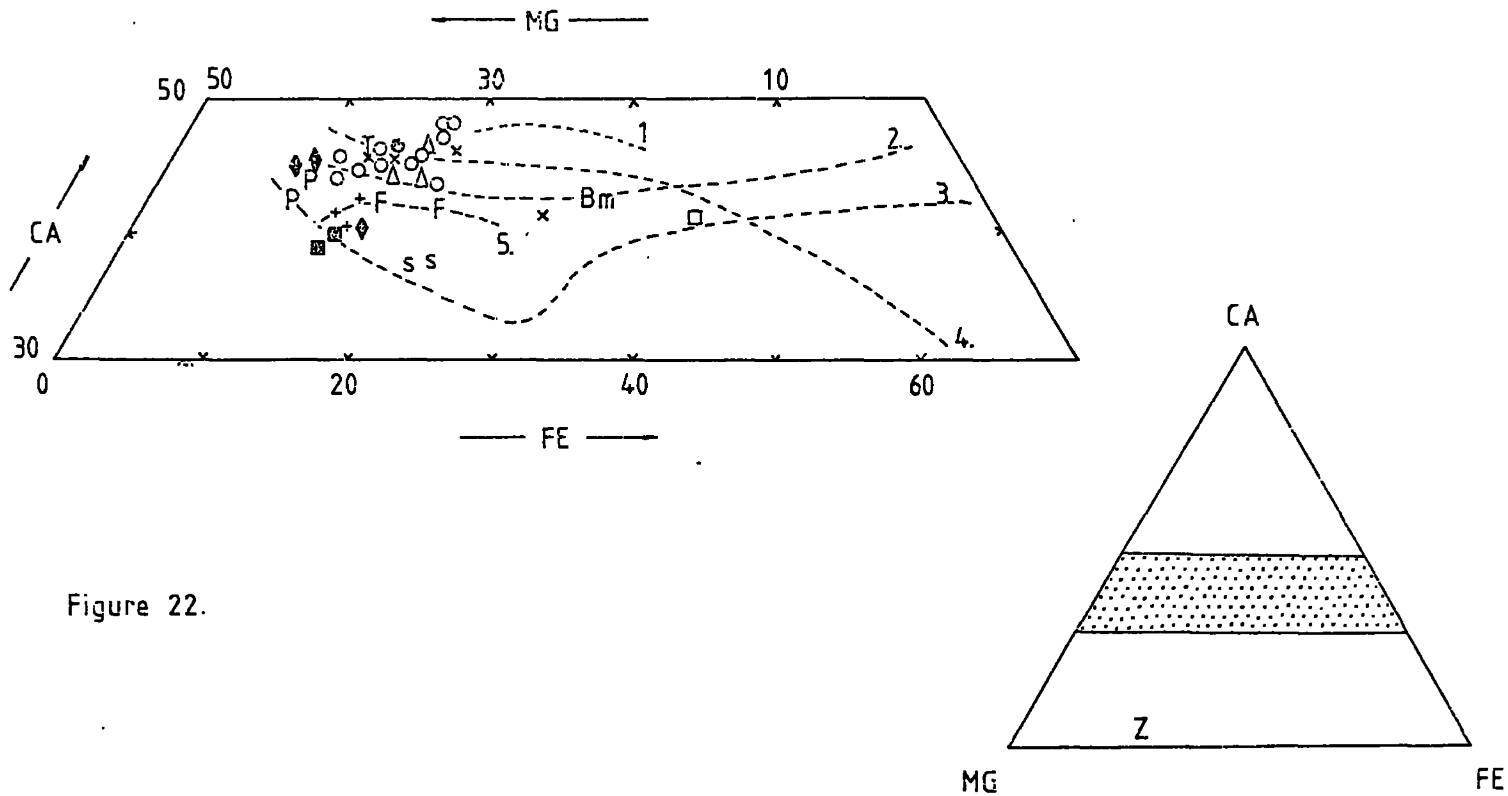


Figure 22.

differentiated alkali dolerite-picrite-teschenite sill of the Shiant Isles (Gibb 1973) and the Dippin Sill of Arran (Gibb and Henderson 1978). The basalts are therefore definitely alkaline in character. The analyses of the clinopyroxene in the picritic basalt Sk751212 which contains a high modal percentage of highly magnesian (Fo_{87}-Fo_{90}) olivines, appear anomalous in having abnormally high Ca and Fe contents relative to the less basic basalts. If the majority of these olivines were 'cumulus' or 'xenocrystic' into a normal olivine basalt this might explain the apparent anomaly always assuming that the conventional trends are strictly adhered to. Short trends such as this are typical of alkaline basaltic rocks whereas longer trends seem to be more common in tholeiitic sequences.

Distinct from the clinopyroxenes of the alkali-olivine basalts are those of the Talisker low-alkali, high-calcium olivine tholeiite. Core analyses reveal only very slight variation and fall towards the diopsidic-augite field boundary while the margins of some of the large poikilitic plates analysed by Esson et al. (1975) are richer in Fe and notably poorer in Ca. Their trend therefore falls between the clinopyroxene trends of the alkali basalts and the Skaergaard 'tholeiite' layered intrusion.

Clinopyroxene phenocrysts and microphenocrysts (including the idiomorphic groundmass/microphenocrysts within the transitional lavas and a possible sill which are often characterised by crude hour-glass-twinning) appear to be much less calcic than the alkali basalt groundmass types and trend towards the Fe apex along a line roughly equivalent to that of the Skaergaard Intrusion. Those of the transitional rocks plot between the Skaergaard and alkali basalt trends.

8.2.i)B. Intermediates

The clinopyroxenes of the hawaiitic and mugearitic lavas from Skye are generally more iron-rich than those of the alkali basalts but considerable overlap is recorded at the basalt-hawaiite transition. The data shown is supplemented by analyses from Muir and Tilley (1961) and reveals that the overall Skye trend is flat-lying with perhaps just a slight increase in Ca, but eventually moves away from Ca across the augite field into the ferro-augite field in the most differentiated rocks examined. The most Fe-rich clinopyroxene of the Cnoc Scarall alkali - trachyte - is a greenish-yellow faintly pleochroic variety. The dominant substitution is however of Mg by Fe despite the drop in Ca in the latter stages.

Slightly zoned titanaugites in specimens Sk740607 and Sk7706 show trends from core to margin, in the same directions ie. towards iron-enrichment coupled to very slight drops in relative Ca.

A comparison with the clinopyroxenes of the Small Isles transitional basalts as presented by Ridley (1973) reveals that those of the Small Isles are distinctly less calcic than those from the Skye alkali-basalts, falling in the region between the latter and the low-alkali olivine tholeiite in figure 22. On Skye, few analyses fall in this field. From west-central Skye the micro-phenocrysts/idiomorphic groundmass pyroxenes of the rare transitional basalts plot here as do the analyses of the groundmass pyroxenes from the Transitional basalt Sk971 of Thompson et al. (1972) and Thompson (1974). This rock has more recently been asigned to the transitional-tholeiitic or Fairey Bridge Magma Type by Mattey et al. (1977). Thus in terms of the En-Fs-Hd-Di quadrilateral, three distinct trends for the Skye lavas and the few analysed intrusions are visible: a similar but not identical conclusion to the elemental geochemistry of the rocks as a whole (see Chapter 9).

8.2.ii) Minor Element Variation

In this category are considered all the elements in

FIGURE 23

Minor element variation within west-central Skye pyroxenes plotted against the Thornton-Tuttle Differentiation Index of the host rock. Elements TiO_2, Al_2O_3, Na_2O, MnO and Cr_2O_3.

Symbols as used in figure 22.

In addition:

I Range from orthopyroxenes in Dun Ard an t-Sabhail composite hawaiite

Trends:
1. Alkalic Suite
2. Tholeiitic and Transitional Suites (plus subalkalic trachyte)

Figure 23

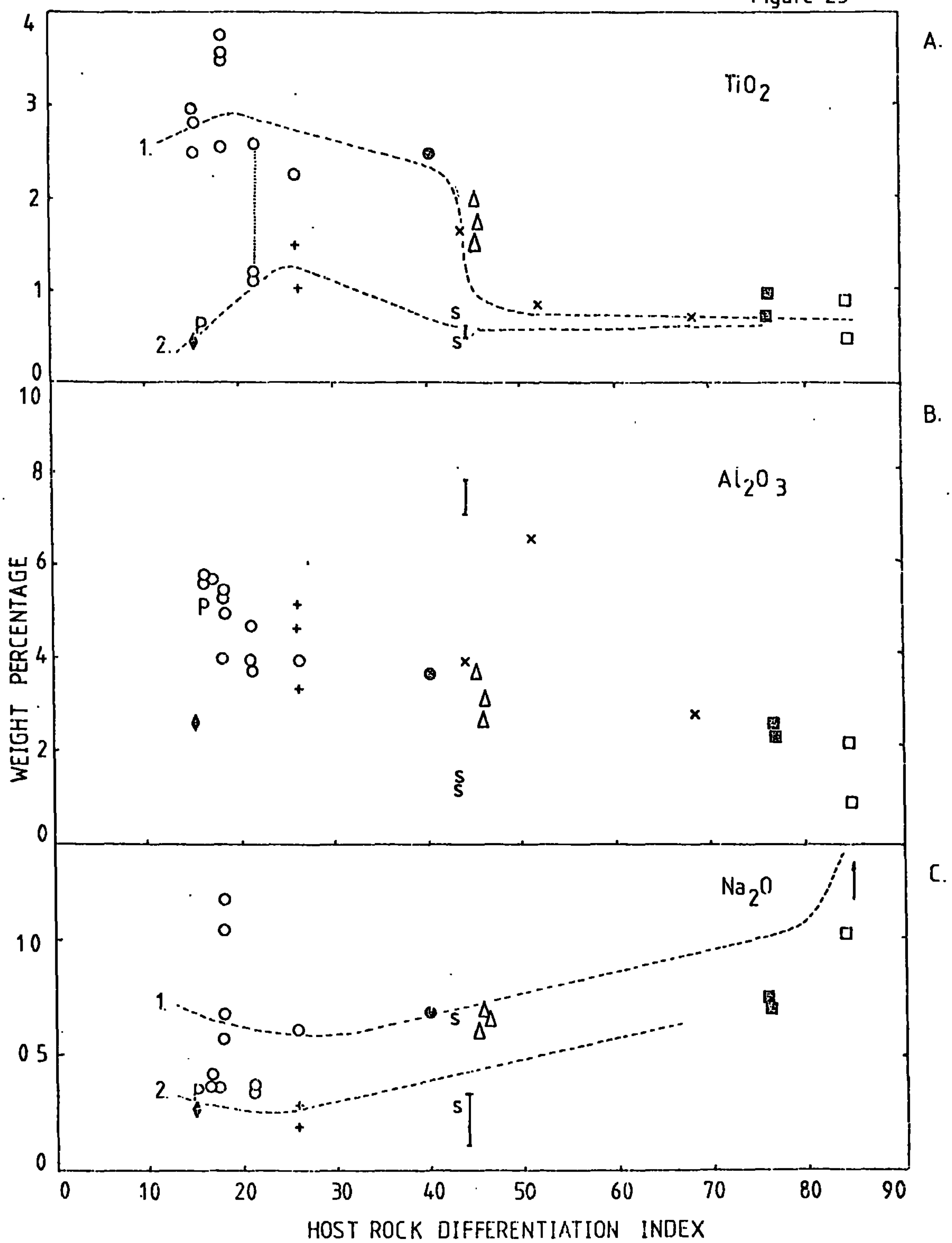

A.
TiO2
B.
Al2O3
C.
Na2O
WEIGHT PERCENTAGE
HOST ROCK DIFFERENTIATION INDEX
0
10
20
30
40
50
60
70
80
90
1.
2.

Figure 23

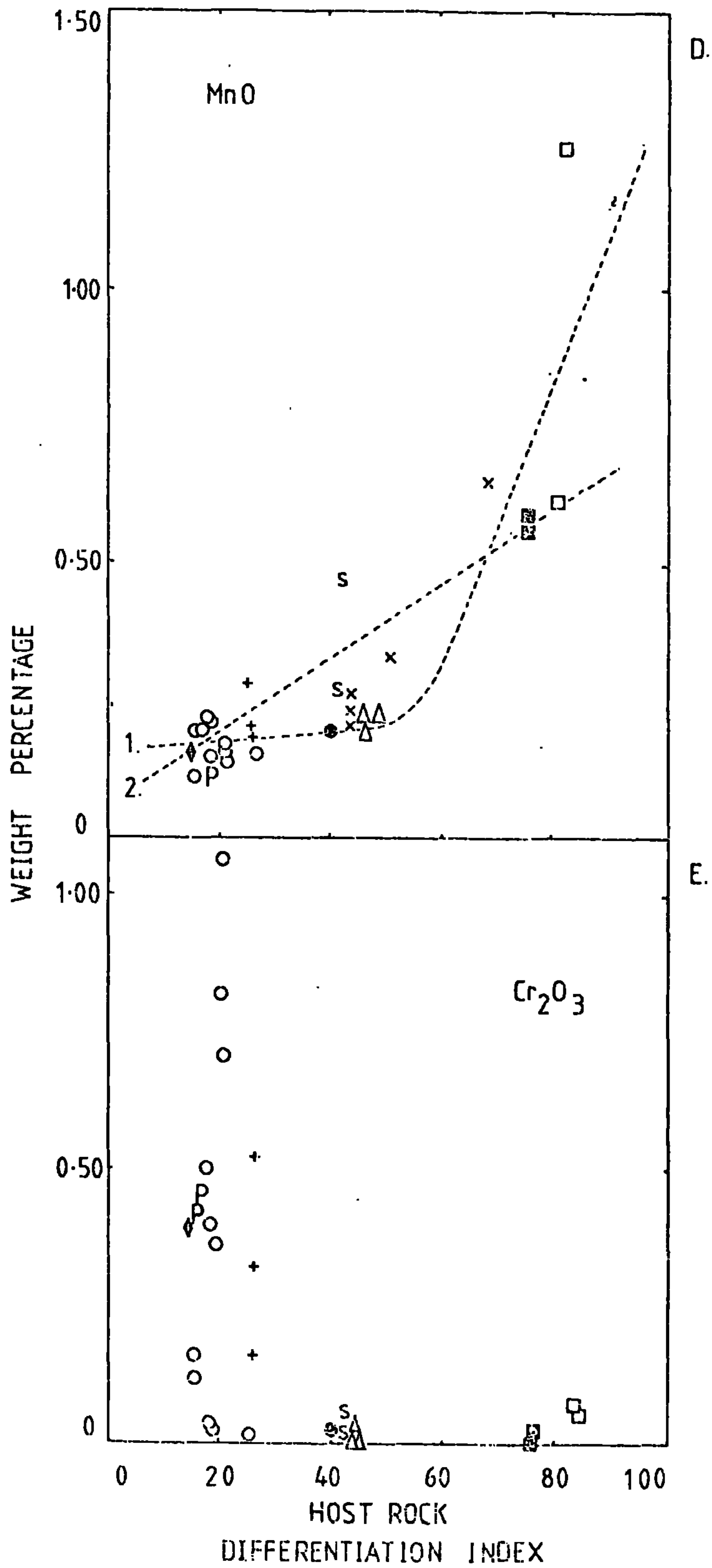
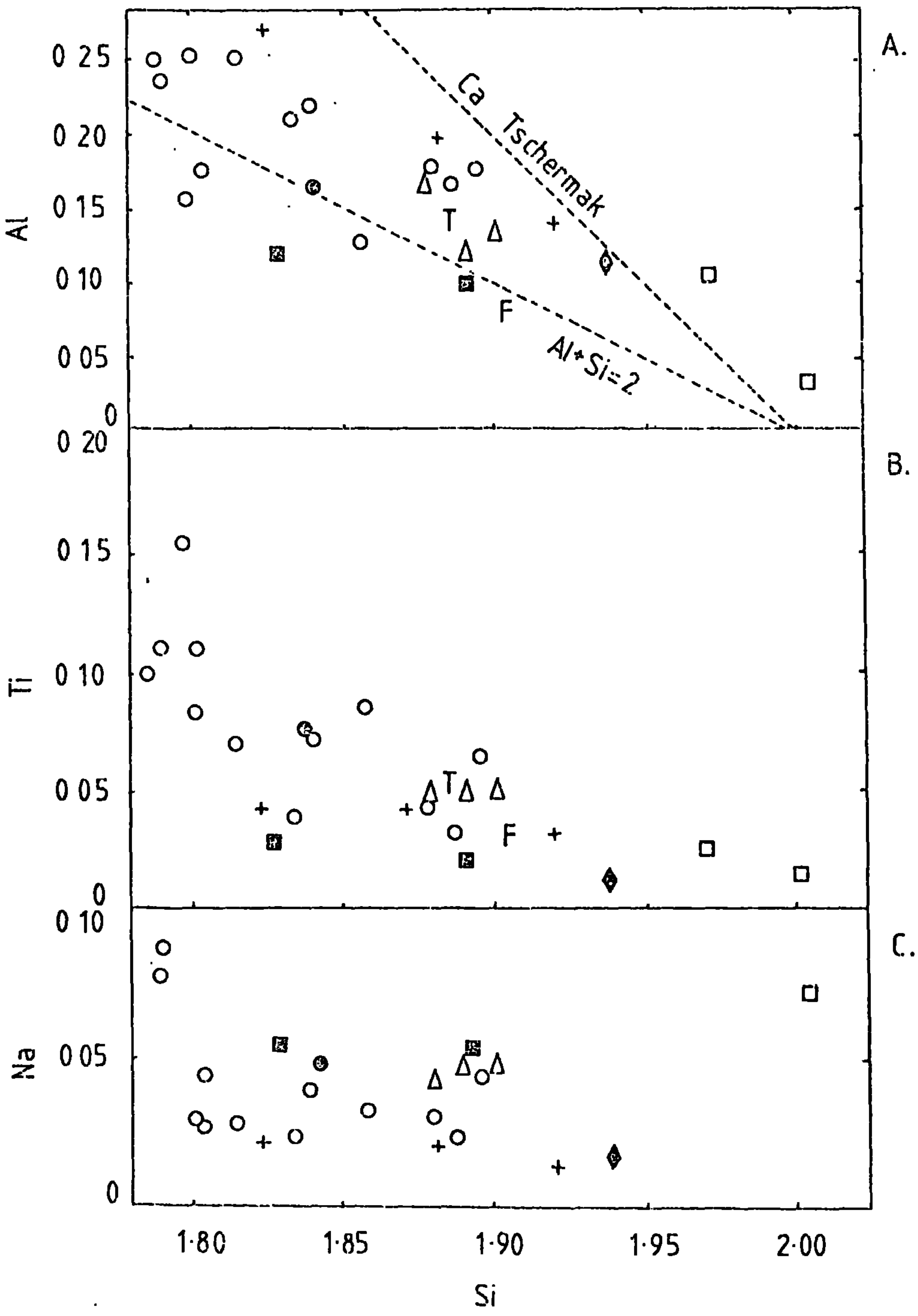

D.
MnO
1·50
1·00
0·50
0
1.
2.
WEIGHT PERCENTAGE
E.
Cr2O3
1·00
0·50
0
0
20
40
60
80
100
HOST ROCK
DIFFERENTIATION INDEX

FIGURE 24

Elemental variation (Al, Ti, Na) in the clinopyroxenes of the Skye lavas based on the Structural formulae plotted against Si. Structural formulae based on 6 oxygens.

Symbols as used in figures 22 and 23.

Figure 24


A.
B.
C.
Ca Tschermak
Al+Si=2
T
F
Al
Ti
Na
Si
0 25
0 20
0 15
0 10
0 05
0
0 20
0 15
0 10
0 05
0
0 10
0 05
0
1·80
1·85
1·90
1·95
2·00

the recorded analyses not represented on the En-Fs-Hd-Di quadrilateral ie. Al_2O_3, TiO_2, Na_2O and MnO as well as Cr_2O_3 and NiO.

8.2.ii)A TiO_2

Clinopyroxenes of alkaline magmas are characterised by high TiO_2 contents in the basaltic rocks. The alkali-basalts of west-central Skye have TiO_2 contents of over 2.5 wt.% with the more olivine-rich flows having the lowest values of the basaltic types (maximum 3.85 wt.%: cf. Thompson 1974) while the low-alkali, high-calcium olivine tholeiite of Talisker has 0.5 to 0.8 wt.% (Esson et al. 1975). New analyses of the Talisker flow fall within this range which is very typical of tholeiitic augites. The transitional clinopyroxene microporphyritic basalt of Beinn an Eoin, Sk751218, contains clinopyroxenes with intermediate values around 1.25 wt.% TiO_2. Thompson (1974) reports values of between 1.2 and 3.5 wt.% for the transitional basalt Sk971. Pyroxene phenocrysts (tholeiitic trend) have much lower values e.g. specimen Sk760814 comparable to those of the Talisker tholeiite. These relative values are borne-out in figure 24B based on Si/Ti variation within the structural formula on the basis of 6 oxygen atoms.

With differentiation, TiO_2 content declines as shown in figure 23A. Although analyses of intermediate lavas are sparse there is perhaps a marked fall around the hawaiite-mugearite transition. This feature could possibly tie in with the start of, or culmination of major opaque microphenocryst precipitation especially if many of the clinopyroxenes began as microphenocrysts themselves. Levels of over 2.5 wt.% fall to under 0.5 wt.% equivalent to the low-alkali tholeiites and remain uniform to the trachytic rocks. Alternatively the scatter on the data may indicate a more gradual but continuous decrease. There is a sharp contrast between the TiO_2 content of core-margin analyses in the basalt Sk740607 with TiO_2 dropping to around 1.0 wt.% but it is not clear whether or not this decrease is gradual or sudden. If sudden and the clinopyroxene began as a micro-phenocryst this could indicate that some of the opaque phases at least were starting to form after clinopyroxene crystallisation was well under way. Contrary to this many, if not most, of the other basaltic rocks either show an increase in TiO_2 (2.50 to 3.85 wt.% in Sk7706) towards the margins coupled to an increase in colour intensity in plane polarised light or remain virtually unzoned e.g. Sk751212. In the more transitional lavas the 'phenocrysts' increase in TiO_2 from 0.57 wt.% in the olivine + pyroxene + plagioclase porphyritic basalt Sk760814 to 0.81 wt.% in the transitional trachyte Sk750806 with a peak of between 1.0 and 1.5 wt.% in specimen Sk751218.

8.2.ii)B $\underline{Al_2O_3}$

Aluminium content within the clinopyroxenes falls with differentiation (figure 23B). The alkali-olivine basalts have moderate values of between 4 and 6 wt.% dropping to between 2.5 and 4 wt.% in the intermediate lavas. The Scarall Trachyte has a lower value, averaging 1.5 wt.%. Alumina content of the low-alkali tholeiite groundmass clinopyrocenes averages 2.7 wt.% making them easily distinguishable from the alkali-basalt types. The transitional basalt lavas have between 3.5 and 4.5 wt.% Al_2O_3 which is much higher than the transitional basalt figured by Thompson (1974) but again intermediate between the alkalic and low-alkali tholeiite basalts. In general, the present study finds higher levels of Al_2O_3 than Thompson for both alkali basalts and transitional types. The andesitic sill (tholeiite trend) carries pyroxenes with similar habits to the transitional basalts and also as minute euhedra - possibly micro-phenocrysts. These have values of 1.2 to 1.4 wt.% Al_2O_3

and compare more closely with the transitional rock of Thompson.

Within the alkaline series; basalt-hawaiite-mugearite-(benmoreite and trachyte) the occurrence of a composite flow of hawaiite (previously termed big-feldspar mugearite) at Dun Ard an t-Sabhail near Fiskavaig has been mentioned previously. The groundmass clinopyroxenes of this unusual flow cannot be distinguished from those of other hawaiites but the rare orthopyroxenes (see 8.2.iii) are apparently Al_2O_3-rich varieties with values of between 7.1 and 7.8 wt.%. These are possibly a little affected by contamination from plagioclase feldspars but even so they carry at least twice as much Al_2O_3 as the other intermediate lavas. They may therefore be important indicators of an Al_2O_3 rich magma or if they began as microphenocryst liquidus phases, they are obviously very important in any consideration of the petrogenesis of the flow.

Variation against Si thus shows that the 'transitional' pyroxenes have more Al in their structure than the other basalts. A decline in Al_2O_3 in both alkaline and tholeiitic trends upon differentiation is noted. Any silica deficiency in the structural formula (see figure 24B) will generally be made up by Al in the Z site, but since a sympathetic variation with Ti exists, the combined, dominant substitution is of the form:

$$M^{++}_{y} + 2Si_{z} \rightleftharpoons Ti_{y} + 2Al_{z}$$ (After Gibb 1973 who reports similar trends within the pyroxenes of the Shiant Isles Sill).

The augites of the alkali-olivine basalts from Skye are even more enriched in Al_2O_3 and TiO_2 than those of the Small Isles reported by Ridley (1973). This is expected considering the less alkaline nature of the Small Isles volcanics. The transitional lava from near Glen Brittle with around 3.5 to 4.5 wt.% Al_2O_3 and 1.25 wt.% TiO_2 is much more comparable to the Small Isles analyses. The low-alkali tholeiite of Talisker with Al_2O_3 2.7 wt.% and TiO_2 averaging 0.47 wt.% appears marginally less tholeiitic than those from tholeiitic suites e.g. Thingmuli (Carmichael 1964) containing an average 1.5 wt.% Al_2O_3 and 1.0 wt.% TiO_2 while the andesitic sill (specimen Sk7626) has 1.2 to 1.4 wt.% Al_2O_3 coupled with 0.5 to 0.9 wt.% TiO_2 and is much more like the Thingmuli series.

8.2.ii)C $\underline{Na_2O}$

Little variation in Na_2O content as expressed in the structural formula is noted (figure 24C), the results being highly variable and possibly partially due to contamination, especially from plagioclase and alkali feldspars. Other sources of error are attributed to the low limit of detection (around 0.3 wt.%) and the experimental error ($\pm$0.1 wt.%). The lack of major variation suggests a limited substitution of the form:

$$M^{++}_{y} + Si_{z} \rightleftharpoons Al_{y} + Al_{z} \quad \text{(Gibb 1973)}$$

In real terms, the alkaline and transitional tholeiitic rocks can almost be distinguished but as the error is so high this cannot be stated with any confidence. There is therefore a possibly detectable increase in Na_2O between the olivine tholeiite (0.26 wt.%), transitional basalt (0.19 to 0.28 wt.%), average alkali-olivine basalt (0.50 wt.%) and the olivine + plagioclase porphyritic basalts (0.6 to 1.0 wt.%). With differentiation a similar increase is recorded in the tholeiite (0.26 to 0.46 wt.%), transitional (0.25 to 0.74 wt.%) and alkaline (0.32 to 0.64 to 0.98 wt.%) series (figure 23C).

8.2.ii)D MnO

Manganese in the analysed clinopyroxenes is generally constant between 0.1 and 0.2 wt.% in the alkali basalts, hawaiites and mugearites but increases in the trachyte to over 0.5 wt.% (0.6 to 1.25 wt.%).Muir and Tilley (1961) record similar values in the intermediates. A similar marked increase in MnO is noted in the olivines from this series (see 8.1). The low-alkali tholeiite has no characteristic MnO content at 0.16 wt.% but the andesite sill, possibly derived from this magma type or the intermediate lavas (average ∽ 0.23 wt.%) averages around 0.38 wt.% MnO. The intermediate trachyte has between 0.55 and 0.59 wt.% MnO. Thus the intermediate/tholeiitic rocks appear to show a more linear increase in MnO with differentiation while the main alkaline series is possibly more staggered as in figure 23D. Thompson (1974) reports MnO = 0.25 wt.% olivine-rich alkali basalts, this being substantially higher than the findings of the present study. He also detects no variation in the transitional lavas which have MnO = 0.24 wt.% and are identical to the transitional basalt from Glen Brittle. Compared to the analyses from the Small Isles, the Skye alkali-olivine basalts have lower values of MnO in the clinopyroxenes (Small Isles averaging about 0.21 wt.% and Skye averaging about 0.15 wt.%). The detection limit for MnO in the analysed pyroxenes runs at about 0.1 wt.% with an error of $\pm$ 0.02 to 0.03 wt.% on each analysis.

8.2.ii)E Cr_2O_3 and NiO

Clinopyroxenes tend to incorporate both chromium and nickel into their structures preferentially compared to silicate melts; the process most strongly favouring the former.

The variation of Cr_2O_3 within the clinopyroxenes follows a rather simple and somewhat predictable pattern which is however much influenced by the low detection limit (<0.1 wt.%) and the likely errors on each analysis (± 0.05 wt.%). Within the basaltic rocks a wide range is evident from over 1.0 wt.% to zero. However, it appears that the coinopyroxenes from the olivine and less olivine rich, olivine + spinel porphyritic basalts have higher Cr_2O_3 than the olivine + spinel porphyritic types such as Sk751212 which in turn have higher values than the obviously more evolved olivine + plagioclase porphyritic basalts. The clinopyroxenes of the intermediate lavas have values lying on or near the detection limit and consequently lower than the alkalic basalts (figure 23E). The pyroxenes of the tholeiitic rocks and transitional lavas also show a trend of abruptly falling Cr_2O_3 with differentiation but cannot here be distinguished from the alkalic trend.

The NiO content is highly variable and shows little systematic variation. The extremely low-levels of detection, coupled to contamination and other likely errors, give highly spurious and variable results for pyroxenes from the same rocks. However, NiO is possibly a little higher in the trachyte of Cnoc Scarall (0.13 wt.%) than in the average alkali-olivine basalt (0.01 to 0.1 wt.% but averaging 0.04 wt.%).

8.2.iii) Orthopyroxenes

The low-alkali tholeiite of Talisker contains clinopyroxene co-existing with both olivine and plagioclase phenocrysts. There is no indication of any reaction relationship between the olivines and the groundmass and neither orthopyroxene or inverted pigeonite was detected. However, as mentioned in Chapter 7, scattered orthopyroxene crystals ($Ca_3Mg_{69}Fe_{28}$) have been discovered in the composite alkaline hawaiite of Dun Ard an t-Sabhail. In the conventional clinopyroxene En-Fs-Hd-Di quadrilateral they plot as subcalcic magnesian hypersthenes (figure 22). They are apparently unzoned and surprisingly homogeneous but this could be due to mechanical breakage (ie. the analyses may be of only partial crystals) during mounting in araldite blocks for analysis. Probe analyses show this phase to have TiO_2 = 0.54 wt.%, Na_2O = 0.23 average wt.% and a very high Al_2O_3 content of 7.75 wt.%. In the structural formula which idealised may be written as:

$$X_{1-P}\ Y_{1+P}Z_2O_6$$

where X=Ca,Na; Y=Mg,Fe^{++},Mn,Ni,Al,Fe^{+++},Cr,Ti; Z = Si,Al it can be seen that the analyses (Appendix 3, Table 2, specimen Sk760703) contain but very little excess Al^{+++}. Direct contamination during analyses is ruled out due to the pyroxenes being analysed isolated from the host rock but it is possible that should they be xenocrysts then considerable reaction may have taken place with the alkalic groundmass.

The following possibilities exist for the derivation of the aluminous orthopyroxene:

i) mantle derivation at source area, high pressure source ∴ high Al_2O_3 although the two do not always correlate positively.

ii) breaking up of high-grade metamorphic basement e.g. pyroxene granulites in which orthopyroxenes are commonly characterised by high Al_2O_3, during ascent of magma.

iii) by reaction of phenocrystic spinel with liquid which is suitably undersaturated in silica and does not carry phenocrystic Al-rich cpx.

iv) direct precipitation from the magma at high pressure.

Unfortunately, deep-seated xenoliths and mantle or cumulative nodules are nowhere found in any of the Hebridean lavas to substantiate the first two possibilities and indeed, the Opx does not look particularly xenocrystic. Possibility three requires the absence of phenocrystic Al-rich Cpx in these rocks and although they are not seen, Boyd (1974) has shown that for the Dun Hill composite, the combined computer simulated fractionation from average alkali-olivine basalt of plagioclase + Al clinopyroxene + magnetite + olivine + hercynite spinel very significantly reduces the least squares residuals. Other lines of evidence also suggest that although not now a phenocryst, the clinopyroxenes may have begun as such (Chapter 7, 8.2.ii)A and Gibb and Henderson, 1978).

8.3. <u>Feldspars</u>

Plagioclase feldspar is present in all the rocks analysed and is frequently found as a phenocrystic or xenocrystic phase. It is mostly confined to the groundmass in the more basic alkali-olivine basalts but forms a conspicuous phenocryst phase in the olivine + plagioclase porphyritic basalts and many of the intermediate lavas. Feldspar macroporphyritic basalts are not common and where found, occur at no overall unique position within the stratigraphic succession although they do make a spread in the lowest units. Alkali-feldspar is either confined to overgrowths on both groundmass and phenocrystic plagioclase or as a phenocryst phase in its own right in the most evolved rocks.

8.3.1 Major Element Variation

Figure 25 shows the range of analyses, recorded in terms of the normative anorthite-albaite-orthoclase (An-Ab-Or) triangle.

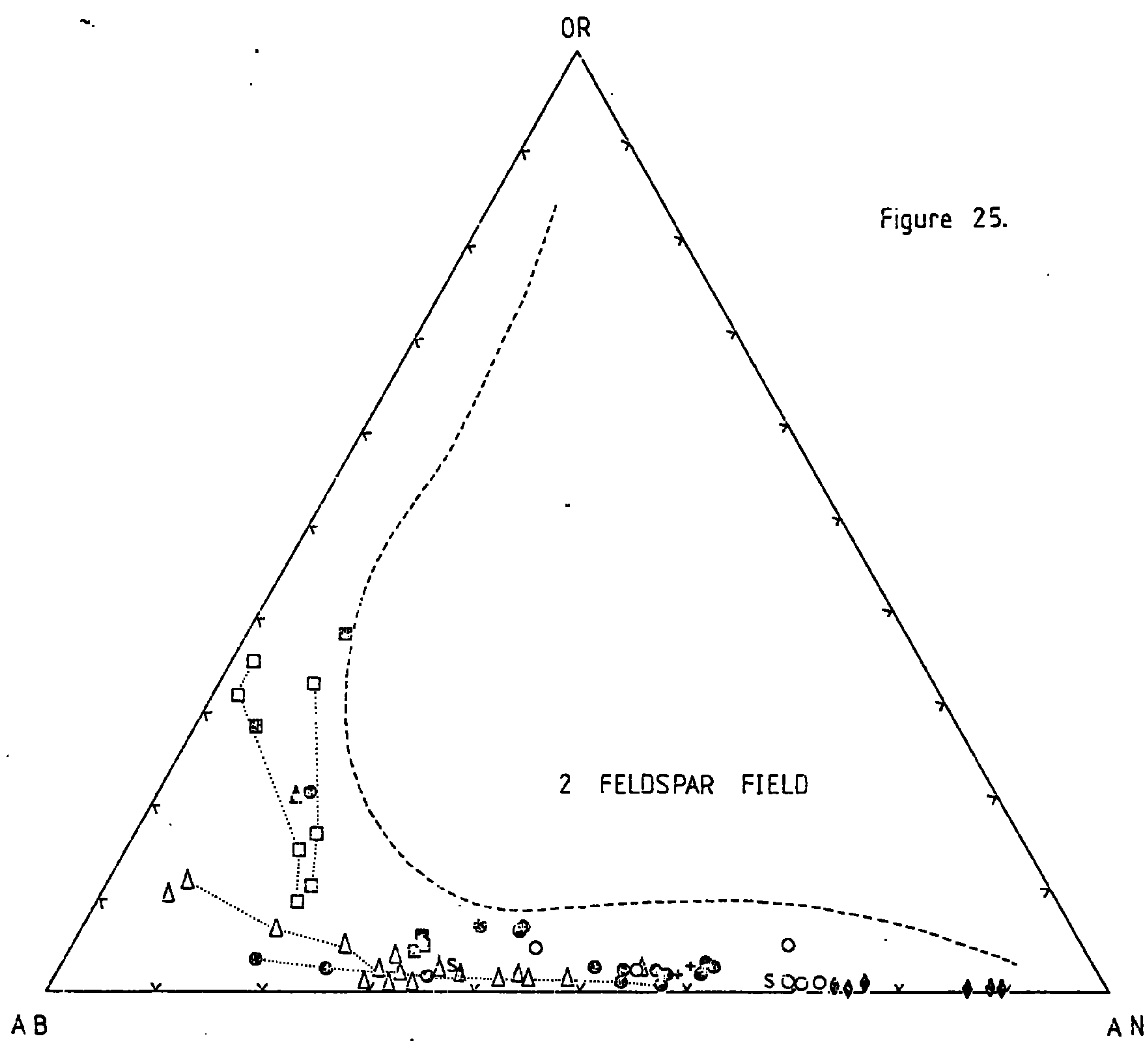
The alkali-basalts (olivine, olivine + spinel porphyries) have groundmass plagioclase feldspars as calcic as An_{73} but they show normal continuous zoning to around An_{61} with little or no increase in the orthoclase component. The analysed hawaiites on the other hand have groundmass feldspars of below An_{54} with zoning extending to An_{42} and with considerable increase in Potassium (figure 25). This coincides with the normative plagioclase range as defined by Muir and Tilley (1961), although the majority appear slightly on the basic side of andesine. Microphenocrysts in hawaiite specimen number Sk740301 have considerably more calcic cores (An_{56}) than the groundmass of An_{50}. However there is complete overlap of plagioclase compositions with the so-called mugearites. The most basic mugearites e.g. specimen Sk740701 with Differentiation Indices between 44 and 48, carry strongly zoned plagioclase microphenocrysts of An_{42-46} and a groundmass of An_{30-36}. Equivalent normative plagioclases indicate that by definition they should still be termed hawaiites. A slight increase in

FIGURE 25

Microprobe analyses of feldspar phenocrysts and groundmass laths normalised into the system Albite-Anorthite-Orthoclase showing the position of the 2-feldspar field. The dotted trend lines join analyses of zoned crystals.

Symbols as used in figures 20-24.

Figure 25.



orthoclase is noted. The outer zones of the phenocrysts are generally irregular and tend to be more potassic than the small groundmass lath cores but the latter are sharply zoned to more potassic andesine-oligoclase. The groundmass feldspar of mugearites such as specimen Sk741101 (Differentiation Index 56) may be as calcic as An_{34} but this sodic andesine very quickly zones outwards through potassic oligoclases of $An_{19}Ab_{75}Or_{6}$ towards an alkali feldspar residuum of $An_{7}Ab_{82}Or_{11}$ which occupies the interstices as ragged overgrowths between the groundmass laths. Hence in general the modal plagioclase has a lime anorthoclase component > plagioclase in the more evolved mugearites such as specimen Sk751801, possibly representing the same flow or next flow below Sk741101, with a Differentiation Index of 61. This rock contains minute groundmass laths of around $An_{26}Ab_{69}Or_{5}$ and is also strongly zoned. The coarse-grained mugearite of Stockval, Sk740810, carries microphenocrysts with cores of $An_{55}Ab_{33}Or_{12}$ with the continuous zoning and groundmass compositions identical to those of the groundmass of the above mentioned hawaiites and basic mugearites, and extending into the mugearite field. The zoning extends to $An_{7}Ab_{83}Or_{10}$ and this is almost identical to the alkali-feldspar residuum of Sk741101 (figure 25). The benmoreite or sodic mugearite of Cnoc Heilla (specimen Sk77011, Differentiation Index 65) also has a sodic andesine groundmass-lath core composition ($An_{38}Ab_{60}Or_{2}$) and an interstitial overgrowth of at least $An_{14}Ab_{65}Or_{21}$ although the size of the laths introduces some problems during analysis. The alkali-trachyte of Cnoc Scarall which is thought to be the most evolved alkalic lineage member in West Central Skye, has tabular, strongly zoned groundmass laths of potassic oligoclase bordering on sodic anorthoclase. The range is $An_{20}Ab_{70}Or_{10}$ through more sodic plagioclases to anorthoclase $An_{8}Ab_{59}Or_{33}$. Large phenocrysts in the trachyte are zoned anorthoclases. The zoning indicates that the phenocrysts are slightly more sodic than the groundmass in general, unlike the phenocrysts of the more intermediate hawaiites and mugearites. Thus the broad trend shown in figure 25 is fairly-well established for the alkali series.

The feldspar macroporphyritic intermediate flow (Differentiation Index 44.9) of Beinn nan Dubh Lochan (Sk740311) carries labradorite phenocrysts of An_{55-58} with some zoning towards $An_{18}Ab_{79}Or_{3}$. The groundmass laths are andesines $An_{38}Ab_{56}Or_{6}$ zoned to $An_{14}Ab_{65}Or_{21}$ (figure 25) which are considerably more potassic than the normal series but like that series tends towards an alkali-feldspar rather than quartz residuum. This again emphases the alkalic nature of the majority of the volcanics.

The transitional basalt Sk751218 has groundmass labradorite-bytownite and the transitional clinopyroxene-porphyritic trachyte of Sleadale Sk750804-6 carries phenocrysts of Andesine ($An_{33}Ab_{62}Or_5$) in a groundmass dominated by minute alkali-feldspar laths ranging to potassic anorthoclases $An_7Ab_{54}Or_{37}$.

The tholeiitic series rocks (Talisker tholeiite and Andesite Sill) have distinctive feldspars. The low-alkali tholeiite is sparsely plagioclase porphyritic although there are local concentrations. The phenocrysts are calcic bytownites to anorthites (An_{87-91}) and show zoning to sodic bytownite An_{75}. Groundmass laths are slightly less calcic but both they and the phenocrysts have very low orthoclase contents. Esson et al. (1975) estimate a bulk composition of An_{82-86}. The sill-rock (Sk7726) carries phenocrysts of calcic labradorite which are partially altered with the appearance of irregular patches of potassic andesine (figure 25).

Only in the more sodic plagioclases of both the alkalic and tholeiitic suites does potassium become significant. In the majority of cases there is likely to be some substantial analytical errors especially in the determination of Na_2O and to a lesser extent K_2O due to volatilisation of the plagioclase $\pm$ alkali feldspar under the electron beam. This in most cases accounts for the low totals but in others, low totals may be due to combinations of beam wandering, current fluctuations and the accidental analysis of minor inclusions of clinopyroxene, apatite, amphibole and other interstitial phases. This is especially true of groundmass analyses within the very fine-grained intermediate lavas and some phenocrysts whose zoning is marked by rings of inclusions eg. specimens Sk760702-3 from the composite flow of Dun Ard an t-Sabhail near Fiskavaig. In total, these errors may produce a cumulative effect in the order of up to 5 wt.%.

Ridley (1973) shows the volcanics of the Small Isles to conform very closely to the Skye trend of Muir and Tilley (1961). The present study is in close agreement with Muir and Tilley's differentiation trend but shows that some intermediate lavas, especially the more basic mugearites and the other finer-grained mugearites may be slightly more depleted in potassium than in the latter. As examples of this specimens Sk741101, Sk751801 and Sk740810 from the Ceaplaich-Stockval region, plot with a much flatter pattern, almost identical to that of the Mull mugearite series (Ridley, 1973, figure 12).

However, these differences appear not to be reflected in the major or trace element geochemistry of the rocks concerned. The analyses concerned are characterised by low totals and the validity of this 'trend' is suspect.

8.3.ii) Minor Element Variation

Practically all the analysed feldspars contain significant amounts of iron but no systematic variation is noted. Trace amounts of magnesium, nickel and rarer manganese or titanium are also recorded but in most cases, and especially in analyses from the groundmass of the fine-grained hawaiites and mugearites, they are most likely attributable to contamination from the accidental analysis of small, granular inclusions of titaniferous magnetite and olivine. Such inclusions are common in zoned crystals and are well developed in the feldspar macroporphyritic hawaiite Sk760702/3. Normal ionic substitutions may account for only a very small proportion of these elements e.g. Fe^{3+} may replace Al^{3+} to a limited extent but any Fe^{2+} present is most likely an impurity.

8.4 Iron-Titanium and Chromium Oxides

Among the lavas of west-central Skye, four principal types of opaque or translucent minerals are found:

a) chrome-bearing spinels or chromites

b) homogeneous titaniferous magnetite (with rare ilmenite exsolution)

c) ilmenite/pseudobrookite

d) hercynite spinel

Chrome-spinels, common in the ultrabasic and picritic intrusions around the margins of the Cuillin Basic Igneous Complex, are restricted to the most basic Skye alkali-olivine basalt lavas. These are basalts, in which, spinel apart, a magnesian olivine is the sole phenocryst phase and indeed may be so abundant that the rocks grade into picritic varieties. In most instances, both the olivine and spinel are interpreted as being early formed phenocrysts but in some they may also in part be cumulus.

Titaniferous magnetite however, is never a phenocryst phase in the olivine + spinel, olivine or olivine + plagioclase porphyritic basalts, being confined to the groundmass where it may assume a variety of habits dependant upon the crystallisation history of the rock. It does however become an important phase in the intermediate rocks. In the hawaiites especially, it forms a microphenocryst phase and is also well represented in the groundmass. Mugearites may or may not be phenocryst bearing. In the more highly evolved alkalic rocks it is mostly relegated to the groundmass and is only present in rare or trace amounts as microphenocrysts. It does form an important phenocryst phase, often with considerable exsolved ilmenite, in the transitional clinopyroxene + plagioclase porphyritic 'trachyte' of Sleadale.

Discrete grains (not phenocrysts) are also found in the Sleadale Trachyte and also from some of the clinopyroxene + plagioclase + olivine + magnetite granular hornfels associated with the margin of the Intrusive Complex. Ilmenite lamellae are occasionally seen in the groundmass magnetites of some basaltic rocks but only very rarely in the microphenocrysts characteristic of the hawaiites and mugearites. It was not found practical to analyse the groundmass opaques of these intermediate lavas.

An aluminous hercynite spinel is recorded from the upper porphyritic unit of the composite flow of Dun Ard an t-Sabhail near Fiskavaig, but, like the aluminous orthopyroxene described in 8.2.iii) is possibly xenocrystic or a disequilibrium phase as it shows evidence of having marginally reacted to some extent with the silicate liquid. It is rimmed by a homogeneous titaniferous magnetite with an intermediate composition towards those of the small microphenocrysts in the hawaiite.

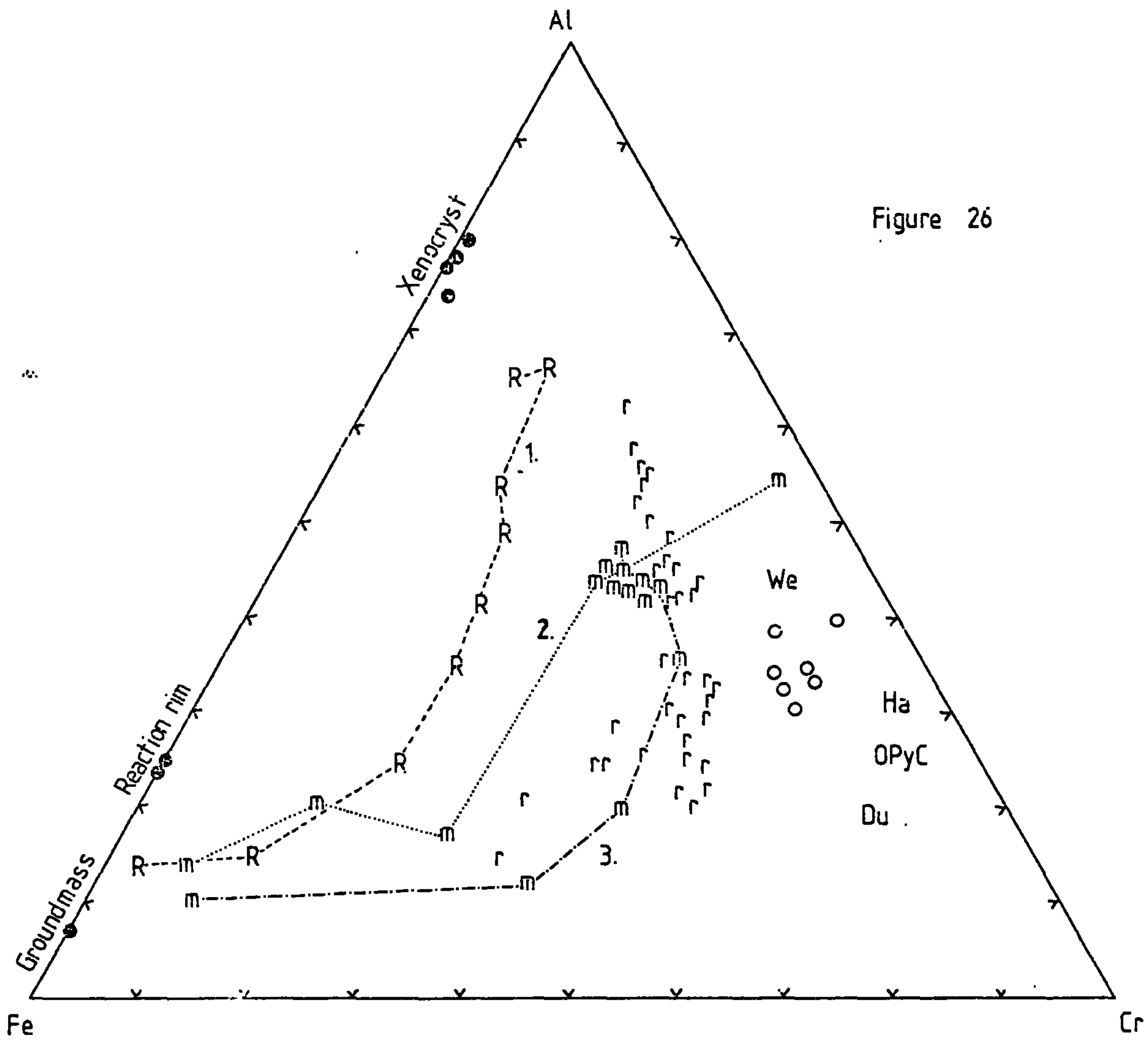
8.4.i) Chrome-spinels

Brown to brownish-red, translucent subhedral chrome-spinels are present in many basaltic lavas. They usually occur enclosed within large euhedral or skeletal-embayed, magnesian olivines indicating that they were an early formed phase, trapped within the olivine as it grew. In many instances they can be seen protruding from the olivines or within embayments in the olivines in direct contact with the basaltic groundmass. A mechanical break-up of the olivines probably due to magmatic flow is probably the cause of this feature. In transitional alkalic lavas from the Small Isles of Inverness-shire, Ridley (1977) reports the extents to which similar chrome-spinels have reacted with the silicate groundmass. The Skye lavas are more alkalic than those from the Small Isles and tend to have higher relative chromium contents in the spinels. Whereas reaction is pronounced in the Small Isles spinels (Ridley 1977, Henderson and Sudaby 1971, Henderson 1975) producing several concentric reaction trends from aluminous chrome spinel towards magnetite in the Ternary plot Al, Fe^{3+} and Cr (figure 26), the chrome-spinels from

FIGURE 26

Chrome-spinels plotted in the system Al-Cr-Fe. Also xenocrysts in composite hawaiite.

	o	Olivine + spinel porphyritic Skye basalt
	●	Hercynite and titaniferous magnetite from the composite hawaiite of Dun Ard an t-Sabhail
	R	Hypersthene normative olivine basalt from Rhum (Ridley 1977)
	m	Nepheline normative alkali olivine basalt from Muck (Ridley 1977)
	r	Rhum layered Intrusion (Henderson and Suddaby 1971; Henderson 1975)
	We,Ha,OPyC,D,	Wehrlite, Harzbergite, Olivine + Pyroxene cumulate and Dunite (Oman Ophiolite Complex)
Trends:	1.	Rhum reaction trend towards Fe apex (Ridley 1977)
	2.	Traverse of strongly reacted spinel from Muck (Ridley 1977)
	3.	Core to rim traverse of reacted spinel from Muck (Ridley 1977)


Al
Fe
Cr
Xenocryst
Reaction rim
Groundmass
Figure 26
We
Ha
OPyC
Du
1.
2.
3.

two Skye, olivine + spinel porphyritic lavas within the Bualintur and Cruachan Lava Groups show little variation. However, in detail, some reaction has taken place resulting in increases in SiO_2, TiO_2, Al_2O_3 and perhaps K_2O coupled to decreases in MgO, and Cr_2O_3 from core to rim in both Sk7616 and Sk751212. Elements CaO and Na_2O appear to give conflicting trends. Manganese increases towards the core of spinels in Sk751212 but is essentially invariant in Sk7616. In figure 26, the Skye spinels are closely comparable to chromites from ultrabasic rocks lying broadly between those of the Rhum intrusion (Henderson 1975) and a representative ophiolite suite from Oman (Al-Khamees, pers. comm.). It is suspected that should a full, comparative study be made, the spinels in the Skye lavas would be shown to have reacted considerably, in a trend concentric to those of the Small Isles.

In terms of the Ti-Fe-Al-Cr plot (figure 27) employed by Thompson (1973) to describe some continuously zoned chrome-spinels from the lavas of the Snake River Plain, U.S.A., the Skye spinels plot close to the Fe-Cr and Fe-Al base-lines near $FeCr_2$ and $FeAl_2$. Roughly similar spinels are recorded from some of Apollo 16 Lunar basalts, but spinels from Tristan da Cunha, Easter Island,

FIGURE 27

Chrome-spinels and titaniferous magnetites plotted in the system Cr-Fe-Ti-Al as used by Thompson (1973).

O	Aluminous-Chrome spinel from Skye (this study) and basaltic titaniferous magnetites
●	Hawaiite titaniferous magnetite
Δ	Mugearite titaniferous magnetite
□	Alkali Trachyte titaniferous magnetite
■	Intermediate Trachyte titaniferous magnetite
1-5	Microprobe traverse from core-margin-groundmass of hercynite-titaniferous magnetite xenocryst in the composite hawaiite of Dun Ard an t-Sabhail.

Data from Thompson (1973):

L	Lunar sample - Apollo 16
x	Makaopuhi lava lake reaction series
Tr	Tristan da Cunha (centre of analyses spread)
Sn	Snake River Plateau basalt (Thompson 1973)
------	East Island trend

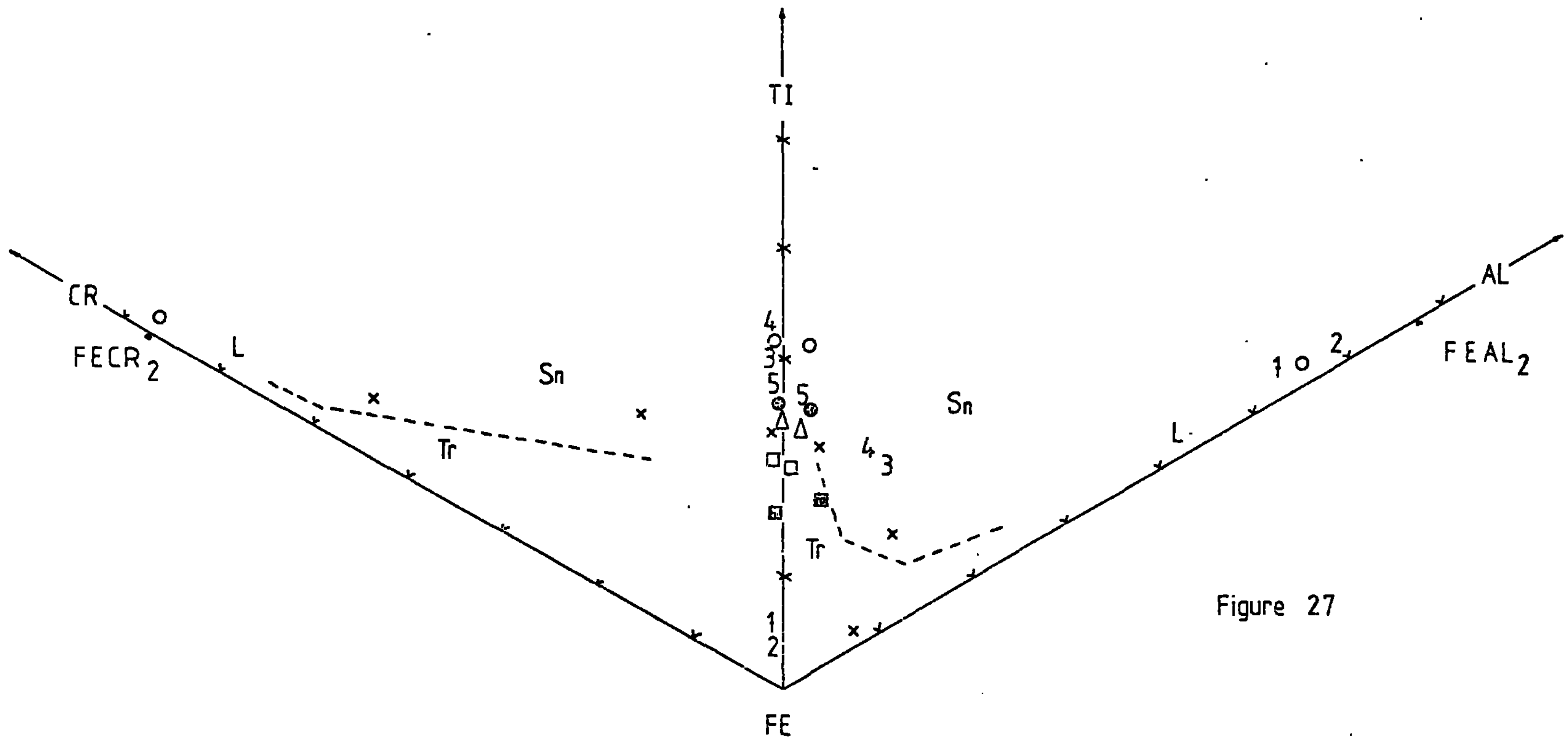


Figure 27

Kilauea and the Snake River Plain appear all to lie on trends of increasing Ti towards titaniferous magnetite compositions. It is likely that most of these spinels may originally have been more chrome-rich but have subsequently undergone reaction with the silicate liquid or other adjacent phases.

In real terms, the Skye spinels contain between 1.0 and 2.5 wt.% of the combined minor elements TiO_2, NiO, MnO, Na_2O and CaO.

8.4.ii) Titaniferous Magnetite

Titaniferous magnetite, whether as poikilitic masses, small interstitial euhedra or granules or as microphenocrysts is ubiquitous in the Skye lavas. Mostly it is homogeneous but occasionally, rare exsolution lamellae of ilmenite may be visible. Similar features are reported from many similar volcanic suites.

In terms of composition, Ridley (1973) reports little significant variation in magnetites from the Small Isles volcanics (excluding the Acid rocks of Eigg). However, by plotting representative analyses of Skye magnetites within the system ulvöspinel-ilmenite-magnetite, some significant compositional differences are noted. These are summarised in figure 28A. The trend so produced is however distorted as, in addition, the magnetites contain

FIGURE 28

Titaniferous magnetites and ilmenites as expressed in the system TiO_2-Fe_2O_3-FeO showing their variation with increasing differentiation of the host lava and reaction series of xenocrystic species in hawaiites and mugearites.

A. System TiO_2-Fe_2O_3-FeO (Rutile, Anatase, Brookite - Haematite, Maghemite - FeO)

Symbols for basalts, hawaiites, mugearites and trachytes as used in figure 27.

In addition:

H High grade basaltic hornfels ilmenite-pseudobrookite and titaniferous magnetite with tie line

■ ▣ Sleadale Intermediate trachyte ilmenite-pseudobrookite and titaniferous magnetite with tie line

1. Sgurr of Eigg pitchstone ilmenite (Ridley 1973)
2. " " " " " (Carmichael 1967)
3. Skaergaard ilmenite

B. Sub-system FeO.TiO_2-FeO-Fe_2O_3 (ilmenite-FeO-Haematite, Maghemite)

●-● Reaction series from core-margin-groundmass of hercynite-titaniferous magnetite xenocryst from the composite hawaiite of Dun Ard an t-Sabhail

Δ·····Δ Reaction series of 'xenocryst' in coarse-grained mugearite Sk740810

Additional information:	FeO . Fe_2O_3	Magnetite
	2FeO . TiO_2	Ulvöspinel

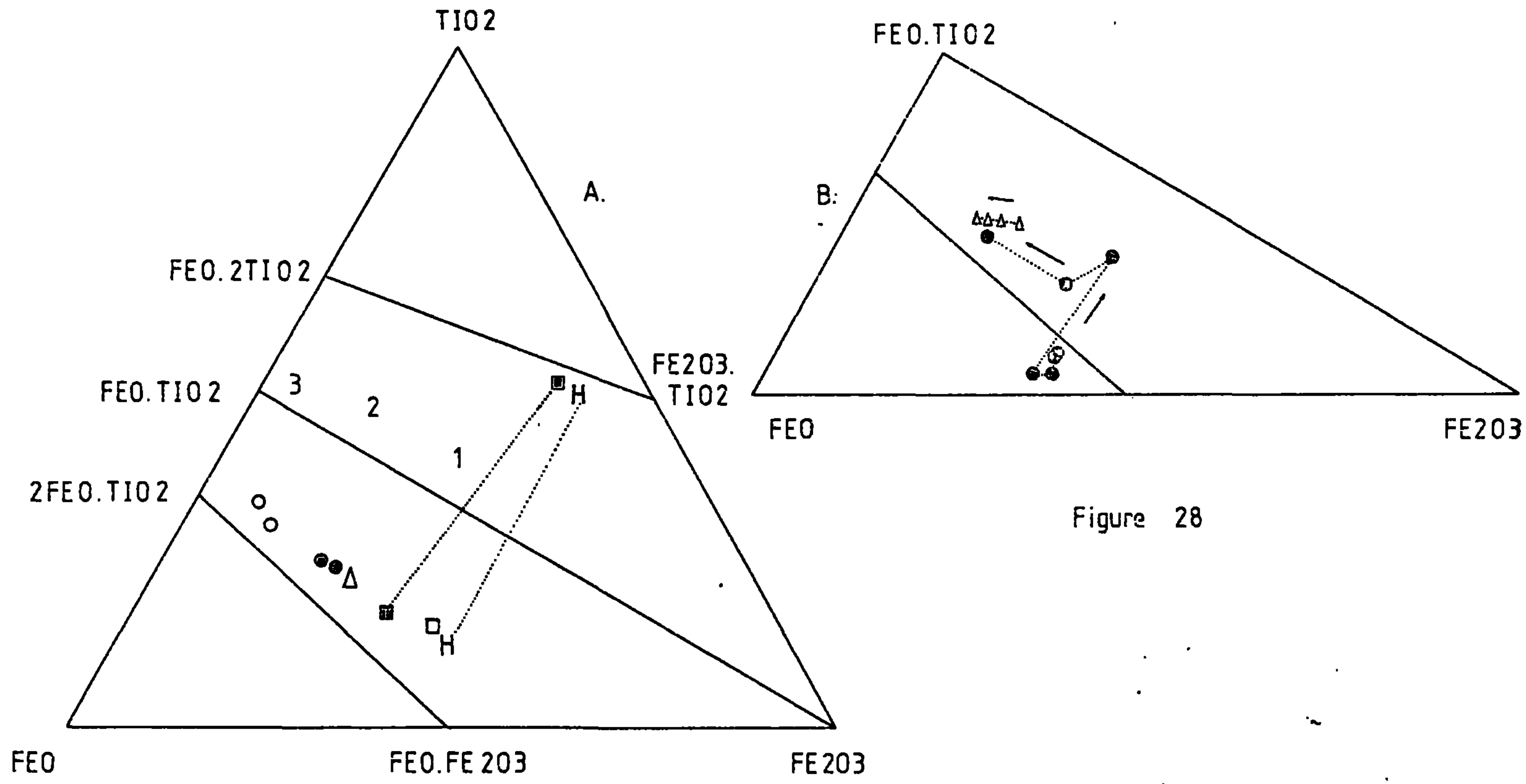

TIO2
A.
FEO.2TIO2
FEO.TIO2
2FEO.TIO2
FE2O3.
TIO2
3
2
1
H
H
FEO
FEO.FE2O3
FE2O3
FEO.TIO2
B:
FEO
FE2O3

Figure 28

several wt.% of aluminium and magnesium and trace or minor quantities of the other elements. A linear series exists between the first formed opaques in the alkali-olivine basalt-trachyte series ranging from close to ulvöspinel in the basalts (groundmass magnetite) towards magnetite in the more intermediate rocks. In part, this trend is likely to be due to presence of rare ilmenite exsolution in the latter thus subtracting titanium. A similar differentiation trend is recognised in the titaniferous magnetites from the Top Square alkaline intrusion of New South Wales, Australia (Wilkinson 1965).

Within certain mugearites or hawaiites e.g. specimen Sk740810, large titaniferous magnetites are often encountered. Possibly these are early phenocrysts which have undergone some degree of resorption and reaction as indicated by a more to rim traverse (figure 28B). Alternatively they could be xenocrystic being derived from the mechanical break-up of wall rocks in the conduit as their rims are slightly more akin to hawaiitic magnetites while the cores more closely resemble the mugearitic magnetites in figure 28A.

Plotted in figure 27 (Ti-Fe-Al-Cr), the Skye magnetites lie on or very close to the Ti-Fe join in both instances. They are more titanium rich than equivalent magnetites from e.g. Tristan da Cunha (in Thompson 1973) but not surprisingly identical to earlier Skye data given by Thompson. A trend from basalt to trachyte similar to that of figure 28 is seen.

In comparison with the magnetites of the Small Isles lavas (Ridley 1973) those of Skye are considerably more TiO_2-rich in terms of weight percent and also appear significantly richer in Al_2O_3. MgO and MgO contents are comparable. Ilmenite is common in the Small Isles volcanics but is rare in the Skye lavas examined. It is present moreso in the evolved rocks than the basalts. In this respect the Skye lavas appear unusual in not producing much in the way of definite ilmenite. This is possibly the controlling factor in producing such high TiO_2 magnetites. Where exsolution is present (increasingly so in the more evolved rocks) the magnetite has lower TiO_2 and this is reflected in the trends developed in figures 27 and 28.

8.4.iii) Ilmenites

Two analyses of a mineral abnormally rich in TiO_2 (48 wt.%) and plotting close to the Pseudobrookite position within the system FeO-Fe_2O_3-TiO_2 are recorded in the Skye lavas (figure 28A); firstly a phenocryst in the transitional trachyte (specimen Sk750806) and secondly accompanying a large poikiloblastic crystal of titaniferous magnetite within an olivine + plagioclase + clinopyroxene granular hornfels near the margins of the Cuillin gabbros (specimen Sk760805). The relative proportion of TiO_2 is similar to that in the ilmenites of the Sgurr of Eigg pitchstone (Ridley 1973) and Skaergaard (Vincent and Phillips 1954, in Deer, Howie and Zussman 1966, p.413 anal.1.) but is considerably different in terms of wt.% - Skye 48, Skaergaard 50, Eigg 45 and 38.

The Skye analyses contain more Al_2O_3, Cr_2O_3, MnO and NiO than comparable ilmenites from a transitional Skye basalt analysed by Thompson (1974). Magnesium contents are identical.

In all, the Skye samples appear to be oxidised ilmenites.

8.4.iv) <u>Hercynite Spinel</u>

Boyd (1974) in a study of composite bodies belonging to the alkali-olivine basalt to trachyte suite includes some examples from Skye and reports the presence of very rare phenocrysts of hercynite spinel in big-feldspar hawaiite upper member of the Dun Ard an t-Sabhail flow. This study confirms their presence but suggests rather that they are either xenocrysts or very early phenocrysts which have marginally reacted with the groundmass producing considerable compositional differences from core to margin.

In size, they range from 0.1mm to over 5mm and have so far only been located within the upper member of the flow. They are black in colour but brownish-translucent in section. Core compositions reveal that substantial $Fe^{2+} \rightleftharpoons Mg$ substitution has taken place with MgO between 12 and 13 wt.%, unlike the spineliferous titanomagnetite margins and groundmass compositions which have MgO at 2 to 3 wt.%. Only very limited $Al \rightleftharpoons Cr$ substitution has occurred and the dominant type is more likely to have been $Al \rightleftharpoons Fe^{3+}$.

The reaction trend is shown in figures 26, 27 and 28B. In figure 27 a trend away from Al towards enrichment in total Fe and TiO_2, followed by a slight drop in Fe but substantial increase in TiO_2 until a composition equivalent to the titaniferous magnetites of other hawaiites is reached, is noted. This trend is mirrored in figure 28B but the presence of MgO and Al_2O_3 in the analyses considerably distorts the picture. Similar trends involving Al and Fe have been noted in chrome-bearing spinels eg. Ridley (1977).

The hercynites show little variation in composition and only low percentages of minor elements. NiO is around 0.1 wt.% rising to 0.15 wt.% at the margins although this is probably not a significant increase, considering an error of between $\pm$0.05 and 0.08 wt.%. However, MnO rises very significantly from 0.15 to 0.4/0.7 wt.% in a similar traverse. Low levels of CaO and Na_2O are only found significantly at the margins and mostly thought to be due to contamination or reaction.

8.5 Biotites and Amphiboles

Secondary biotite and amphibole are found to some extent in nearly all the lavas examined.

Biotite is a common deuteric mineral, associated with titaniferous magnetite but only becomes significant and phenocrystic in the most evolved lavas such as those in the Bracadale region (Anderson and Dunham, 1966; Thompson et al. 1972). No such lavas are seen in west-central Skye and primary poikilitic biotite is only really prominent in some sections of the Portnalong benmoreite. No analyses were made.

Amphibole, in the form of basaltic hornblende or a similar calcium hornblende is found as an important constituent in two of the lavas examined. In both cases (specimens Sk740311 feldspar macroporphyritic hawaiite and Sk7705 alkali trachyte) it is strikingly brown to light brown to reddish-brown pleochroic and is generally euhedral (see Chapter 7, plates 60 + 73). The coarse grain size of Sk740311 indicates that the hornblende is a groundmass constituent and is not considered a micro-phenocryst. The euhedra in specimen Sk7705 however, are obviously phenocrysts. Unfortunately, due to myriads of small magnetite inclusions and exsolution blebs, the analyses (Appendix 3 , Table 4) are somewhat confused and obviously contaminated. This, and alteration suggest that the analyses would be of little value. Nevertheless the compositions are comparable in most respects to the lamprobolites/basaltic hornblendes of Sk740311 excepting MgO which is much lower. Cleavage traces on a few examples give typical amphibole-type angles. Significant TiO_2 and Na_2O also appear in the analyses of both Sk740311 and Sk7705 but are abnormal in the latter due to alteration and contamination. Alternatively, the scattered phenocrysts in specimen Sk7705 may be somewhat similar to kaersutite, a titanian amphibole related to lamprobolite.

Greenish to pink to brownish green pleochroic groundmass phases in Sk7705 are thought to be sodic pyroxenes. However, some development of interstitial hornblende which is deeply pleochroic also characterises this rock and along with biotite is possibly best ascribed to deuteric alteration.

8.6 Accessory Minerals

True accessory minerals, thus excluding secondary alterations and zeolites are not too common and often difficult to recognise primarily because of the rather fine grain size of the majority of the lavas. Analcite may occur interstitially in some of the olivine basalts but it too is thought to be mostly of secondary origin. Despite the obvious alkalic nature of the basic volcanics no primary analcite or nepheline or their pseudomorphs was found. That such phases do occur in related alkalic rocks from the Tertiary Igneous Province has been shown by Gibb (1978). Free quartz is seen in very small amounts, possibly in micro-amygdales although not abundantly, within the transitional quartz-normative trachyte/ andesite of Sleadale but is not recorded in any other lavas affirming their alkalic undersaturated affinities. If phenocrystic, the quartz would be co-existing with a rather strange assemblage of plagioclase + alkali feldspar + magnetite + clinopyroxene + apatite and it might be suspected that this lava flow was in some way hybridised or mechanically mixed. A quartz + 2 feldspar phenocryst assemblage characterises known intrusive hybrids such as those of the Marscoite Suite. Apatite is a major constituent (although here considered accessory) of only the trachytic rocks but in truth it must be fairly abundant within the interstices of the hawaiites and mugearites as it alone can be responsible for the relatively high P_2O_5 contents of the respective analyses. It occurs as pale bluish-pink to bluish-grey diachroic euhedra in glomeroporphyritic aggregates along with plagioclase + clinopyroxene + magnetite in the Sleadale Trachyte but in the more alkalic rocks is generally elongated parallel to their flow structures and the characteristic cross-sections are rare. In all cases it is full of minute opaque inclusions of unknown constitution.

CHAPTER 9

GEOCHEMISTRY OF THE TERTIARY VOLCANICS AND ASSOCIATED ROCKS

9.1 Introduction

The earlier studies of Hebridean Lavas (Harker 1904, 1908; Bailey et al., 1923; Kennedy 1931; Patterson 1955; Muir and Tilley 1961; Tilley and Muir 1962) recognised that the major lava-fields were characterised by mildly undersaturated to transitional alkaline types while the plutons and lavas of the 'Central Intrusive' areas were apparently associated with a more silica-saturated 'tholeiitic' lineage. Rapid quantitative analytical techniques were not available to these workers and many of the concepts and magma series established were founded upon what must now be regarded as a very limited amount of data on probably altered samples (Muir and Tilley 1961). Not until the last decade or so have the lavas and associated minor intrusions of the Tertiary Igneous Province been the subjects of renewed and concerted geochemical and structural research. The work of Thompson et al. (1972), reassessing the major element chemical variation in the lavas from the northern half of the Isle of Skye earlier investigated by Anderson and Dunham (1966) has suggested that within the mildly alkaline series, two distinct trends or lineages can be recognised. Recent studies of the Tertiary Mull volcanics has revealed a similar pattern (Beckinsale et al., 1978) while the widespread lavas in Central and Southern Scotland apparently consist of several closely comparable but distinguishable lineages (MacDonald 1975; et al. 1977) The abundant minor intrusions of the Tertiary Province as a whole, especially the Regional Dyke Swarms might be expected to reveal a wider range of lineages of 'magma-types' than the volcanics as many of the latter have long since been eroded away. That this is indeed the case is adequately reflected in the geochemical studies of the Skye Regional Dyke Swarm by Mattey et al. (1977) and the Mull, Islay and Jura Regional Dyke Swarms by Lamacraft (1978). Many of the magma-types thus defined are either absent or at best poorly developed in the associated lava fields and consequently the range of lithologies and types defined by the lavas does not reveal the complete picture.

This chapter reports the analyses (major and trace elements) of the lavas and a representative selection of intrusions from west-central Skye and compares them to previously established types.

9.1.i) Sampling

Throughout the area studied (figure 1) exposure is varied and the degree of alteration of many of the lavas high and pervasive. Wherever possible, fresh or apparently fresh samples were collected from continuous cliff sequences or from successive flow-terraces, care being taken to avoid highly weathered or amygdaloidal specimens except where this was necessary for comparative chemical and secondary mineralisation studies. Both features however, were found upon examination in thin section to be virtually impossible to eliminate. As a general indicator of relative freshness, the presence of unaltered olivine is a useful criterion. All the basaltic rocks sampled have fresh olivine and only in a few cases have these crystals been partially pseudomorphed. Likewise, groundmass clinopyroxene is generally fresh. The intermediate rocks show an increasing tendency of interstitial groundmass alteration to chlorite + serpentine + magnetite assemblages. Thompson et al. (1972) saw this as correlating with the appearance of deuteric amphibole in these lavas subsequent to extrusion. Only limited groundmass amphibole was encountered in the intermediate lavas of west-central Skye but an obvious example of its probably ubiquitous presence is seen in specimen Sk740311; a coarse-grained feldspar macroporphyritic hawaiite from Beinn nan Dubh Lochan (see Chapter 7, plate 60). Minor intrusions were sampled in much the same manner although to a lesser extent than the volcanics. Samples were also collected from the various intergroup sedimentary horizons and widely distributed 'boles' and are dealt with towards the end of this chapter. Finally, lavas, intrusions and variously graded hornfels were also sampled within the thermal metamorphic and hydrothermal aureole developed around the Cuillin Hills Intrusive Complex; the results being discussed in the following chapter.

9.1.ii) Sample preparation and analysis

Individual samples, after having had any weathered surface and vegetation removed on a diamond impregnated grinding wheel, were split into small chips using a Cutrock Engineering Hydraulic Splitter. A few fresh-looking (minus weathered surfaces or foreign matter) coarse-gravel sized pieces were then passed through a Sturtevant 2" x 6" Roll Jaw Crusher in order to reduce their size prior to grinding to a fine powder in a Tema Laboratory Disc Mill (T100) with a tungsten-carbide Widia grinding barrel for a period of time usually not exceeding four minutes and often substantially less in order to give a sufficiently fine powder and reduce excessive oxidation

(Fitton and Gill, 1970). The collected powders were then pressed into rock-powder briquettes on a manually operated hydraulic press delivery 5-6 tons P.S.I. using a PVA inert binder (MOWOIL) and labelled. The chief advantage of this method over fusion techniques is the considerable saving in time; disadvantages are numerous but include the need for sophisticated computer correction techniques after analysis. Selected powders were analysed for $H_2O_{(Total)}$, FeO and CO_2 (Table 8).

Both major and trace element determinations were carried out on a Philips PW1212 Semi-Automatic Sequential X-ray Fluorescence Spectrometer incorporating a Torrens Industries TE108 Automatic sample loader. The analytical data thus produced for unknowns and standards alike was corrected for Mass Absorption and Matrix effects as described by Holland and Brindle (1960, 1966) and Reeves (1971).

The standards used were a selected combination of U.S.G.S. and Lunar International Standards supplemented by a selection of wet chemically analysed rocks, mostly of alkaline or mildly-alkaline to transitional affinities from such localities as East Greenland, Reunion and Skye itself.

The C.I.P.W. Normative data (Appendix 2) was

TABLE 8

Non-X.R.F. Analyses of selected rocks for H_2O (total), FeO and CO_2.

Specimen	Type	H_2O	FeO	FeO (Standard)	CO_2
Sk740104	ol.B	2.97	8.39	9.51	n.d.
" 0201	ol+pl.B	2.74	11.19	11.37	0.06
" 0202	Haw.	2.03	12.07	12.34	0.10
" 0204	Mug.	1.33	10.62	9.89	n.d.
" 0401	"	1.01	10.61	10.55	0.09
" 0501	Haw.	2.28	6.89	9.52	0.11
" 0512	"	0.66	9.77	10.63	0.03
" 0606	Aphyric B	2.75	8.65	9.79	n.d.
" 0607	ol+sp.B	2.54	10.24	10.39	0.04
" 0801A	Mug.	1.80	10.54	11.30	n.d.
" 1002	ol.B	2.67	9.48	11.30	0.05
" 1101	Mug.	2.30	9.22	10.19	0.05
" 1103	ol.B	2.28	9.44	11.03	n.d.
" 1111	Haw.	1.13	9.52	11.21	n.d.
Sk750301	ol+sp.B	4.01	10.13	10.82	0.11
" 0303	Amy "	7.22	11.89	11.47	0.30
" 0305	Bole	3.54	2.46	18.23 (total)	0.84
" 0707	ol+pl.B	2.01	10.41	10.66	0.06
" 0805	Int.Trachyte	0.97	3.53	3.26	n.d.
" 0810	L.A.T.	1.17	9.03	9.67	0.07
" 0813	L.A.T.	0.70	9.26	9.41	0.05
" 1212	ol+sp.B	1.47	9.67	10.31	0.05
" 1801	Mug.	1.37	8.93	8.89	0.03
" 1901	pl.macro B(meta)	4.49	9.85	9.79	0.11
" 1902	" " "	2.17	10.37	8.32	0.18
Sk760703	Comp.Haw.	1.27	7.31	8.27	0.07
" 0809	Peridotite	2.76	8.35	9.86	0.02
" 03	Alk.Trachyte	0.66	3.82	3.75	0.01
" 04	" "	1.80	3.97	4.12	n.d.
" 26	Andesite Sill	2.18	8.02	8.08	0.02
" 29	" "	2.04	9.13	8.30	0.03

calculated using the computer program NORMCAL; a modified translation by a former Durham post-graduate student, R.C.O. Gill, of an Atlas Autocode Program developed by R.F. Cheeney at Edinburgh University.

Coombs (1963) and Thompson et al. (1972) advocated allocating standardised values of Fe_2O_3 to each analysis on the basis of total alkali (K_2O + Na_2O) content so that a more direct comparison could be made between samples (especially their norms) as this would tend to allow for the post-extrusion oxidation of the lavas. Their example has been followed in this thesis despite evidence that this procedure causes changes of several percent in normative ferromagnesian minerals especially, which in some cases are sufficient to change the norms from silica-saturated (hypersthene normative) to silica undersaturated (nepheline normative) and vice-versa. This method also takes no account of the alkali content introduced into the rocks by zeolite depositing hydrothermal solutions. The standardised values were calculated as follows:

Alkalis Range %	Standardised Fe_2O_3 value %
0-2	1.00
2-3	1.25
3-4	1.50
4-5	1.75
5-6	2.00
6-7	2.25
7-8	2.50
8-9	2.75
9 and over	3.00

These are a modified version of those of Thompson et al., arranged to encompass a wider range of total alkalis. Also using this technique, FeO (Standardised) was calculated from the total Fe_2O_3 (XRF Analysis). These standard values are compared with those arrived at directly by wet-chemical analyses in Table 8. Several samples show that FeO (Standard) approximates quite well to FeO (Wet Chemical Analysis) and the technique is therefore reasonably reliable. However, several other analyses show widely differing values (up to 2 wt.%) and indicate that the data and its interpretation should still be treated with caution.

The accuracy achieved in following the analytical procedures used in this department is uncertain but the precision of the results is considered satisfactory considering the number of samples, standards and various variables likely to effect the analysis. By running samples at the beginning and end of successive analyses the errors in each were found to be as set out in Table 9. Also, by comparing samples collected from various positions within the same flow, e.g. trachytes Sk750804-06 and Sk7625 (Sleadale) and also Sk7603-05 (Scarall) and the benmoreite Sk77010-11, a measure of the intraflow variation at the more evolved end of the lavas is found (Appendix 1, Table 4). A feature

TABLE 9

Approximate errors in X.R.F. Analyses achieved by analysing specimens at the start and end of successive runs (±).

		Sk751211-12 olivine + spinel basalt	Sk740305-06 olivine basalt	Sk750703A-B Mugearite
wt.%	SiO_2	0.06	0.16	0.12
	Al_2O_3	0.12	0.85	0.01
	FeO (Standard)	0.17	0.41	0.04
	MgO	0.03	0.50	0.13
	CaO	0.01	0.18	0.05
	Na_2O	0.01	0.03	0.43
	K_2O	0.01	0.04	0.24
	TiO_2	0.01	0.15	0.4
	MnO	0.01	-	-
	P_2O_5	-	0.04	0.05
ppm	Ba	-	42	24
	Nb	1	3	2
	Zr	1	4	2
	Y	2	-	2
	Sr	7	22	110
	Rb	-	1	-
	Zn	-	3	6
	Cu	2	1	3
	Ni	5	5	4
	Cr	105	-	2

of all the analyses, despite the corrections applied is the high totals which, when H_2O and CO_2 (Table 8) are considered in addition, are usually in excess of 100%.

9.2. Classification

The geochemical classification scheme utilised in this study involves the following criteria: normative and modal feldspar types, the Thronton Tuttle Differentiation Index (normative % Quartz + Albite + Orthoclase + Nepheline) and whether or not the rock is saturated or undersaturated with respect to silica. The total alkalis content of the basaltic rocks has also been used on a relative basis and the division of the rock types into the various petrographic types outlined in Chapter 7 appears to have little effect on the geochemistry of individual types except where phenocrysts are abundant e.g. olivine + spinel porphyritic, olivine + plagioclase porphyritic or feldspar macroporphyritic basalts.

Basaltic rocks all have Differentiation Indices generally less than 30-32 and contain both modal and normative labradorite (figures 25 and 32). Alkalic Suite basalts are characterised by high total alkalis (approximately 2-4½%) relative to those of the Tholeiitic Suite. The majority of alkali-olivine basalts contain substantial olivine as a phenocryst phase and their norms are characterised by high olivine values with nepheline or hypersthene. In addition, they usually contain a mesostasis of zeolites and commonly analcite. The Tholeiitic Suite basalts contain normative olivine and hypersthene and those distinctive in their alkali and calcium contents are termed low-alkali, high-calcium olivine tholeiites (LAT's) in accordance with the classifications of Thompson et al.(1972) and Esson et al.(1975). A third group of basaltic rocks are transitional to the Alkalic and Tholeiitic rocks, containing sparce olivine and occasionally clinopyroxene microphenocrysts accompanying rare plagioclase microphenocrysts. They too contain normative olivine and hypersthene. In general terms the Alkalic Suite basalts (olivine ± spinel ± plagioclase porphyritic) possess a higher percentage normative olivine than the other basalts, with the Transitional Suite having characteristically intermediate values. Quartz only appears in the norms of some tholeiitic dykes.

Classification of hawaiites and mugearites using the Thornton-Tuttle Differentiation Index, if restricted to specific intervals results in discrepancies with classifications based on the original definitions of these rock types by Harker (1904) and Iddings (1913) and redefined and restricted by Walker (1952), Wells (1954)

MacDonald (1960) and Muir and Tilley (1961). Approximate boundaries between basalt and hawaiite are at D.I. = 30-32 and between hawaiite and mugearite at D.I. = 45-50. The normative feldspar ranges for hawaiite and mugearite are Andesine An_{30-50} and Oligoclase An_{15-30} respectively although some overlap occurs if the Differentiation Index is used as the primary datum.

The boundary division between mugearite and benmoreite occurs at about D.I. = 65; that between benmoreite and trachyte at around D.I. = 75 with the normative and modal feldspars both becoming still more progressively sodic and potassic. Evolved members of the sub-Alkalic Suite can usually be distinguished in the field by their pale-grey colour compared to the darker hues of the equivalent rocks of the Alkalic Suite. Petrographically, those rocks with D.I. $>$ 65 are very distinctive in the field as they may contain obvious phenocrysts of biotite, quartz and amphibole in addition to alkali-feldspar (Anderson and Dunham 1966; Thompson et al. 1972). Such species are not found in the less salic lavas. The trachytes both carry normative quartz + hypersthene.

Microprobe analyses of groundmass feldspars in this study (Chapter 8; Appendix 3, Table 3) indicate that in many instances modal feldspar is not the equivalent of normative feldspar or that the range is different to those quoted by Tilley and Muir (1962, 1964) and Muir and Tilley (1961). Thus some hawaiites may contain groundmass plagioclase laths with cores as calcic as labradorite and some mugearites may have andesine as opposed to the expected oligoclase. This point that the feldspars generally fall towards more calcic compositions than expected has also been made by Keil *et al*. (1972) and Boyd (1974). In this study, where overlap of criteria occurs, the Differentiation Index has been given priority and the lavas named accordingly.

9.3 Chemical variation and petrogenesis of the lavas and intrusions

On geochemical grounds alone some four suites, some perhaps representing true 'magma types', are identified among the lavas and intrusions of west-central Skye. In the following chapter these are referred to as:

a) An Alkalic Suite
b) A Subalkalic Suite
c) A Transitional Suite
d) A Tholeiitic Suite

The Tholeiitic Suite, which includes an ultrabasic group and a low-alkali, high-calcium olivine tholeiite group is well represented by minor intrusions and the marginal plutonic rocks of the Cuillin Hills Intrusive

Complex as well as by the Talisker Lava Group, while the Alkalic Suite is almost entirely represented by the lavas and is consequently the main subject of this chapter. A possible sub-alkalic suite, in many respects similar to the Silica- and Potassium-rich and Iron- and Titanium-poor transitional trend within the Skye Main Lava Series of Thompson et al. (1972) is identified on limited data. Evidence for two or more, often sub-parallel, such lineages within what had previously been considered as single suites of alkaline or mildly alkaline affinities has been detected in Mull (Beckinsale et al., 1978) and the Midland Valley of Scotland (Carboniferous) (MacDonald, 1975; MacDonald et al., 1977) in addition to Skye. The Transitional Suite referred to above comprises a small number of lavas and possibly minor intrusions and is in some respects similar to the Fairey Bridge magma type defined by Mattey et al. (1977) having characteristics similar to the Alkalic and Tholeiitic Suites or intermediate towards them. No high-alumina types appear within the lavas.

The pertinent chemical characteristics in terms of both major and trace elements of these suites are shown in figures 29-45 and discussed in turn.

9.3.i) The Alkalic Suite

The majority of lavas sampled appear to constitute a single, often broadly defined trend or lineage, most having 'transitional' or mildly alkaline characteristics but in detail ranging from either nepheline + olivine, or occasionally more transitional hypersthene + olivine normative basalts through rather Iron- and Titanium rich hawaiites and mugearites to benmoreite and the alkali-trachyte of Cnoc Scarall. Their major and trace element variation against the Thornton-Tuttle Differentiation Index and Iron/Magnesium ratio is shown in figures 29 and 30 respectively, while figures 31 and 32 show the ternary AFM and normative feldspar plots.

Taking the basaltic rocks (Differentiation Index < 32, Fe/Mg < 0.7), the majority of which are not aphyric, but rather, carry substantial amounts of olivine ± enclosed chrome spinel or olivine + plagioclase phenocrysts (see Chapter 7), they plot within the alkaline field well above the division line between Hawaiian alkalic and tholeiitic basalts in a total alkalis versus silica plot (MacDonald and Katsura, 1964) and above a similar division between previously analysed Hebridean alkalic and tholeiitic rocks (Ridley, 1973 figure 5). Although containing both hypersthene- and nepheline-normative examples they fall within the field of alkali basalts. The division between these normative types in this study is shown by the dotted line (4) in figure 33 and does not correspond to the

FIGURE 29

Major and trace element data for the volcanic and intrusive rocks of west-central Skye plotted against the Thornton-Tuttle Differentiation Index.

A. Lavas:

- ● Alkalic and sub-Alkalic Suites
- o Composite hawaiite of Dun Ard an t-Sabhail
- + Transitional Suite
- ♦ Low-alkali, high-calcium olivine tholeiite (Tholeiitic Suite)

B. Intrusions:

- ⊖ Ultrabasic plutonic
- ⊕ Gabbros
- ⊖ Granophyre veining
- S Inclined sheets and sills
- ⚹ Dykes

Trends: 1.Relatively Iron-rich alkalic trend
2.Relatively Iron-poor sub-alkalic trend

N.B. These trends correspond loosely with those of Thompson et al.(1972) and are especially evident with elements K_2O, TiO_2, SiO_2, Fe(total), Na_2O and many trace elements e.g. Ba, Nb, Zr, Sr and Zn. At high D.I's there is generally a broad zone which may correspond to these trends.

Figure 29-A

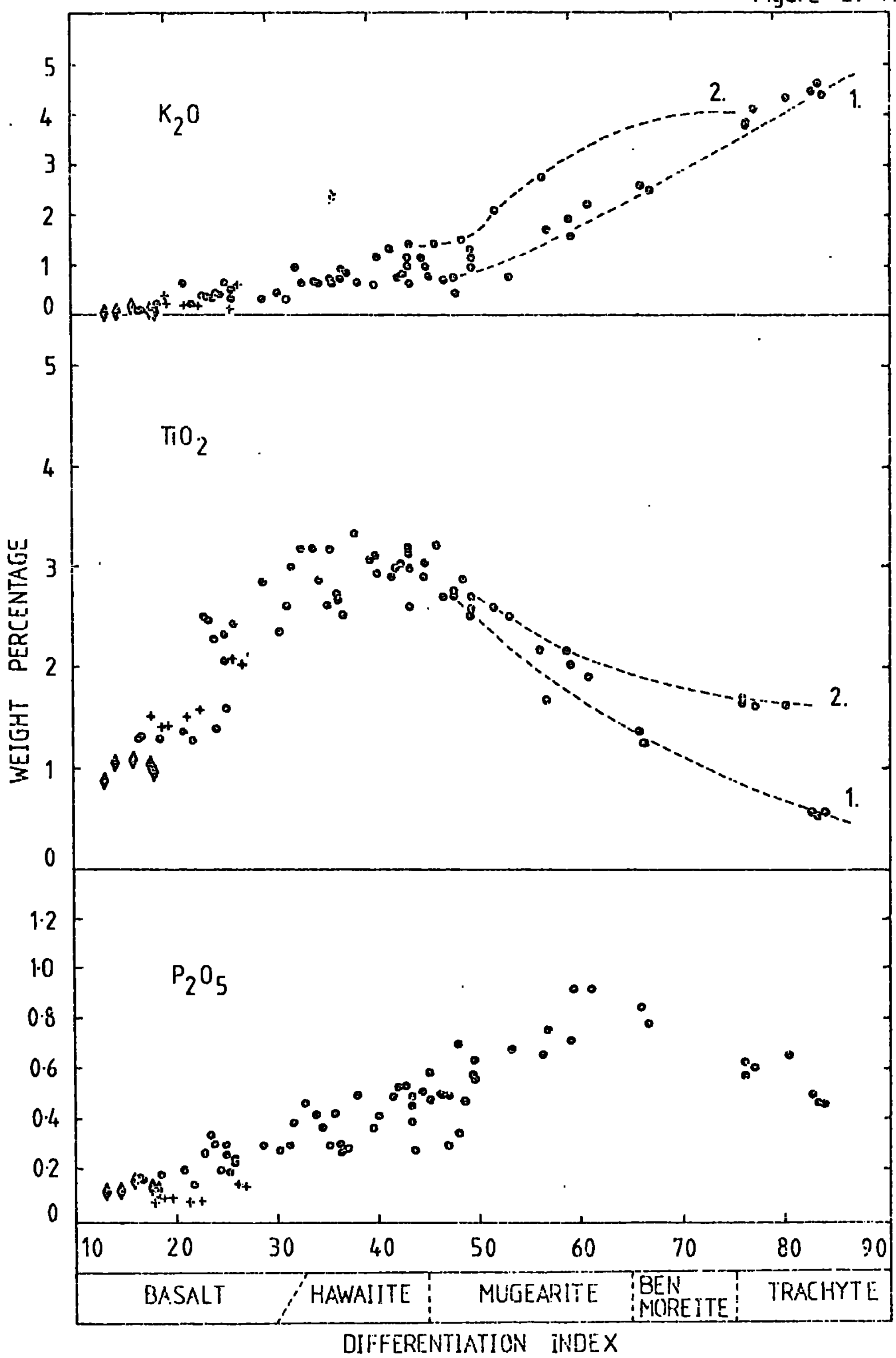
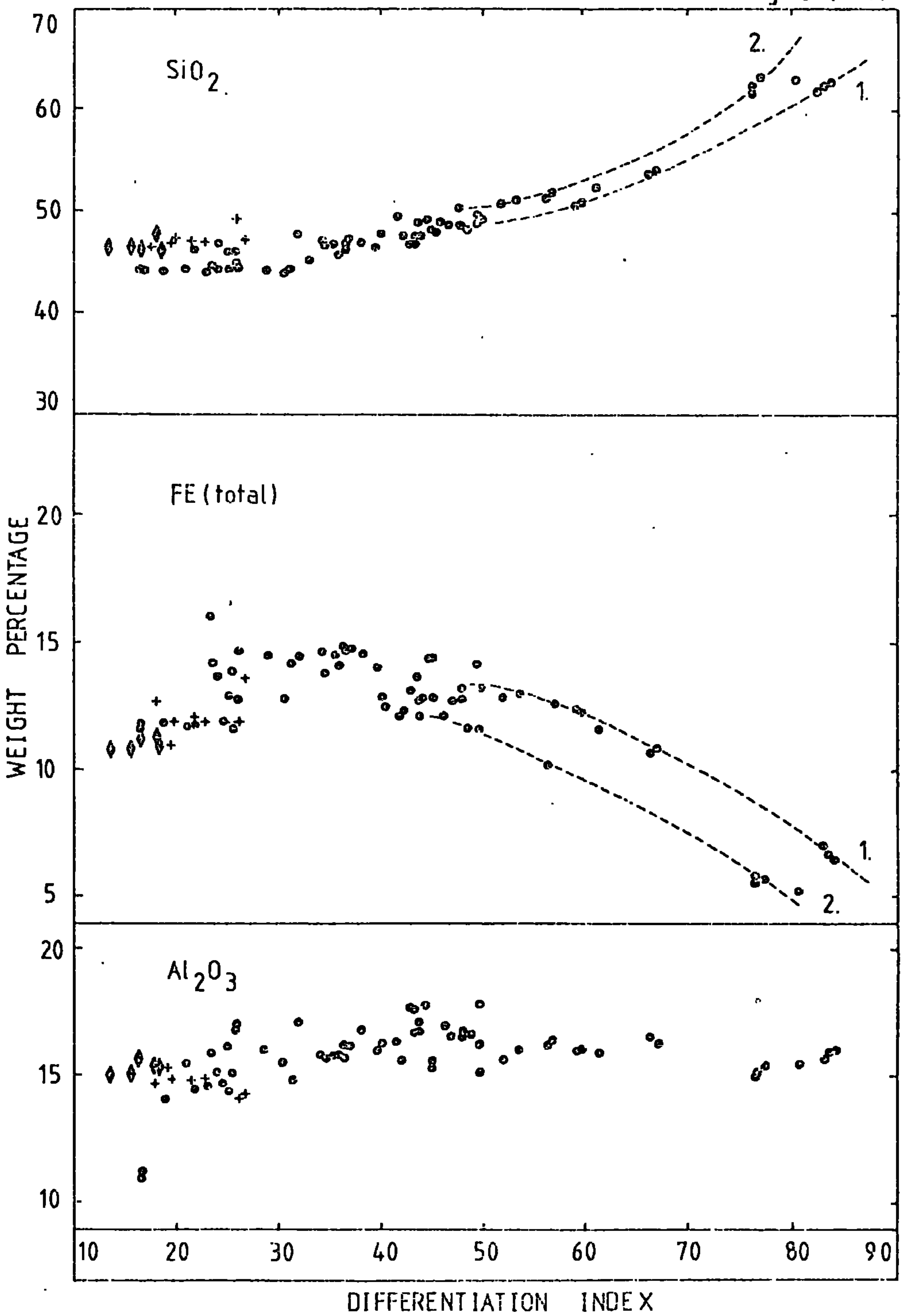

K2O
TiO2
P2O5
WEIGHT PERCENTAGE
5
4
3
2
1
0
1·2
1·0
0·8
0·6
0·4
0·2
2.
1.
10
20
30
40
50
60
70
80
90
BASALT
HAWAIITE
MUGEARITE
BEN MOREITE
TRACHYTE
DIFFERENTIATION INDEX

Figure 29-A



70
60
50
40
30
SiO2
2.
1.
20
15
10
5
FE (total)
1.
2.
20
15
10
Al2O3
WEIGHT PERCENTAGE
10
20
30
40
50
60
70
80
90
DIFFERENTIATION INDEX

Figure 29-A

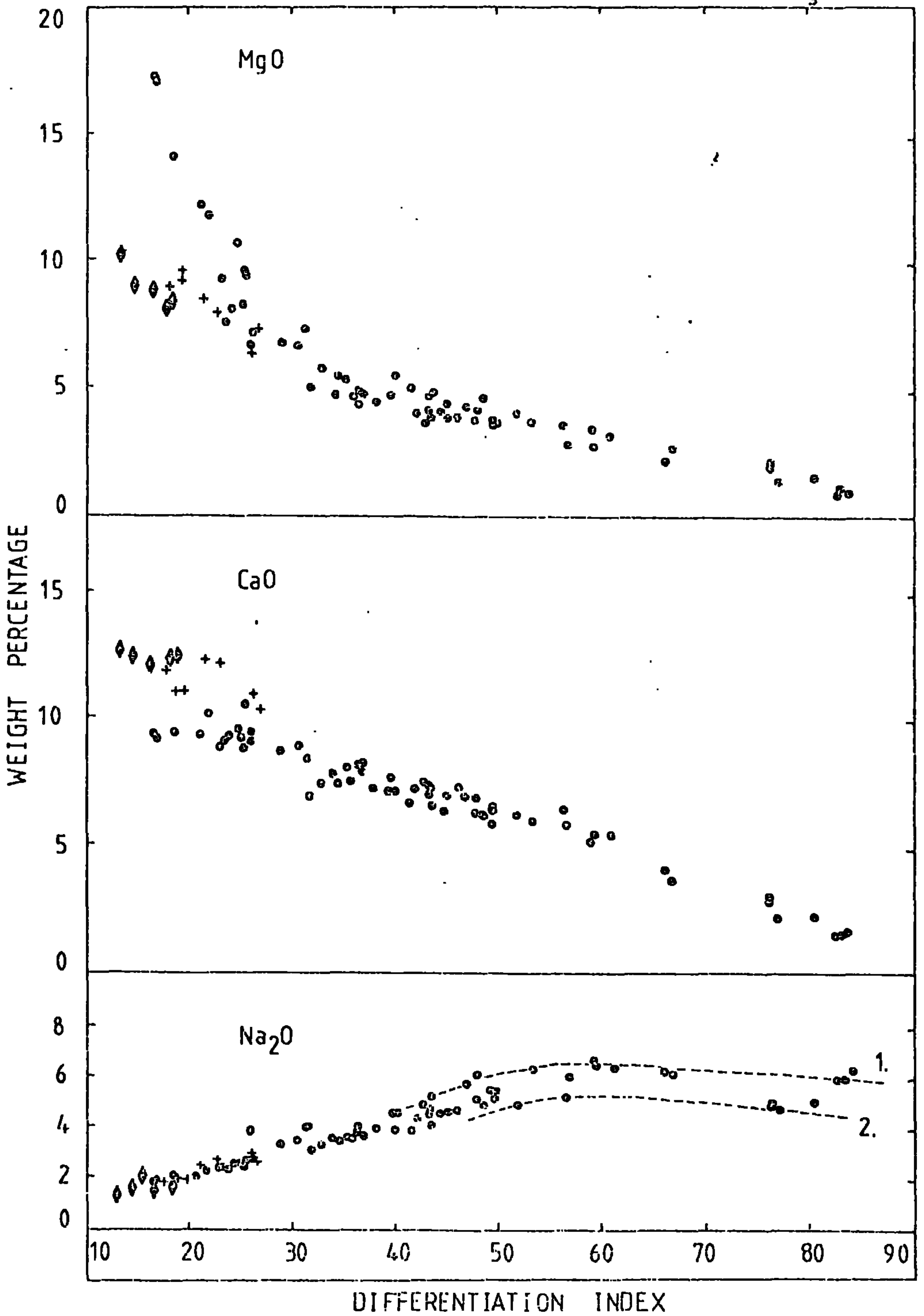

MgO
CaO
Na_2O
WEIGHT PERCENTAGE
DIFFERENTIATION INDEX
20
15
10
5
0
15
10
5
0
8
6
4
2
0
10
20
30
40
50
60
70
80
90
1.
2.

Figure 29-A

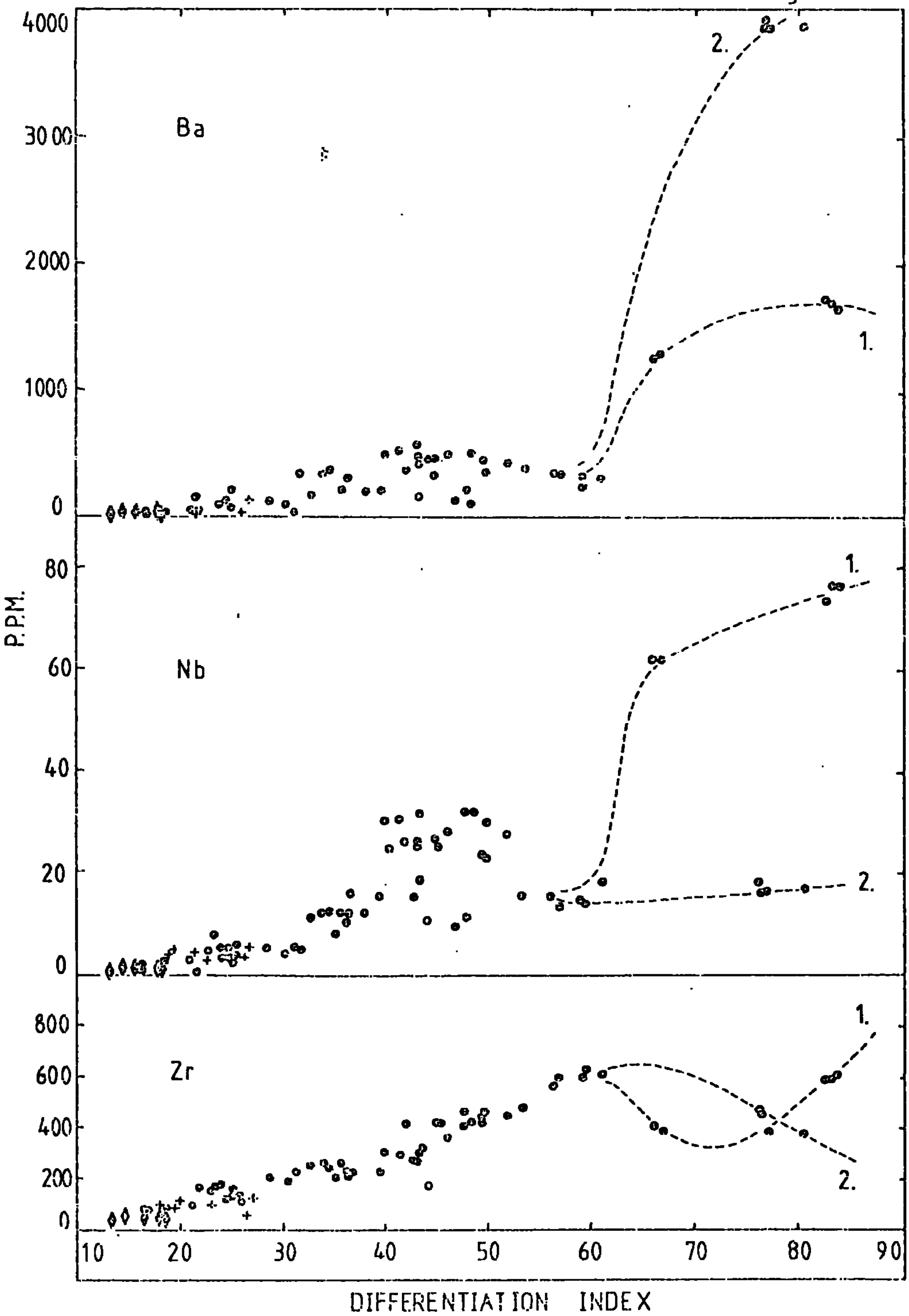

4000
3000
2000
1000
0
Ba
2.
1.
80
60
40
20
0
Nb
1.
2.
800
600
400
200
0
Zr
1.
2.
P.P.M.
10
20
30
40
50
60
70
80
90
DIFFERENTIATION INDEX

Figure 29-A

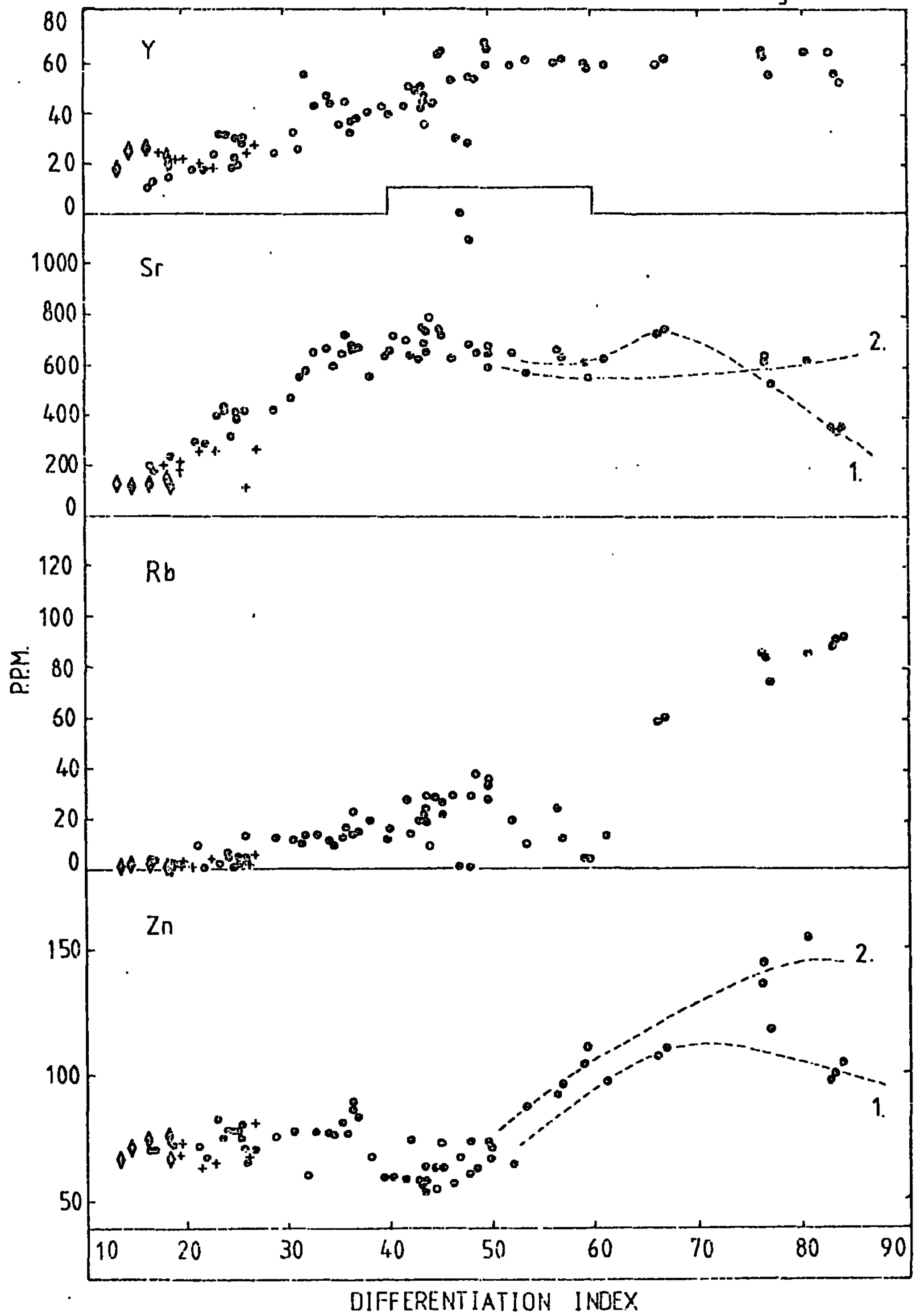

80
60
40
20
0
Y
1000
800
600
400
200
0
Sr
2.
1.
120
100
80
60
40
20
0
Rb
P.P.M.
150
100
50
Zn
2.
1.
10
20
30
40
50
60
70
80
90
DIFFERENTIATION INDEX

Figure 29-A

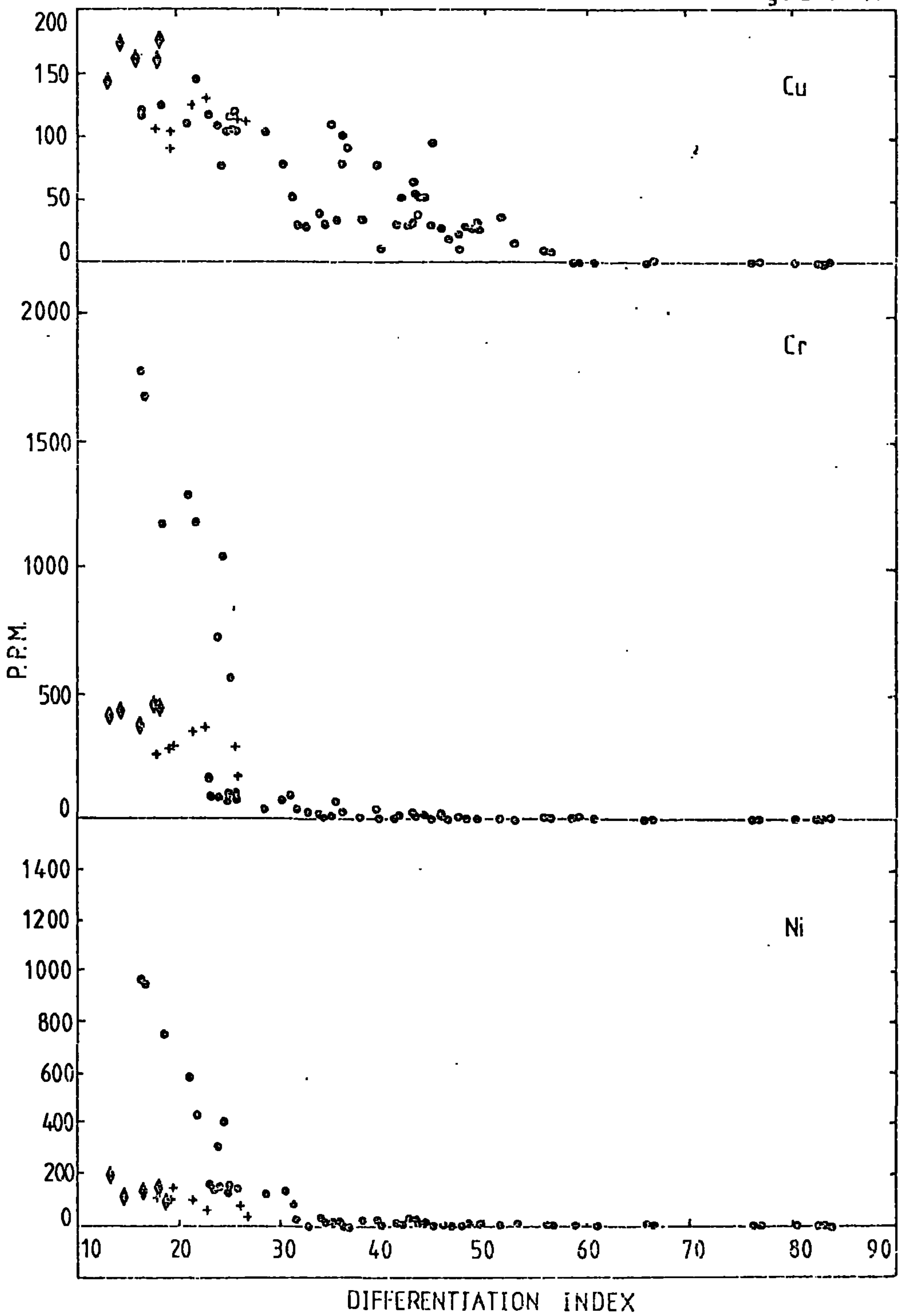

Cu
Cr
Ni
P.P.M.
200
150
100
50
0
2000
1500
1000
500
0
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
DIFFERENTIATION INDEX

Figure 29-B

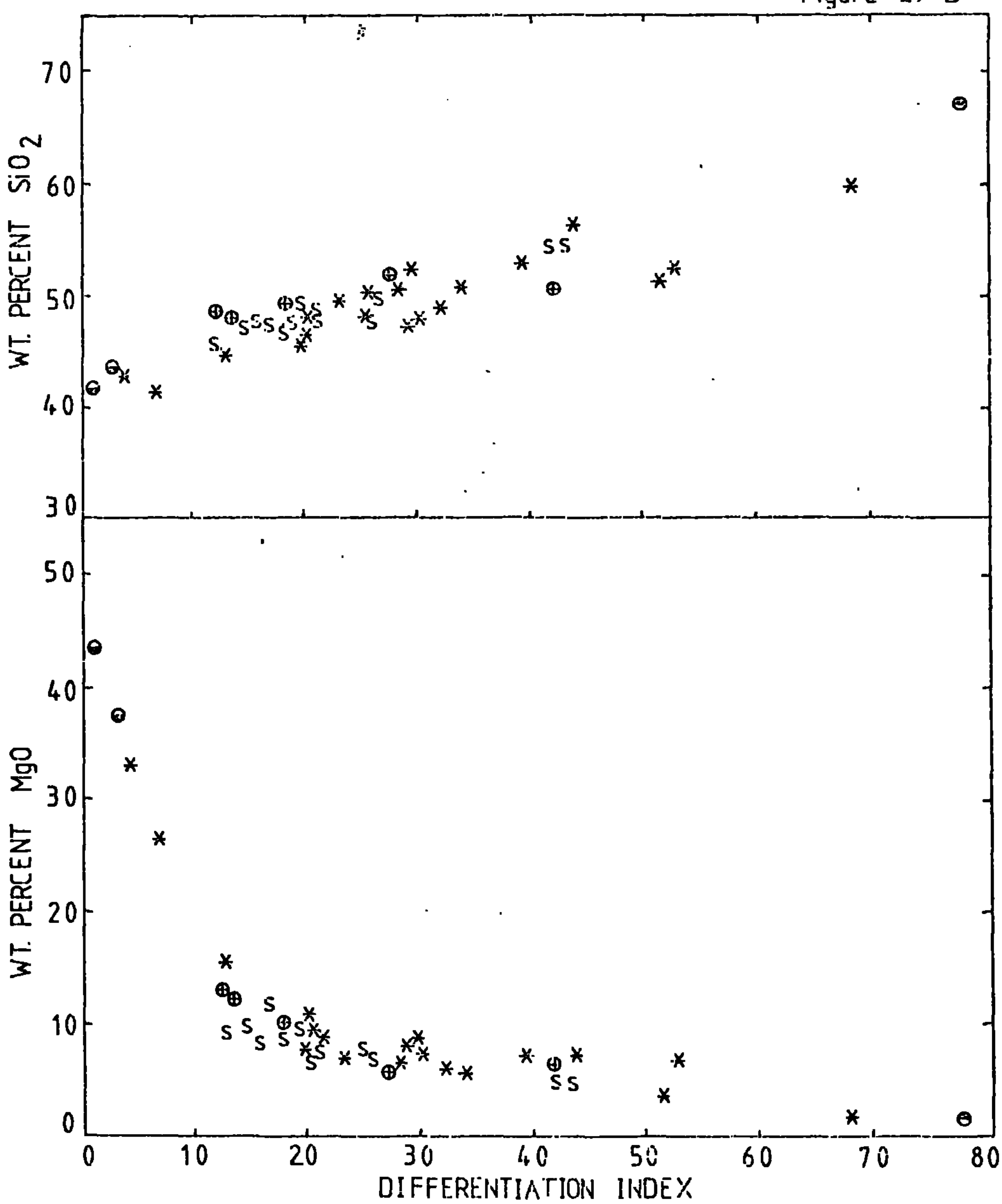

WT. PERCENT SiO2
70
60
50
40
30
WT. PERCENT MgO
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
DIFFERENTIATION INDEX

Figure 29-B

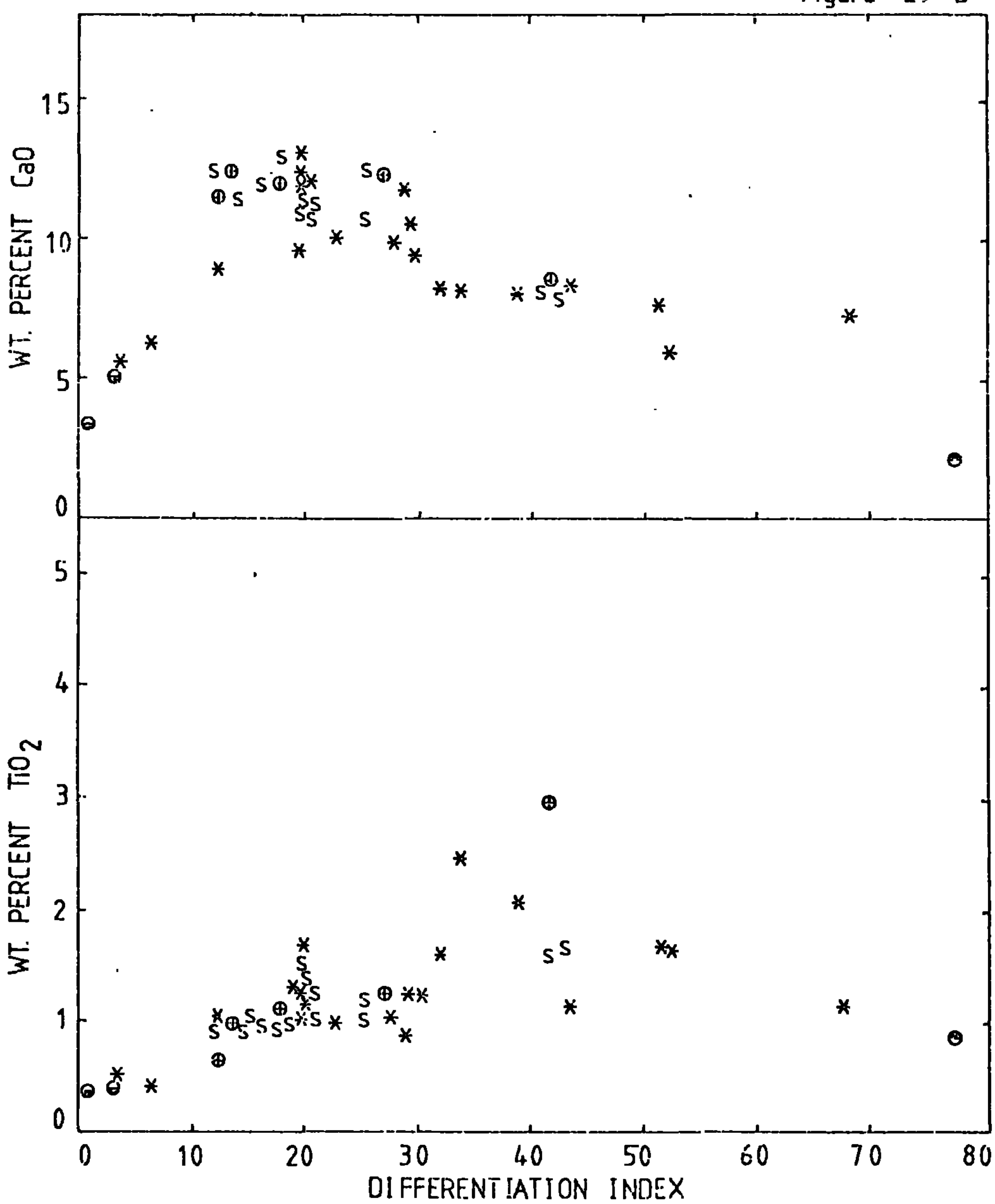

WT. PERCENT CaO
WT. PERCENT TiO_2
DIFFERENTIATION INDEX
0
5
10
15
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80

Figure 29-B

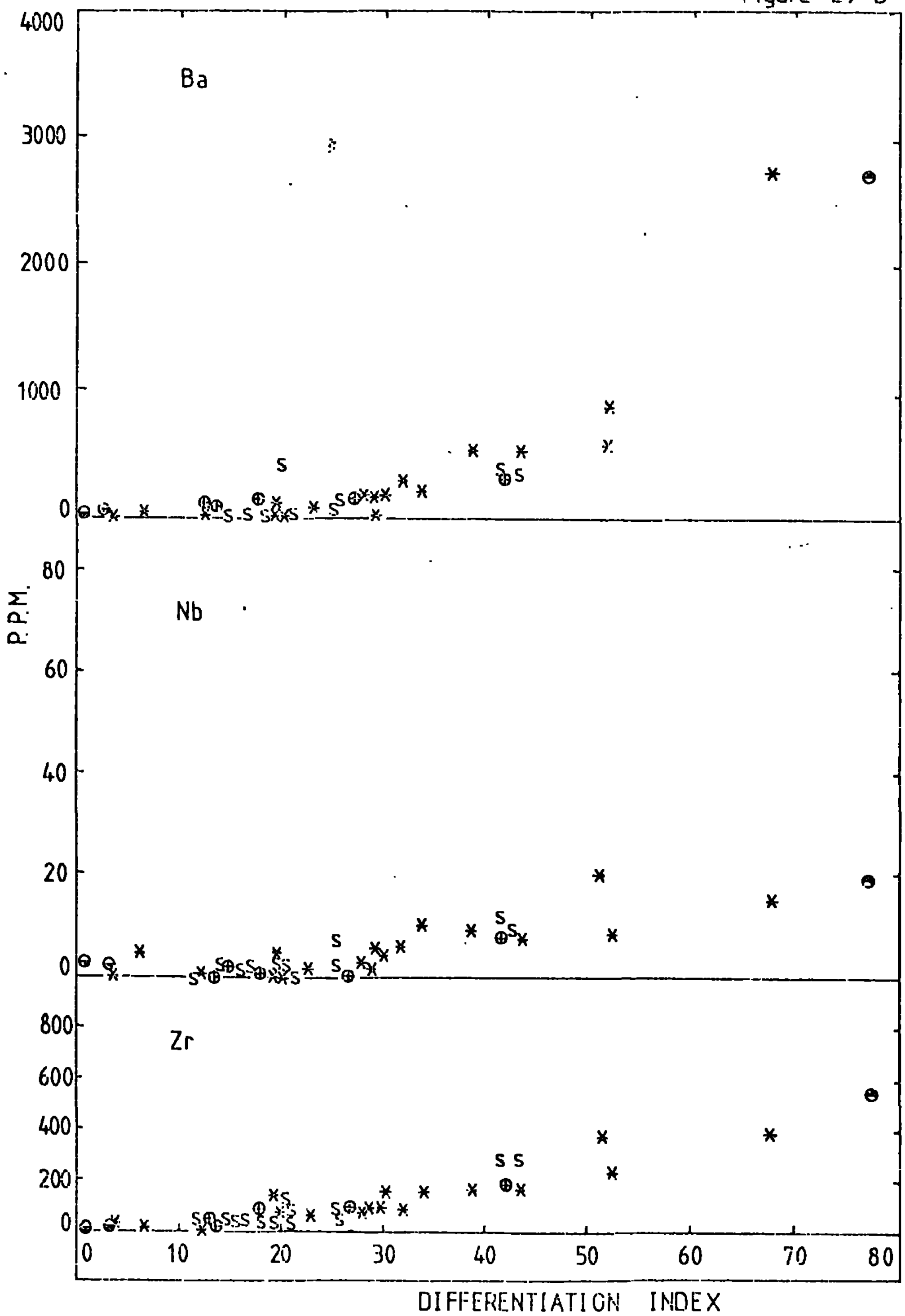

4000
3000
2000
1000
0
Ba
80
60
40
20
0
Nb
800
600
400
200
0
Zr
P.P.M.
0
10
20
30
40
50
60
70
80
DIFFERENTIATION INDEX

Figure 29-B

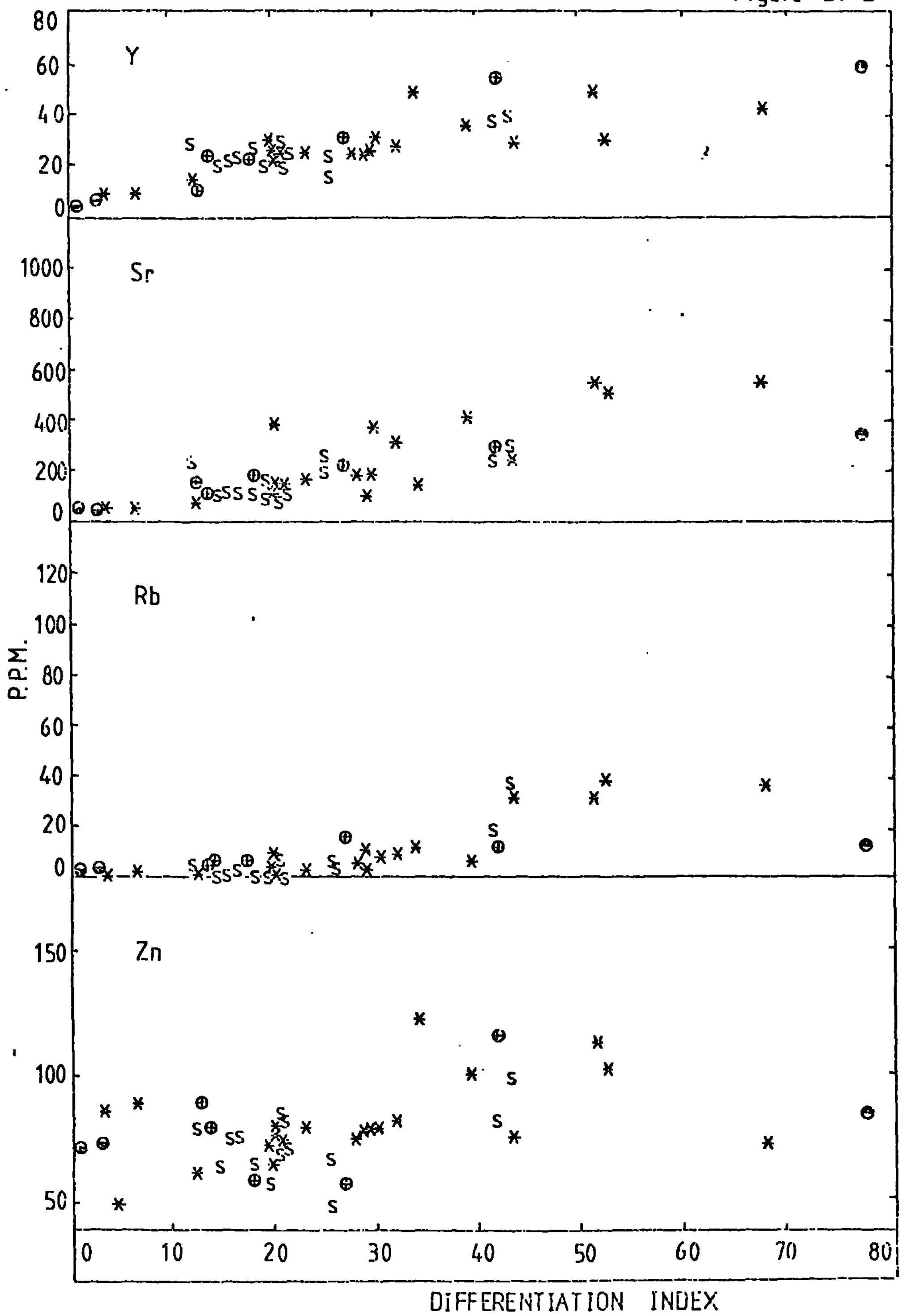

Y
Sr
Rb
Zn
P.P.M.
80
60
40
20
0
1000
800
600
400
200
0
120
100
80
60
40
20
0
150
100
50
0
10
20
30
40
50
60
70
80
DIFFERENTIATION INDEX

Figure 29-B

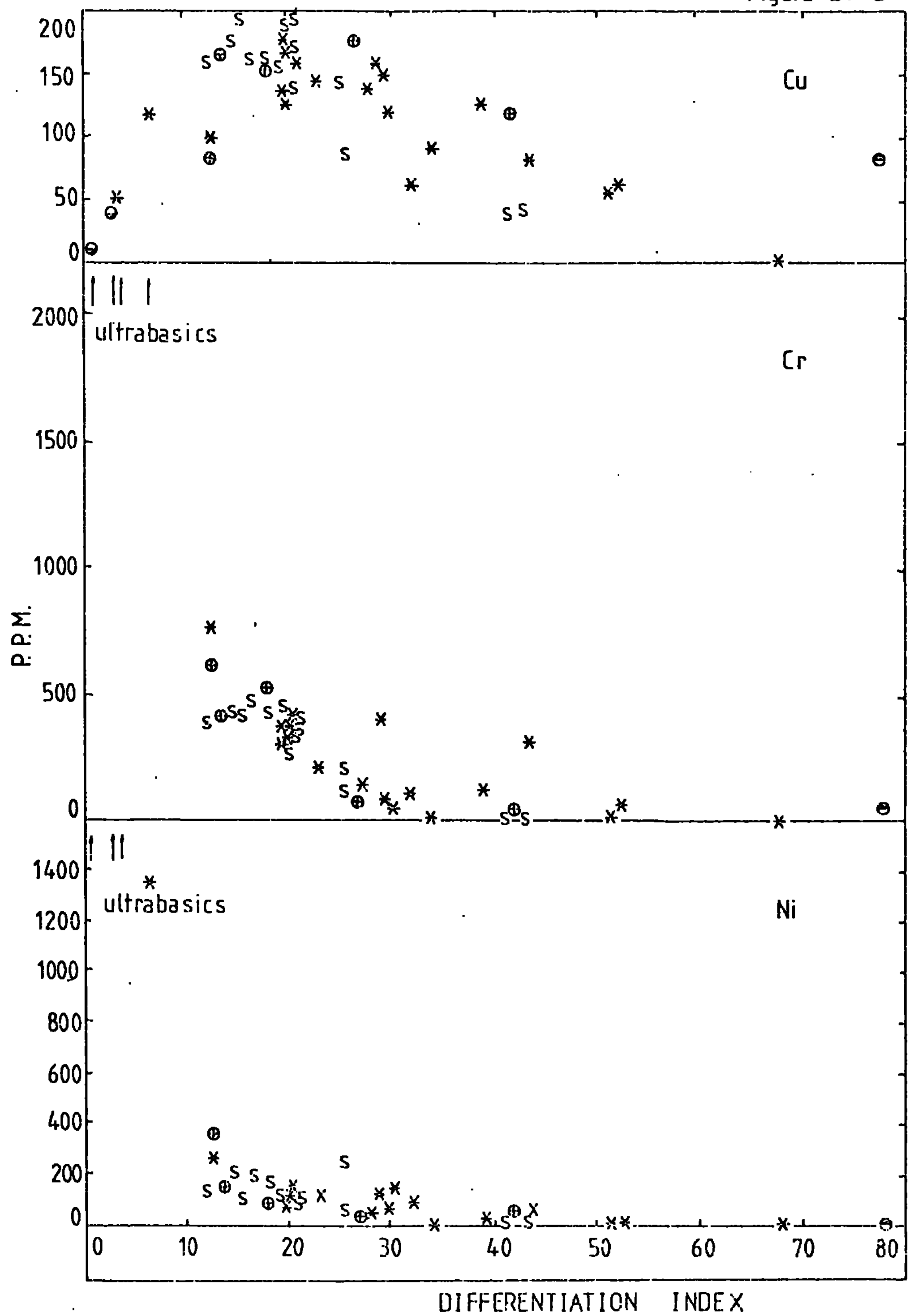

Cu
Cr
Ni
ultrabasics
ultrabasics
P.P.M.
DIFFERENTIATION INDEX
0
10
20
30
40
50
60
70
80
200
150
100
50
2000
1500
1000
500
1400
1200
1000
800
600
400

FIGURE 30

Major element variation plotted against the ratio iron/iron + magnesium for the lavas of west-central Skye compared with the trends developed in the Skye lavas as discovered by Thompson *et al*.(1972).

Alkalic-Subalkalic Suite		Other Suites	
○	Basalt	+	Transitional Suite basalts
●	Hawaiite	♦	Low-alkali, high-calcium olivine tholeiite
△	Mugearite		
▲	Benmoreite		
□	Trachyte of Cnoc Scarall		
■	Trachyte of Sleadale		

Trends: 1. Iron-rich, silica-poor trend of Thompson *et al*. (1972)

2. Iron-poor, silica-rich trend of Thompson *et al*. (1972)

Figure 30

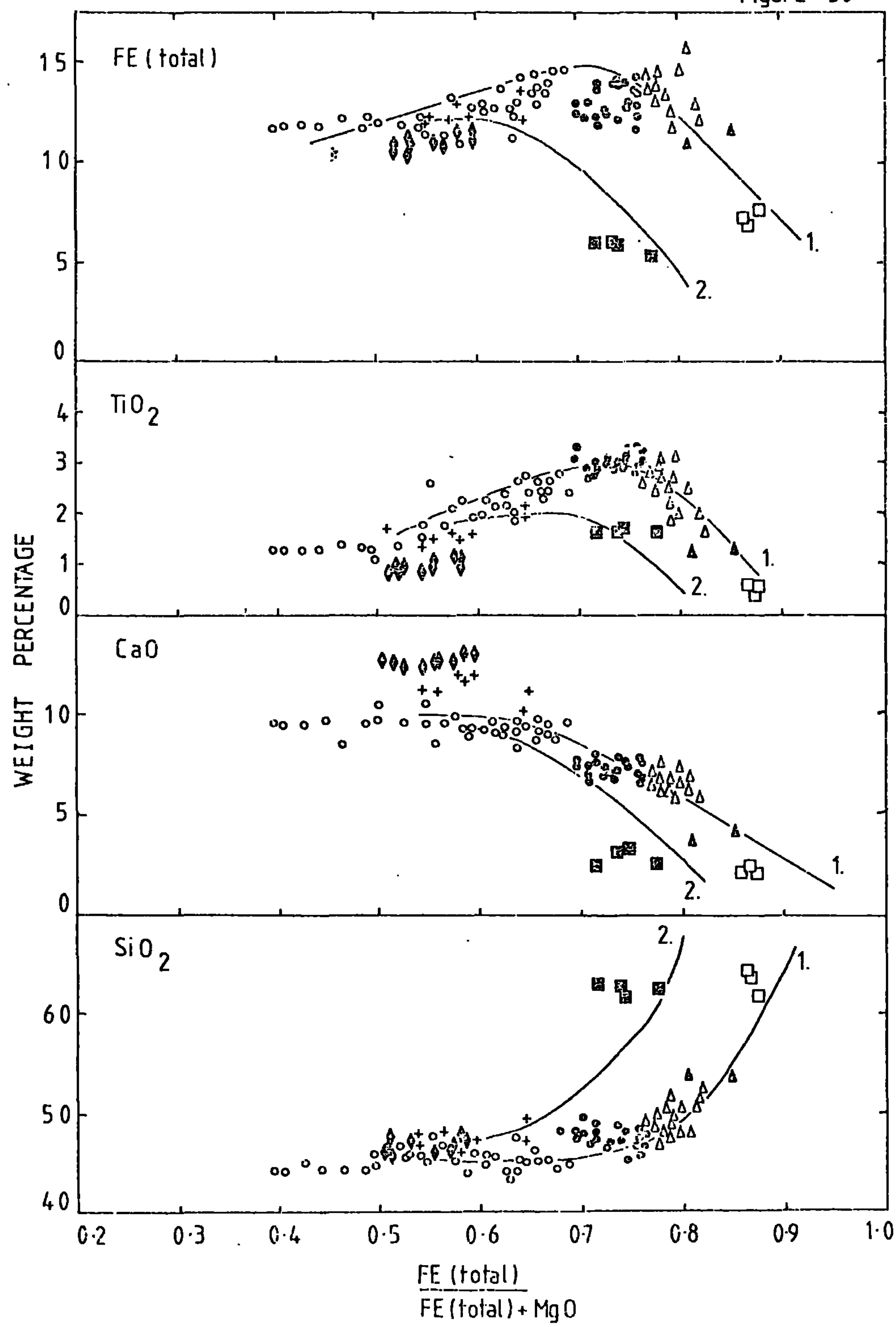
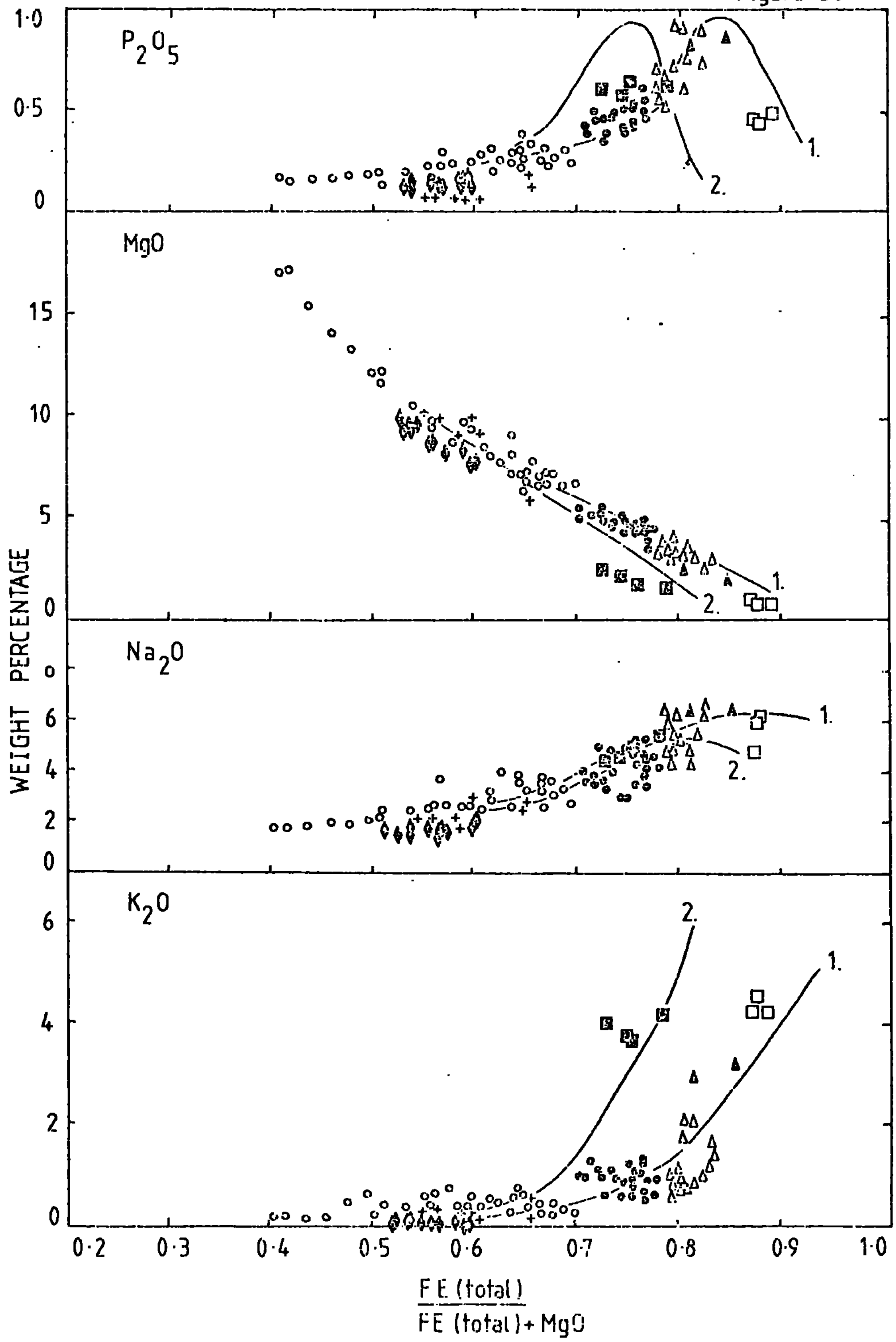

FE (total)
TiO2
CaO
SiO2
WEIGHT PERCENTAGE
15
10
5
0
4
3
2
1
0
10
5
0
60
50
40
1.
2.
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
FE (total) / FE (total) + MgO

Figure 30


P_2O_5
MgO
Na_2O
K_2O
WEIGHT PERCENTAGE
1·0
0·5
0
15
10
5
6
4
2
1.
2.
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
FE (total) / FE (total) + MgO

<u>FIGURE 31</u>

Ternary AFM plot for the lavas of west-central Skye. Symbols as used in figure 30 and possible trends as in figure 29.

Figure 31

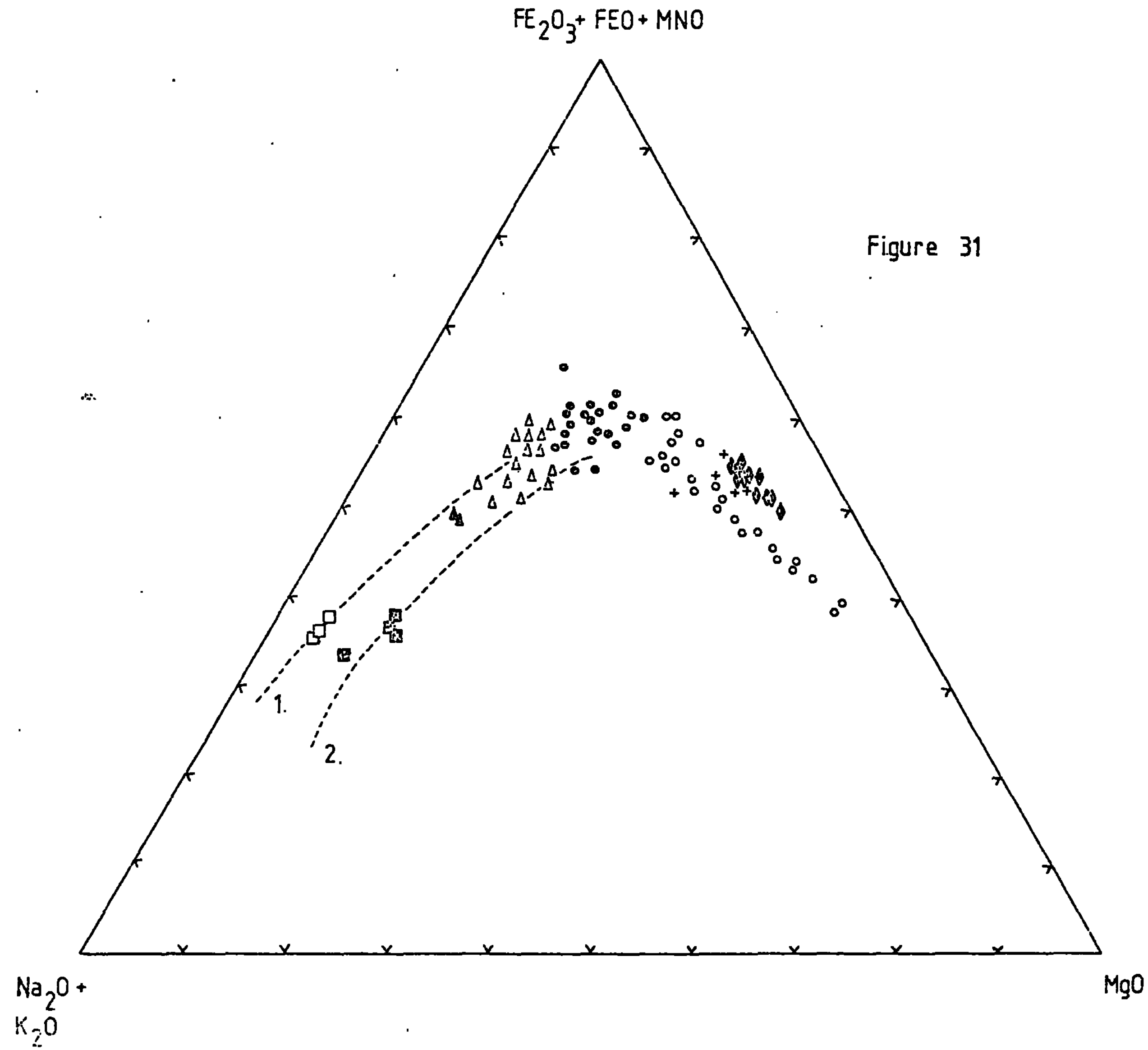


FIGURE 32

Normative feldspars of the west-central Skye lavas in the system Anorthite-Albite-Orthoclase. Symbols as used in figures 30 and 31. Trend lines as in figure 29.

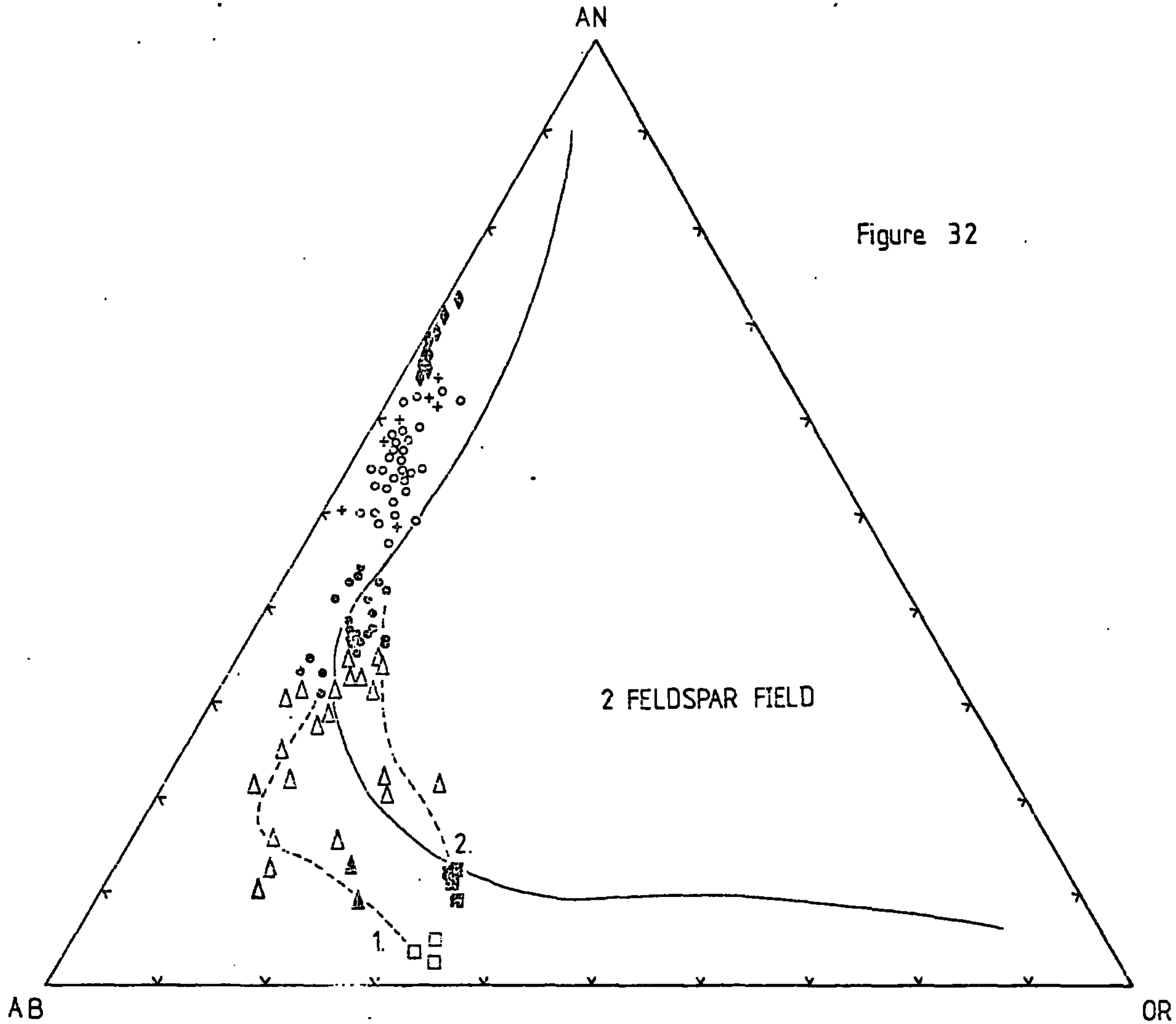


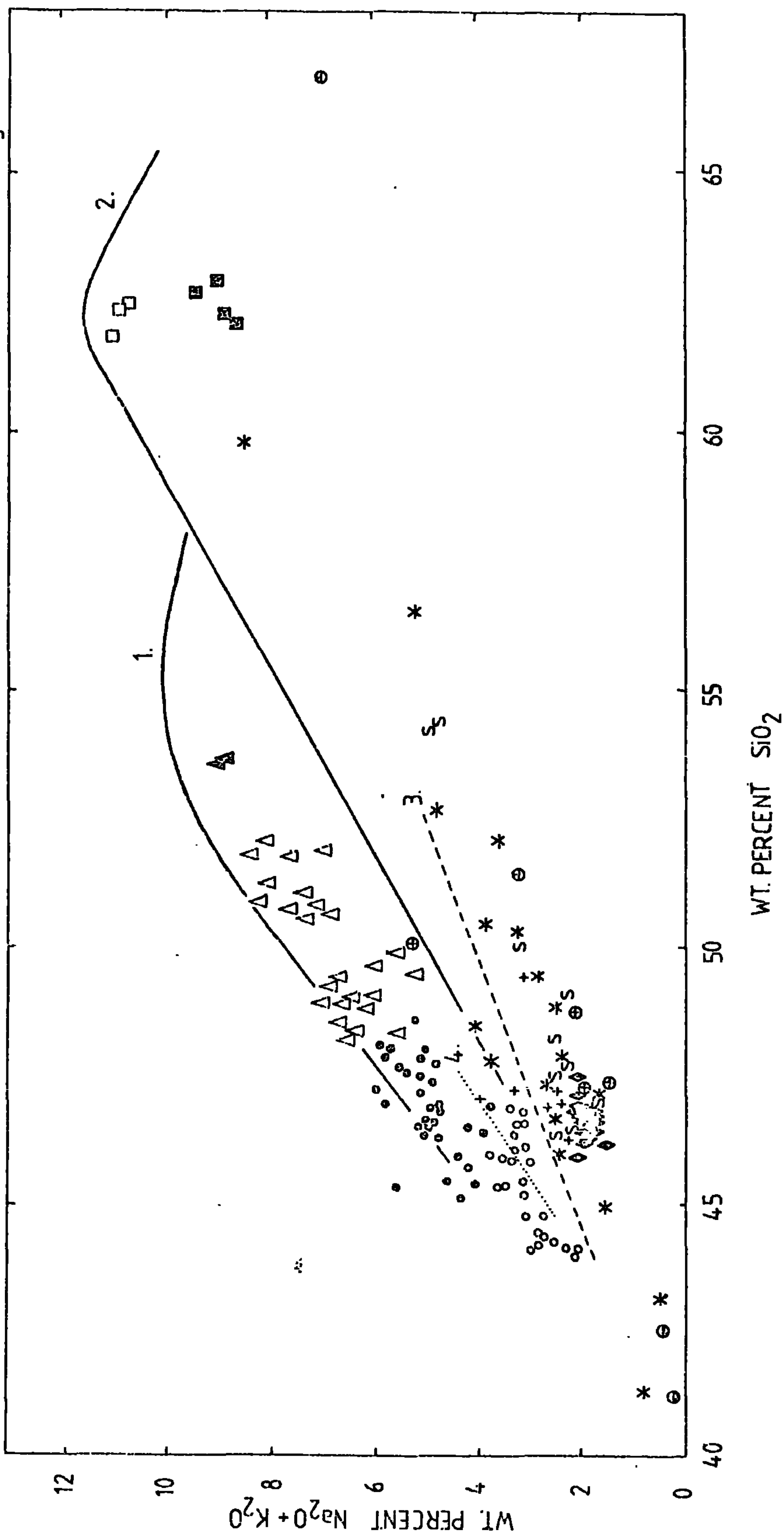
Figure 32

FIGURE 33

Total alkalis ($Na_2O + K_2O$) versus silica plot for the volcanic and intrusive igneous rocks of west-central Skye. Symbols as used in figure 30 for the volcanics and figure 29 for the various intrusions.

Trends: 1. Iron-rich, silica-poor trend (Thompson et al., 1972)
2. Iron-poor, silica-rich trend " " "
3. Hawaiian division line separating alkali-olivine and tholeiitic lavas (MacDonald and Katsura (1964)
4. Approximate position of division line of Ne + Ol and Hy + Ol normative basalts, west-central Skye

Figure 33


WT. PERCENT $Na_2O + K_2O$
WT. PERCENT SiO_2
0
2
4
6
8
10
12
40
45
50
55
60
65
1.
2.
3.
4.

alkalic-tholeiitic division but is not, surprisingly, close to that defined by Thompson et al. (1972) for the lavas of northern Skye, lying above the plane of critical silica saturation. That these basaltic rocks (and some hawaiites) form a continuum across this plane, is indicated in figure 34; a projection from plagioclase into the normative system olivine-clinopyroxene-nepheline or quartz. Several other suites e.g. Deccan and Aden possess this transitional feature. As the analyses fall close to the olivine-clinopyroxene join in this figure, a projection from either the nepheline or quartz apex onto the plane olivine-clinopyroxene-plagioclase (An-Di-Fo plane) will be fairly representative of the analyses. This is shown in figure 35 and the basalts show a tendency to cluster close to the boundary of the olivine and spinel fields. They are thus truly transitional basalts, although called alkalic in this study, transcending both the critical plane and the low-pressure thermal divide close to it. However, if the various basaltic types (based on petrography) are differentiated in this figure, a linear-type relationship exists between the olivine + spinel, olivine, and olivine + plagioclase porphyritic basalts, trending away from the olivine apex and thus indicating some degree of olivine control and fractionation at relatively low-pressures. In the variation diagrams of figures 29, 30 and 36 these

FIGURE 34

The basaltic lavas of west-central Skye plotted in terms of the normative system Nepheline-Olivine-Quartz-Clinopyroxene indicating the essentially transitional nature of many of the lavas classified as Alkalic or sub-alkalic suite. The position of sub-calcic aluminous augite (Thompson 1974) is also shown and shows its importance in controlling the basalt-hawaiite transition.

o Alkalic suite basalts

+ Transitional basalts

⧫ Low-alkali, high-calcium olivine tholeiite of Preshal More and Preshal Beg

◉ Sub-calcic, aluminous augite

Figure 34

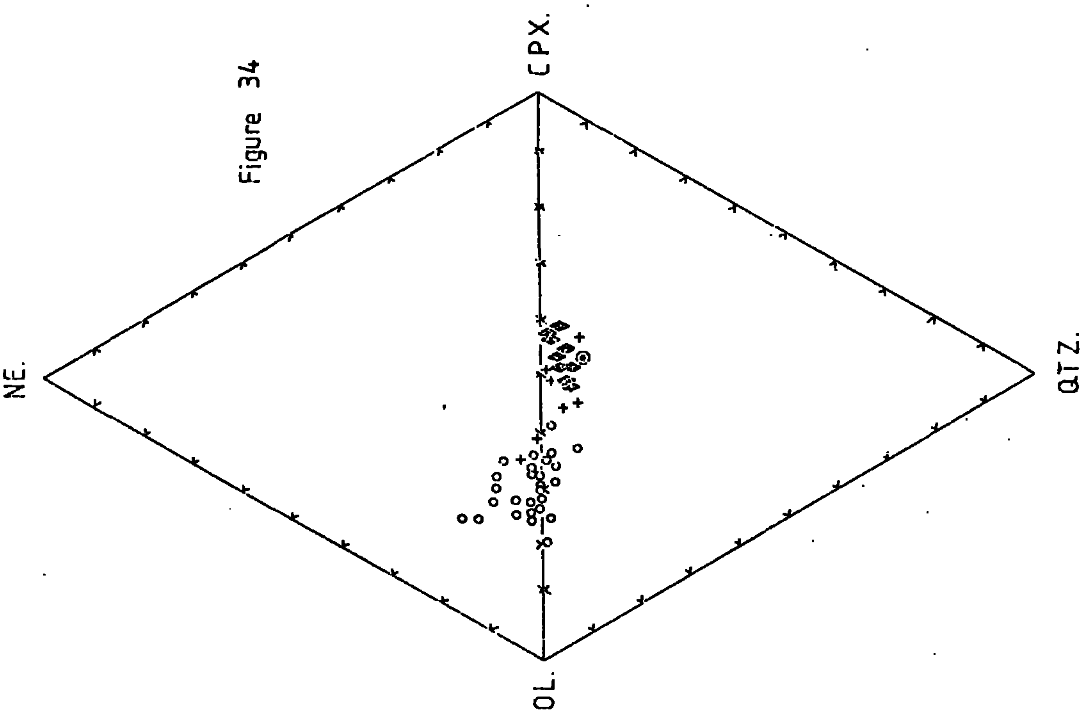


FIGURE 35

Representative basaltic lavas and minor intrusions from west-central Skye projected into the Ternary system Anorthite-Diopside-Forsterite. This figure clearly illustrates some degree of 'olivine-control' on the alkalic lavas as they cut across the forsterite-spinel boundary and also how the tholeiites and transitional basalts (lavas and intrusions) tend more to cluster around the piercing point quite distinct from the main lava series.

● Olivine + spinel porphyritic basalt (Alkalic Suite)

o Olivine porphyritic basalt(Alkalic Suite)

■ Olivine + plagioclase porphyritic basalt (Alkalic Suite)

\+ Transitional Suite basalt

♦ Low-alkali, high calcium olivine tholeiitic basalt

S Inclined intrusive sheets

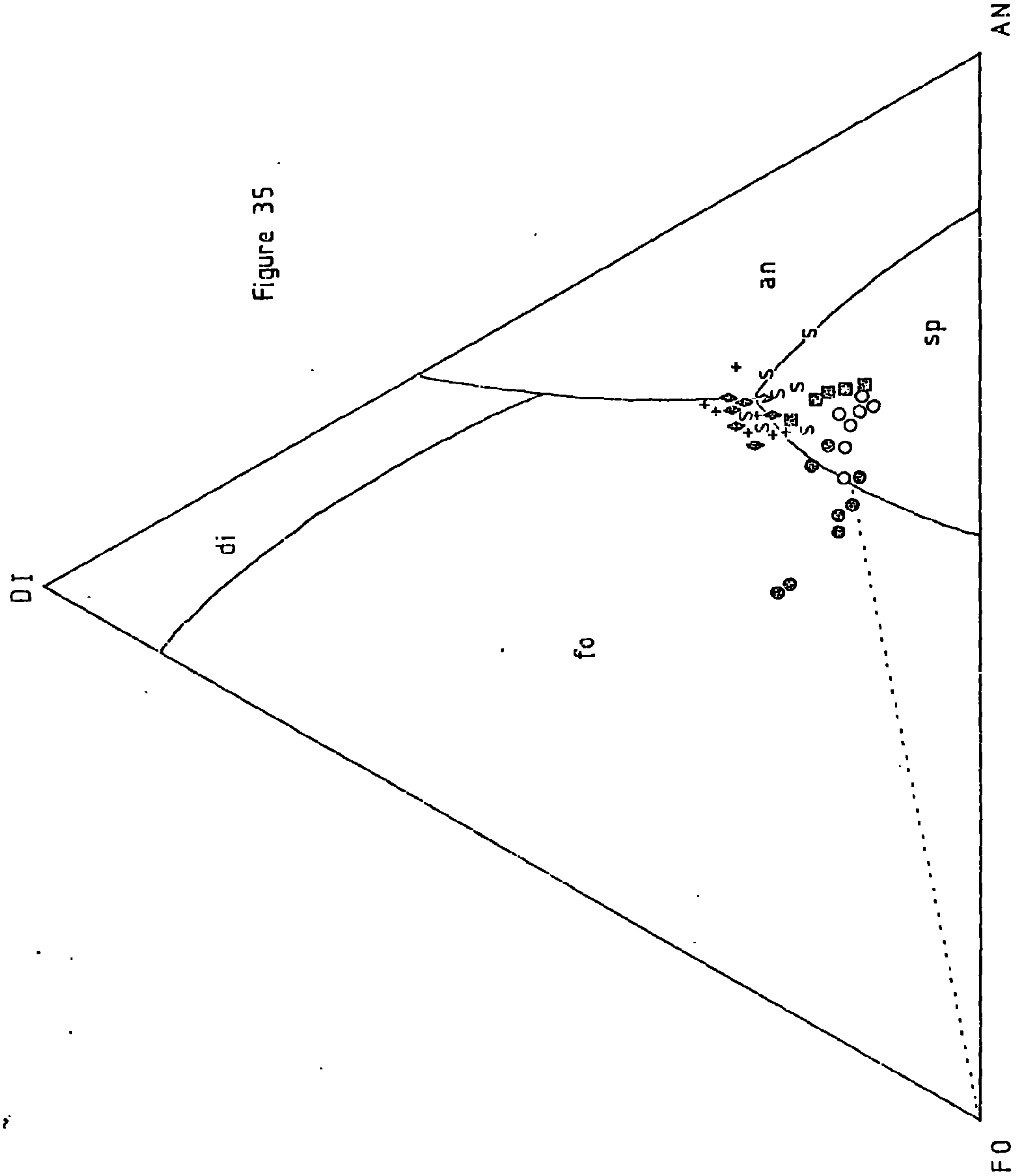


Figure 35

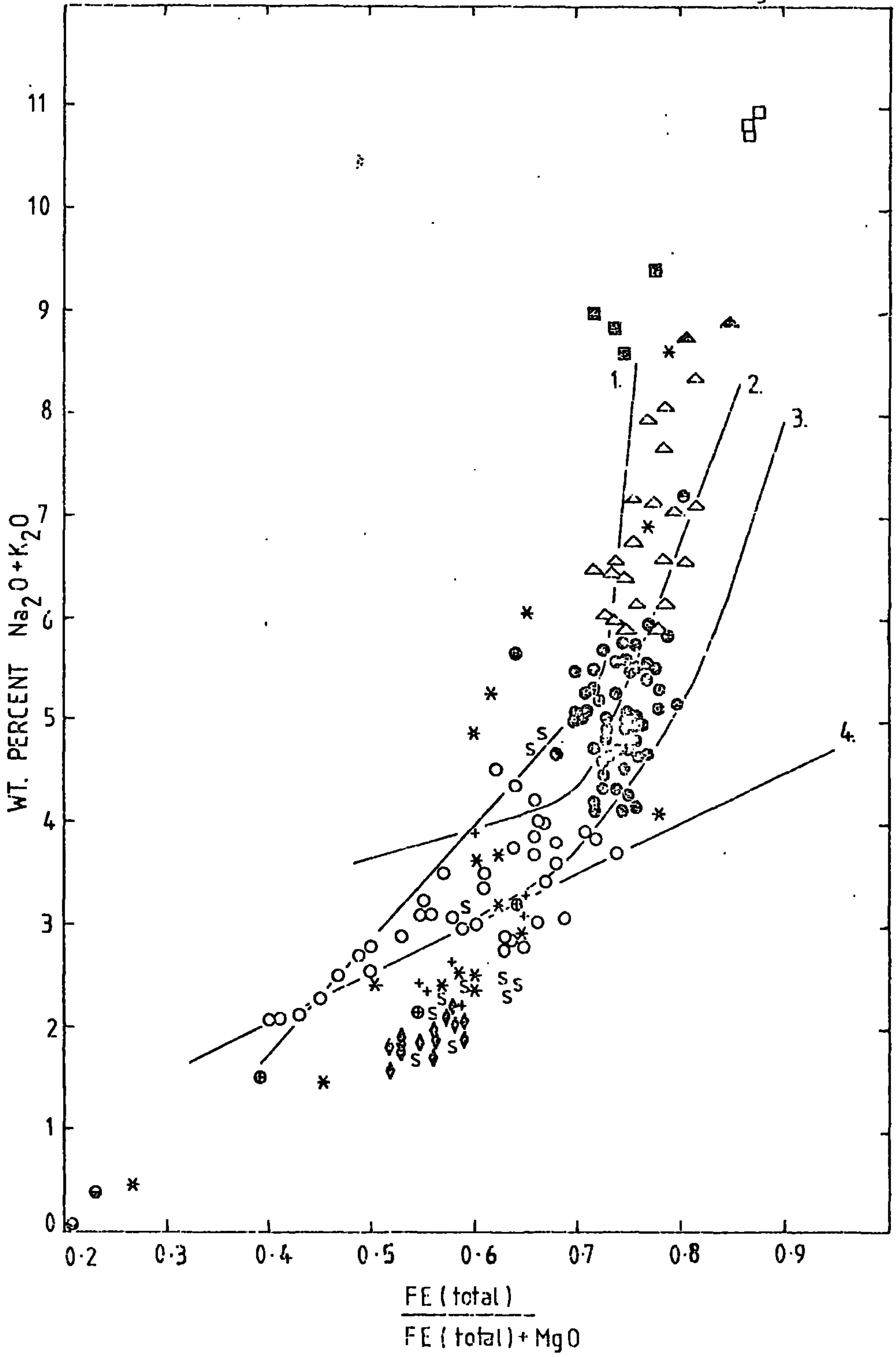
FIGURE 36

Plot of total alkalis (Na_2O + K_2O) versus the ratio iron/iron + magnesium for volcanic and intrusive igneous rocks from west-central Skye. Symbols as used in figure 33.

In addition: Trend Lines 1. Hawaiian alkalic series
2. Hebridean alkalic series
3. Ardnamurchan cone-sheets
4. Kilauea tholeiitic series

Sources: 1,2,4, Tilley et al. (1965)
3. Holland and Brown, Figure 8 (1972)

Figure 36


WT. PERCENT $Na_2O + K_2O$
0
1
2
3
4
5
6
7
8
9
10
11
1.
2.
3.
4.
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
FE (total)
FE (total) + MgO

basaltic types are again mostly distinctive. The olivine + spinel porphyritic basalts are highly magnesian, and in addition, contain substantial chromium and nickel contents which fall dramatically, with rising Differentiation Index, towards olivine and olivine + plagioclase porphyritic basalts. Subtraction of a magnesian olivine and chrome-spinel alone appears to be a controlling factor in the genesis of the more mildly magnesian, alkali-olivine basalts. With differentiation towards the intermediate lavas there is apparently a single trend. Thompson et al. (1972) sub-divide the mildly alkaline Skye Main Lava Series into two distinct geochemical lineages. This is shown by the trend lines in figures 30 and 33. The data for west-central Skye plot either intermediate to these (figure 30) or on, or immediately adjacent to the silica-poor, iron-rich trend (figure 33). The differences in detail between the more alkalic of the Skye trends as defined by Thompson et al. and the equivalent trend in this study are probably due to no more than interlaboratory variation. This strong adherence of the Alkalic Suite, from basalt-hawaiite-mugearite-benmoreite-trachyte, to an apparently single trend is complicated by a few intermediate lavas, possibly forming part of a Subalkalic Suite. This is reflected in figure 36, taken from Holland and Brown (1972), and seems to define a trend at variance with previously established trends. This figure, for the west-central Skye data, also neatly discriminates between the basalts of the Alkalic, Transitional and Tholeiitic Suites for a given Iron/magnesium ratio although there is overlap to some extent between the last two. The full analyses and partial C.I.P.W. normative data for these is given in Table 10.

Before discussing the elemental variation within the suite it should be mentioned that there are no great differences in trace element chemistry between the hypersthene- and nepheline-normative basalts and hawaiites. Only Sr, Zr and Nb appear on average to be only very marginally higher in the former. As the main differences between these basalts therefore appear to be in those elements considered to be unstable during hydrothermal alteration e.g. MgO, Fe_2O_3, CaO and Na_2O etc. (see later) and this is necessarily reflected in the normative composition of the rocks involved, then this suggests that to a large and very probably controlling extent, the presence of normative hypersthene in most is due to post-consolidation processes such as hydrothermal alteration, metamorphism and weathering rather than petrogenetic processes. This feature of the Hebridean Plateau Magma Type was also recorded by Tilley and Muir (1962) but refuted by Thompson et al. (1972). As will be shown consequently, the near aphyric Transitional Suite in west-central Skye may provide evidence to suggest that

TABLE 7

Major and trace element data, partial C.I.P.W. norms and selected element concentration ratios for representative 'basaltic' rocks from West-Central Skye.

	Low-Alkali Tholeiite						Gabbros	Transitional			
	75	75	75	75	75	75	76	75	75	75	75
Spec.	0809	0810	0814	0908	0910	0915	0808	1201B	1203	1216	1218
wt.%											
SiO_2	46.25	46.97	46.48	46.89	46.34	47.64	47.28	47.36	47.15	47.12	49.47
Al_2O_3	15.03	16.39	16.53	15.17	15.64	15.28	11.85	15.00	15.33	14.96	14.35
Fe_2O_3*	12.06	12.01	11.42	12.51	12.44	12.39	11.22	13.12	13.30	13.11	13.23
MgO	10.32	8.65	8.48	9.08	8.92	8.30	15.86	9.72	9.33	8.06	6.48
CaO	12.48	12.63	12.46	12.44	12.01	12.43	11.54	11.04	11.17	12.22	10.94
Na_2O	1.45	1.95	1.80	1.63	1.78	1.98	1.41	2.02	2.03	2.69	2.92
K_2O	0.11	0.09	0.07	0.08	0.10	0.15	0.09	0.39	0.31	0.22	0.16
TiO_2	0.89	0.84	0.86	1.06	1.07	1.06	0.63	1.41	1.43	1.57	2.10
MnO	0.20	0.19	0.18	0.21	0.19	0.21	0.16	0.17	0.16	0.18	0.19
P_2O_5	0.12	0.10	0.12	0.12	0.16	0.13	n.d.	0.19	0.10	0.08	0.15
ppm											
Ba	n.d.	n.d.	n.d.	6	15	16	96	125	94	66	60
Nb	n.d.	2	n.d.	n.d.	1	n.d.	2	5	4	3	4
Zr	32	30	31	44	46	40	33	102	95	85	55
Y	17	16	18	24	25	21	11	21	21	17	25
Sr	116	111	106	107	118	143	149	188	204	259	101
Rb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4	4	3	2	2
Zn	68	74	67	73	75	77	90	73	69	66	70
Cu	142	138	164	176	165	161	85	104	90	130	114
Ni	203	194	190	121	143	149	302	157	106	65	83
Cr	417	411	425	412	381	457	616	290	286	364	178
Fe/Fe-Mg	0.52	0.56	0.55	0.56	0.56	0.58	0.39	0.55	0.56	0.60	0.65
D.I.	13.3	17.2	16.1	14.5	16.0	17.9	12.6	19.6	19.2	22.8	26.0
Na/Na-K	0.95	0.97	0.98	0.97	0.96	0.95	0.96	0.89	0.91	0.95	0.97
K/Rb	457	374	291	332	415	623	182	809	858	913	664
Rb/Sr	0.0172	0.0180	0.0189	0.0187	0.0170	0.0140	0.0268	0.0213	0.0147	0.0077	0.0198
Sr/Ba	9.43	9.02	8.62	17.83	7.87	8.94	1.55	1.50	2.17	3.92	1.68
Zr/Nb	21.33	15.00	20.67	29.33	46.00	26.67	16.50	20.40	23.75	28.33	13.75
Zr/Y	1.88	1.88	1.72	1.83	1.84	1.91	3.00	4.86	4.52	5.00	2.20
Ti/Y	314	314	286	265	256	302	344	402	408	533	504
Ti/Zr	167	168	167	145	140	159	115	83	90	111	229
norm %											
Ne	-	-	-	-	-	-	-	-	-	1.7	-
Di	22.5	21.8	20.4	22.6	20.3	23.7	25.5	19.3	18.9	26.5	23.2
Hy	9.3	4.9	8.3	11.8	9.5	9.6	8.5	8.9	8.8	-	13.8
Ol	16.5	16.2	14.0	12.7	15.0	11.7	23.8	16.2	15.8	16.9	4.6
An	34.9	36.2	37.8	34.5	35.3	32.9	26.0	31.0	32.1	28.4	25.9

	Hy norm Alkalic				Ne norm Alkalic					
	75	75	74	76	75	75	75	75	75	74
Spec.	0604	0707	0606	0304	0118	1001	1206	1209	0602	1001
wt.%										
SiO_2	46.83	46.04	47.01	45.33	45.50	46.36	44.12	43.95	46.03	[illegible]
Al_2O_3	14.73	15.20	15.98	15.78	16.26	15.16	14.41	14.70	14.37	[illegible]
Fe_2O_3*	12.99	13.38	13.11	14.63	14.65	12.75	15.37	17.67	12.96	13.90
MgO	10.60	9.86	8.54	6.88	9.71	9.40	9.63	9.34	11.83	[illegible]
CaO	9.50	9.40	9.23	9.79	9.75	10.47	8.76	5.86	10.13	[illegible]
Na_2O	2.55	2.59	2.79	2.75	2.71	2.62	2.57	2.55	2.36	2.65
K_2O	0.37	0.55	0.73	0.30	0.35	0.62	0.43	0.36	0.22	0.54
TiO_2	1.40	1.82	1.82	2.39	2.11	1.61	2.34	2.52	1.28	[illegible]
MnO	0.18	0.19	0.18	0.20	0.21	0.19	0.19	0.15	0.19	0.18
P_2O_5	0.21	0.26	0.25	0.26	0.22	0.20	0.27	0.27	0.16	0.33
ppm										
Ba	124	234	264	145	85	218	88	14	23	[illegible]
Nb	3	5	4	4	3	2	5	4	n.d.	5
Zr	122	166	150	165	127	131	146	149	93	169
Y	18	18	26	20	25	19	22	23	18	[illegible]
Sr	314	435	431	446	356	390	381	393	275	438
Rb	n.d.	2	4	5	5	2	4	2	n.d	9
Zn	78	84	78	72	87	81	75	83	67	[illegible]
Cu	78	85	80	74	124	114	105	116	144	115
Ni	404	289	128	37	154	151	155	181	427	294
Cr	1039	696	404	180	72	555	92	155	1161	343
Fe/Fe-Mg	0.53	0.55	0.57	0.66	0.58	0.55	0.56	0.63	0.50	0.56
D.I.	24.2	25.7	28.5	25.8	23.7	25.2	25.1	23.0	21.4	25.3
Na/Na-K	0.91	0.88	0.85	0.93	0.92	0.87	0.90	0.92	0.94	0.88
K/Rb	837	2283	1515	498	631	2573	892	1494	415	[illegible]
Rb/Sr	0.0112	0.0046	0.0093	0.0112	0.0141	0.0051	0.0105	0.0051	0.0101	0.0206
Sr/Ba	2.53	1.87	1.63	3.08	4.19	1.79	4.33	28.07	11.96	2.58
Zr/Nb	40.67	33.20	35.50	41.25	42.33	65.50	29.20	37.25	24.47	33.80
Zr/Y	6.78	9.22	5.77	8.25	5.08	6.90	6.64	6.48	5.17	9.94
Ti/Y	466	606	419	717	506	508	637	657	427	655
Ti/Zr	69	66	73	87	100	74	96	102	83	66
norm %										
Ne	-	-	-	-	1.7	1.3	0.1	1.2	0.2	0.7
Di	15.0	13.9	12.7	14.5	13.0	19.0	12.9	12.2	17.1	9.8
Hy	4.3	1.3	3.8	3.2	-	-	-	-	-	-
Ol	23.3	24.0	19.0	18.2	25.7	21.7	27.0	29.5	27.9	27.1
An	28.2	28.8	29.6	30.8	31.0	28.3	27.5	27.9	26.9	31.3

*Total Iron as Fe_2O_3

Ratios calculated with Rb = 2 in Low Alkali Tholeiite (After Esson et al. 1975)

'Average' values used for Rb, Ba, Nb in all classes where not in analyses

n.d. not detected

variation producing olivine + hypersthene normative, mildly alkalic basalts may be due to magmatic processes as suggested by Thompson et al.

Within the Alkalic Suite of west-central Skye total iron, Na_2O, K_2O, TiO_2, P_2O_5, Ba, Nb, Zr, Y, Sr and Rb increase with differentiation from basalt to hawaiite; the remainder either falling sharply as in the case of MgO, Cr and Ni or remaining fairly steady as with SiO_2, CaO, Zn and Cu. At the basalt-hawaiite boundary (basaltic hawaiite; iron/magnesium ~0.7; Differentiation Index 32) there is a slight hiatus in the number of analyses recorded similar to that found for many anorogenic suites by Thompson (1972). This pattern of variation continues throughout the hawaiites until at around Differentiation Index 40-45, SiO_2 K_2O and Nb increase more sharply and TiO_2 and total iron begin to fall. As the mugearite stage is reached at Differentiation Index ~ 45 and iron/magnesium ratio 0.77, there is no further change in the major elements but Y and Sr flatten out while Ba, Nb and Rb appear to fall slightly before continuing to increase. With further differentiation of the major elements, only P_2O_5 changes; showing a sharp decrease at around Differentiation Index 65, ie. benmoreite. Of the trace elements, Sr decreases a little through this stage to trachyte while Y, and Zr stay more or less constant. Correspondingly Rb, Zn, Ba and Nb increase towards the alkali-trachyte. Hence in the intermediate members of the Alkalic Suite Y, Rb, Ba, Nb and Zr behave very much as true incompatible elements being continually enriched in later fractions and being substantially excluded from any fractionating phases until a very late stage. Of the major elements K_2O, Na_2O, SiO_2 and to some extent P_2O_5 behave in a similar fashion. Broadly speaking, these major changes in the variation pattern can be matched almost directly to phenocryst content. The basaltic variation has already been mentioned and the incoming of substantial and eventually dominant titaniferous magnetite as a phenocryst phase in the hawaiites and early mugearites is reflected in the variation of total iron and TiO_2 in these rocks. This moderate enrichment in iron but continuous enrichment in alkalis is also reflected in figures 31 and 36. Olivine, plagioclase feldspar and magnetite continue to appear as microphenocrysts up until the benmoreite stage when olivine is lost and apatite, although common interstitially as slender euhedral needles in the mugearites, is joined by amphibole and biotite as major phases accompanying magnetite and plagioclase. Alkali feldspar is a common phase in the alkali trachyte. Phenocryst mineralogy and possible fractionating phases can also be matched to the trace element variation. Barium substitutes only for K^+ among the common cations and although it enters early formed potassium minerals it is not usually depleted in the magma until a very late stage where it will enter K-feldspar more readily than other phases. The identical variation of barium and potassium suggests that no or only very limited K-feldspar fractionation has taken place during the genesis of the Suite as we see it as is also evidenced from the petrography of these rocks (Chapter 7). Niobium normally behaves as a true incompatible element, not entering any phases until very late in the differentiation sequence, as a consequence of it possibly existing as large $(NbO_4)^{3-}$ complexes which being larger than $(SiO_4)^{4-}$ will lead to their concentration in late fractions and residual melts but its complex behaviour in the intermediate lavas suggests some partitioning into titaniferous magnetite microphenocrysts. Zirconium steadily increases then remains constant or falls away slightly. Zircon $(ZrSiO_4)$ is the only phase which accommodates Zr readily although it may also be found in alkali pyroxenes and apatite and this tallies well with the fall-off in P_2O_5 at around Differentiation Index 60 but it is equally possible that zircon is the fractionating phase. Yttrium has a complex behaviour but is somewhat identical to Zr in its variation in the rocks of west-central Skye and behaves in a totally different fashion during differentiation in passing from basalt to mugearite compared with the 'equivalent' suite from Mull (Beckinsale et al., 1978). These authors, in finding that Y decreased markedly in mugearites relative to related basalts, suggested that garnet (the only common phase with a preference for Y) was important in their genesis. The proposed mechanism was not that of low pressure fractional crystallisation but rather differential partial melting of a relatively homogeneous garnet-lherzolite source at high pressure. This is obviously not the case with the Alkalic Suite in west-central Skye as indicated in figures 29 and 37. However, for the basaltic rocks only, the data has the same distribution and gradient as Beckinsale et al's Group III lavas. Yttrium possibly enters late apatites and this may help explain its variation here. Strontium increases from basalt to hawaiite and falls slightly through mugearite to trachyte. This suggests that intermediate plagioclase was important in the differentiation sequence at this point. Rubidium increases from basalt to trachyte in tandem with K_2O, as K^+ is the only major element of comparable size and the electronegativities and ionisation

FIGURE 37

Trace element concentrations in the lavas of west-central Skye, plotted against Zr. Also major element plot of TiO_2 against P_2O_5. Symbols as used in figure 33. A-traces B-majors.

In addition: Trend lines 1. Group I Basalt-Mugearite-Benmoreite Series (Alkalic)

2. Group II Hypersthene normative more 'tholeiitic basalt-intermediate series

Source: Mull Volcanics - Beckinsale et al., 1978

N.B. The two trends outlined here are thought by Beckinsale et al. to be broadly the equivalents of Thompson et al's (1972) Skye Main Lava Series (trends 1 and 2 in figure 30, 33 etc) SMLS but as shown here there are obvious and important differences especially in the case of the more incompatible elements such as yttrium.

Figure 37-A

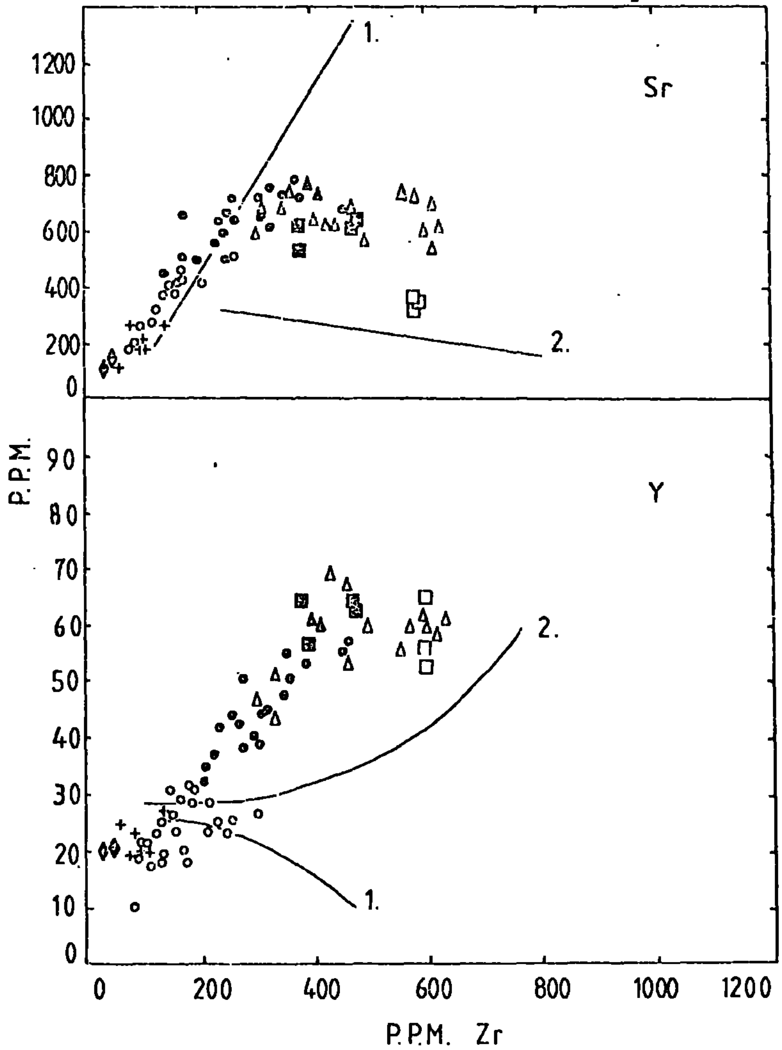

1200
1000
800
600
400
200
0
1.
2.
Sr
90
80
70
60
50
40
30
20
10
0
Y
P.P.M.
0
200
400
600
800
1000
1200
P.P.M. Zr

Figure 37-A

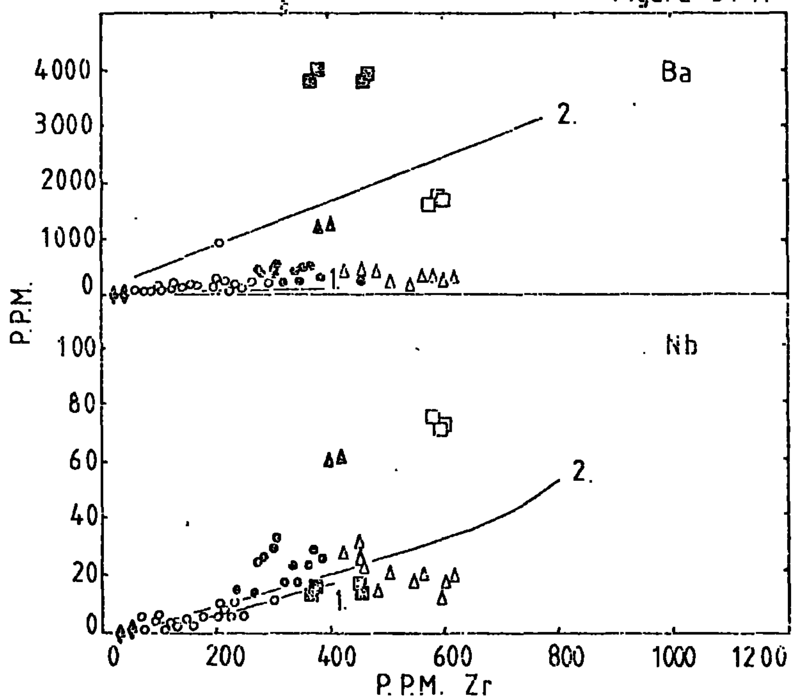
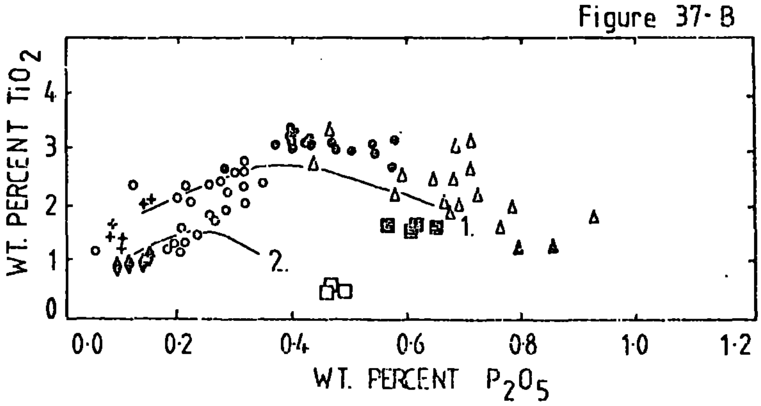


Figure 37-B



potential of both elements are very similar. In this way it acts very much as an incompatible element. However, a number of mugearites appear to be markedly Rb depleted suggesting either accumulation of feldspar on a large scale (eg. Upton 1960), derivation from an already depleted source region or the presence of residual phlogopite in the mantle source region as suggested by Thompson et al. (1972). That the later might be the major contributory factor is revealed by the west-central Skye data behaving contrary to that of Beckinsale et al's Mull Group I data with K_2O behaving incompatibly but not to the same degree as Sr, Ba and Nb (mentioned above) and in a more or less identical fashion to Y. The concentrations of both nickel and chromium decrease by factors of about 10 and 40 in passing from basalt to mugearite respectively and as mentioned previously are best explained by fractional crystallisation of olivine and chrome-bearing spinel at an early stage (fig.38). Although both copper and zinc are commonly associated with the sulphide phase rather than the silicates they appear to possess a systemmatic variation with differentiation in the Alkalic Suite lavas of west-central Skye. Copper as Cu^+ will enter the plagioclase lattice substituting for Na^+ and Ca^{2+}, and in other minerals containing Fe^{2+}.

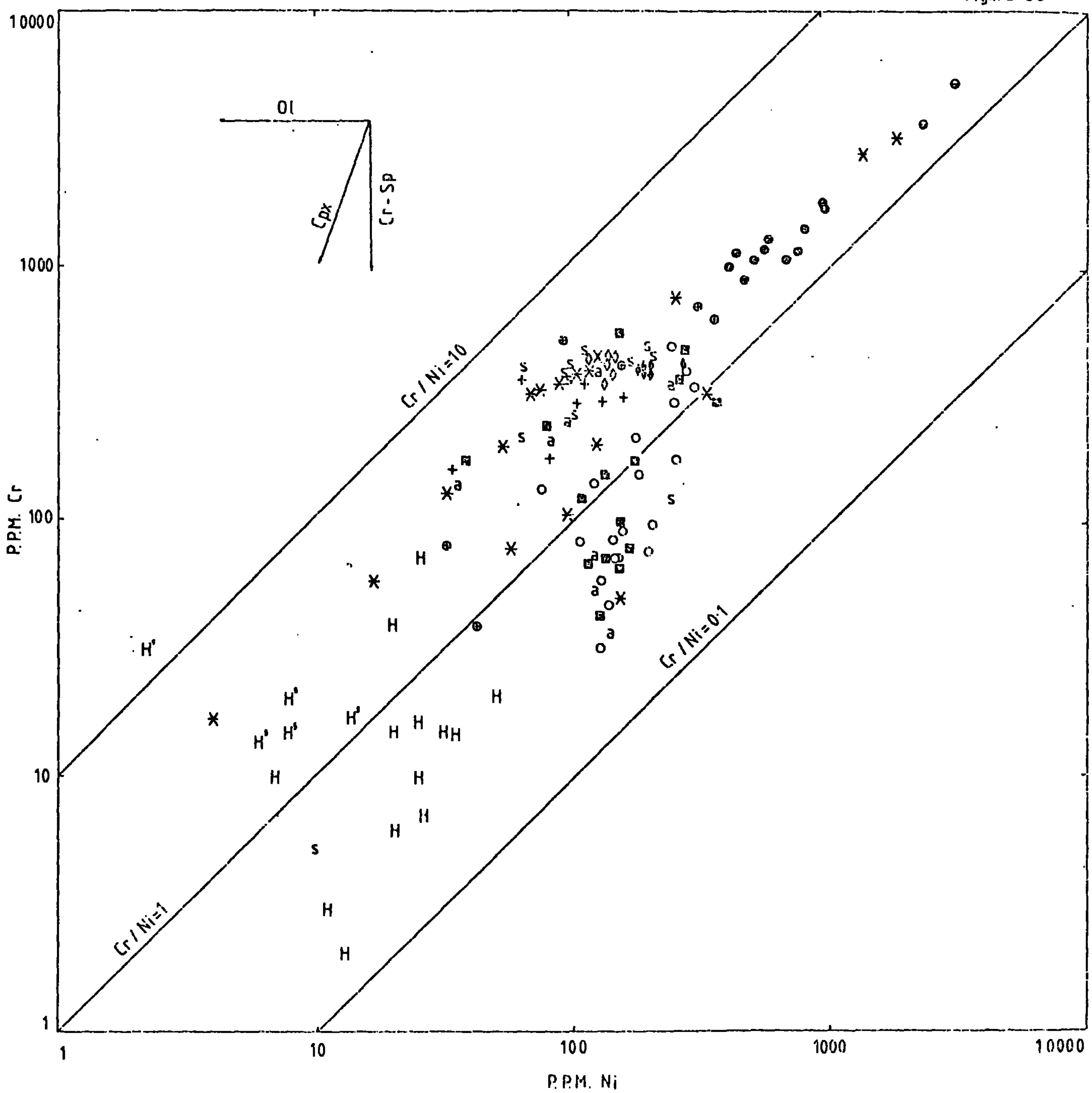
FIGURE 38

Log-Log plot of Cr versus Ni for the west-central Skye volcanics and intrusions. Symbols for the intrusive rocks are as used in figure 29.

In addition: Lavas:

●	Olivine + spinel porphyritic basalt	Alkalic Suite
o	Olivine porphyritic basalt	"
■	Olivine + plagioclase porphyritic basalt	"
H	Hawaiite	"
a	Aphyric basalt	
H^s	Sub-alkalic hawaiite from Sleadale	Sub-Alkalic Suite
+	Transitional Suite basalt	
⧫	Low-alkali, high-calcium olivine tholeiite of Preshal Beg	
◊	Low-alkali, high-calcium olivine tholeiite of Preshal More	

Figure 38


10000
1000
100
10
1
P.P.M. Cr
1
10
100
1000
10000
P.P.M. Ni
Ol
Cpx
Cr - Sp
Cr / Ni=10
Cr / Ni=1
Cr / Ni=0·1

Accordingly as CaO and total iron both decrease from basalt to trachyte this pattern might be expected of Cu as is indeed the case; the variation most closely (when the Tholeiitic and Transitional Suites are also considered) following that of calcium. By way of contrast zinc increases slightly with differentiation from mugearites onward. Ionic parameters are important here with Zn^{2+} being nearly the same size as Fe^{2+} but with the Fe-O bond as indicated by ionisation potential and electronegativity data, being less covalent resulting in the entry of zinc into late Fe^{2+} positions and an increase during fractionation.

Relative to the lavas of the Small Isles (Ridley 1971, 1973; Emeleus and Hoey pers. comm.) the Alkalic Suite in west-central Skye is apparently characterised by marginally higher total alkalis, TiO_2 and possibly P_2O_5 and correspondingly slightly lower CaO. In this respect, although the Skye Alkalic Suite is in truth very much a transitional suite as mentioned previously, the Small Isles volcanics appear even more 'transitional' possibly precluding any direct correlation (but see Binns et al. 1973). In terms of the very limited, published trace element data (Ridley 1973) they are very similar. When compared and contrasted against the 'Plateau' lavas of Mull and Morven (Bailey et al., 1925; Beckinsale <u>et al</u>., 1978) the Skye lavas are again virtually identical in most respects. The Alkalic suite of west-central Skye (equivalent to the Si-poor, Fe-rich basalt-benmoreite trend of Thompson <u>et al</u>.) is closely comparable to trend or lineage I from basalt to benmoreite and trachyte of the Mull lavas as recently subdivided by Beckinsale <u>et al</u>., but there are notable and important differences especially in trace element chemistry as indicated by the behaviour of Sr, Zr and Y and already referred to above.

The mafic and more basic high-MgO, olivine-rich basaltic lavas (the olivine + spinel porphyritic type of this study) were considered by Thompson (1974) to be the crystallised equivalents of true primary magmas derived by partial melting of a relatively iron-rich spinel-lherzolite upper mantle at around depths of 50-60 kms beneath Skye for the following reasons:

1. The olivine crystallised during high pressure experiments had a forsterite content equivalent to the observed natural olivines.
2. Assuming that these rocks represented liquids and thus no accumulation of olivine had occurred, then calculated values of the distribution coefficient K_D between liquid-olivine pairs agreed well with established values.
3. The olivines were accompanied by an Aluminous Chromite phase suggestive of an origin at high pressure and similar chromite in volcanic rocks from the Small Isles (Ridley 1972) were not in equilibrium with their surroundings when unprotected by the normally enveloping olivine phenocrysts.

The nature of the volcanic conduits and the probable configuration of the magma-reservoir plexus possibly existing beneath Skye during the early Tertiary (Anderson and Dunham 1966; Thompson et al. 1972), suggest that uprise of magma to the surface would not be rapid enough to preclude some fractionation. Viscosity restrictions and density contrasts, due to the phenocrysts content of the magmas involved, and their volatile contents, would also result in variable, but generally leisurely uprise of magma. This would have the effect of allowing fractionation to take place at various levels, as well as the possibility of batch mixing and crustal contamination to occur. Thus, some of the olivine + spinel lavas seen at the surface today might approximate towards, but should not be considered as true primary magmas. The concept of a picritic parental magma for the Skye Main Lava Series (Thompson et al. 1972) is mostly retained but there are no erupted representatives. Some basalts do, however, tend towards picritic basalts both in chemistry and petrography.

Studies of the picritic minor intrusions of the Hebrides by Drever and Johnson (1958) concluded that they possibly represent liquids which have suffered only minor loss of olivine during ascent from their origins as partial melts of ultrabasic mantle rocks. The olivine-rich, olivine + spinel porphyritic basaltic lavas could conceivably be further steps along the same evolutionary pathway, as many, such as

Sk751212 contain large, generally unzoned olivine phenocrysts associated with chrome-spinel or chromite and show little or no evidence for a reaction relationship of either with the groundmass as is the case for some minor picritic intrusions. The most MgO-rich basalts considered here are more magnesian than that studied by Thompson (1974) (17.2 wt.% as opposed to 11.08 wt.%) but not so magnesian as picrites from the flood-basalt terrains of Deccan (Krishnamurthy and Cox, 1977) or Baffin Bay (Clarke, 1970); the latter being considered by some to be likely contenders for the title of Primary Magmas.

As shown in the preceeding sections and variation diagrams the olivine + spinel porphyritic basalts have considerable ranges of chemistry and modal proportions of both olivine and spinel. Using the same argument of Thompson (1974a) and Mattey et al. (1977) whereby the presence of cumulate olivine could be detected by the calculated composition of expected liquidus olivine of a liquid being more magnesian than that of the observed phenocryst cores, this can be applied to the west-central Skye data using the formula of Roeder and Emslie (1970) as follows and summarised in Table 11.

$$K_D = \frac{\left[\overset{ol}{X}_{FeO}\right] \times \left[\overset{liq}{X}_{MgO}\right]}{\left[\overset{liq}{X}_{FeO}\right] \times \left[\overset{ol}{X}_{MgO}\right]}$$

where $\left[\overset{ol}{X}_{FeO}\right]$ is the mole-proportion of FeO in olivine etc and K_D = the Distribution Coefficient = 0.33 as used by Cawthorn <u>et al</u>. (1973), Mattey <u>et al</u>. (1977) and broadly confirmed for Skye data by Thompson (1974).

Only the most magnesian basalt, specimens Sk751211 and Sk751212 from the Cruachan Group show Olivine $Fo_{observed}$ $<$ Olivine $Fo_{calculated}$, suggesting very limited olivine accumulation if any. By way of the same reasoning as Thompson (1974) this rock could therefore represent a primary magma if considered to represent a liquid. The large skeletal, quench-textured olivines would tend to support this. If it were a direct melt then an implied Mgx100/Mg+Fe ratio of 90 for the olivines and pyroxenes in the upper mantle source region would result, which although in agreement with the calculations of Green and Ringwood (1967), O'Hara (1965,1968,1970) and Green (1970) are at variance with those of Kuno and Aoki (1970), Kushiro (1973) and Thompson (1974) who propose a more iron-rich upper mantle having a ratio of around 85. The other basalts of this group show olivine

TABLE 11

Calculated liquidus olivine compositions compared with observed phenocryst core compositions in some basaltic rocks from West-Central Skye.

	Specimen	Type	Fe/(Fe+Mg)	Calculated liquidus olivine Fo	Observed Phenocryst Core Fo
1.	Sk751211-12	ol + sp	0.40	90.0-89.7	89.5
2.	Sk740607	ol + sp	0.49	86.4	88.9
3.	Sk7616	ol + sp	0.50	85.8	88.5
4.	Sk750602	ol + sp	0.50	85.9	88.0
5.	Sk741002	ol	0.60	56.6	81.2
6.	Sk740801	ol + pl	0.69	61.4	69.0
7.	Sk751001	ol + pl	0.55	53.3	85.1
8.	Sk750907	L.A.T.	0.59	81.1	81.7
9.	Sk750809	L.A.T.	0.52	84.8	[85.8]
10.	Sk982	L.A.T.	0.53	87.3	[84.7-87.2]
11.	Sk983	L.A.T.	0.55	86.1	91.0-82.0

Analyses 1-7 Alkalic Suite

9 Chill zone of Preshal Beg - no olivine analysis

10-11 Calculated Fo from Esson et al. (1975) Table 1 observed core range in same paper

Observed values in square brackets in analyses 9-10 from L.A.T. rocks with like Fe/(Fe+Mg) ratio from Mattey et al. (1977).

$Fo_{observed}$ > olivine $Fo_{calculated}$. Rather than suggesting that these are rocks into which olivine has accumulated, the converse is implied, ie. they represent magma minus olivine phenocrysts. This also apparently applies to the relatively MgO-poor olivine and olivine + plagioclase porphyritic basalts in the Alkalic Suite, which if they had equilibrated in shallow sub-surface reservoirs for any length of time (as is evidenced by the thick interflow sediments and boles) would be expected to have lost at least some olivine by gravitative settling. Mixing of fresh batches of magma with the residue would also tend to complicate the chemistry of these rocks, producing a wide scatter of data.

Thompson et al. (1972) noted that for the rest of Skye the values of K_2O and the ratio K:Na are on the average higher in the hypersthene-normative members of the Skye Main Lava Series relative to the nepheline-normative basalts. This was also emphasised by Thompson (1974); the suggested reason being that a Titanium-bearing, hydroxyl phlogopite was a residual phase for small degrees of anatexis during the genesis of the nepheline-normative ie. silica undersaturated basalts. This phase would also incorporate substantial TiO_2 by definition and upon incongruent melting during a greater degree of partial melting would cause rising pH_2O, together with a subsequent increase in the silica content of the melt which would become progressively silica saturated, but contain higher values of K_2O, K:Na, TiO_2 etc. relative to the first (under-saturated) melts, contrary to the pattern of most other volcanic suites. The data for equivalent basalts from west-central Skye is shown in Table 8 and Appendix 1. In general terms both nepheline- and hypersthene-normative basalts show considerable ranges in both major and trace element compositions and there appears to be no systematic difference between them but selection of suitable pairs which are geographically and stratigraphically linked eg. specimens Sk750602 and Sk750604 (both olivine + spinel porphyritic basalts from the Tusdale Group) may show some differences with SiO_2, K_2O, TiO_2, K:Na ratio higher in the hypersthene-normative example. Also Ba, Zr, Sr and possibly Nb are slightly higher suggesting that a smaller partial melt may be the main control . Olivine porphyritic specimens Sk741001 and Sk741002 from the Arnaval Group show broadly similar variations but notably K_2O is reversed. The data of Thompson et al. cannot be dismissed but data from this study in west-central Skye seem to indicate that no clear difference exists and consequently the role of phlogopite in the mantle beneath Skye is evolved salic members of other alkali suites are mostly thought to have formed by low-pressure crystal fractionation of hawaiitic magmas and this is probably the case for the Skye lavas (for example MacDonald 1968; Wilkinson 1969; Cox et al. 1970; Barberi and Varet 1970; Thompson et al. 1972; Upton and Wadsworth 1972; Flower 1973; Thompson 1974; Upton 1974 ; MacDonald 1975).

Melting experiments at 1 Atmosphere showed conclusively that clinopyroxene was not a liquidus phase in the Skye lavas (Thompson et al. 1972), while petrographic evidence although not completely reliable reveals it never to be an obvious phenocryst phase in any of the alkalic basalts encountered. However, various diagrams, crystal-extract calculations and field evidence suggest that an aluminous sub-calcic augite was an important contributory phase. Figures 38 and 34 showing a log/log plot of Cr against Ni and the normative Ternary projection into the fields Ne-Ol-Cpx-Qtz respectively and also the plot of Differentiation Index against the degree of silica saturation (Thompson et al. figure 9, Thompson 1974, figure 8) all show the need for a suitable clinopyroxene to produce hawaiites. Petrographic mixing equations using the 'least squares' method have been applied to relevant Skye data by Thompson (1974) and Boyd (1974) both indicating that despite the lack of conclusively demonstrable parent-daughter, basalt-hawaiite pairs among the lavas which would tend to rule-out such a rigorous mathematical approach, the sum of the residuals ie. a measure of the 'closeness of fit' is considerably reduced by the introduction of an aluminous clinopyroxene ie. the fit of calculated to observed analyses is enhanced. High pressure melting experiments from 1 atmosphere to 30 Kb by Tilley <u>et al</u>. (1965) on a high-MgO, olivine basalt from Skye are discussed by Thompson (1974) and it is shown that at 17 Kb clinopyroxene is a liquidus phase along with olivine + a Ca-poor pyroxene + possibly spinel, generating a 5 phase point. Thus for clinopyroxene to have been an important precipitating phase during the genesis of the hawaiites, this genesis must have occurred initially at high pressures. The slight hiatus in the number of rocks having compositions equivalent to basaltic-hawaiite ie. around DI 30-32, Fe/FeXMg 0.7, noted as a general characteristic feature of many anorogenic suites by Thomspon (1972) apparently holds good for the data presented herein (see for example figures 29 and 30). His suggestion that hawaiites represent the residual fractions of batches of partially crystallised to semi-solid mostly nepheline-normative MgO rich magmas at depths near to the crust-mantle interface,with rising pH_2O acting as a rupturing agent allowing the evolved liquids to reach the surface or sub-surface reservoirs, probably holds good, as apart from gravitative settling and flow-differentiation during ascent, filtration of liquid from a static crystal mush,as seen for example in drill-holes penetrating semi-solid lavas such as lava lakes, is the only really viable mechanism whereby evolved rocks can be produced from a basic parental liquid (excepting large scale contamination). This partial crystallisation is in effect a crystal fractionation process although not governed by gravitative segregation of a low-density residual liquid as it would be in a near surface magma chamber. Rising pH_2O would help to explain the presence of olivine + plagioclase microphenocrysts in all hawaiites despite the evidence of high pressure studies by Thompson (1974b) that olivine is not a liquidus phase at any pressure in a hydrous system. The trace element data outlined in this section, in conjunction with those of Thomspon et al. (1978) which includes rare-earth element data, tends to confirm this evidence that fractional crystallisation of the 'basaltic' possibly high MgO magmas to hawaiite occurred at depth. Thompson et al.

(1978) see this as having taken place at about 35 kms depth by precipitation of olivine (10%), plagioclase (15%) and aluminous sub-calcic augite (20-25%). Moorbath and Thompson (1978) give details of $^{87}Sr/^{86}Sr$ variation which supports a near Moho depth for the origin of the majority of the basalt-benmoreite suite ie. the Alkalic Suite.

Additional evidence for the role of an aluminous sub-calcic augite comes from the work of Donaldson (1975) which has shown that some of the mafic inclusions within plagioclase megacrysts in the allivalitic dykes of Skye are of this phase. Also some basalts described in Chapter 7 possess slightly zoned large ophitic plates of titaniferous augite which may have begun as micro-phenocrysts therselves. Some of the Rhum hawaiites may also carry indications of small clinopyroxene micro-phenocrysts (Emeleus, pers. comm.). Similar, but much better developed clinopyroxenes figure as an important phase in the alkaline sills of the South of Arran (Gibb and Henderson 1978). Xenocrysts of a possible high-pressure origin are found scattered throughout the composite hawaiite of Dun Ard an-t-Sabhail at the locality of the same name near Loch Bracadale. These consist of a relatively Alumina-rich orthopyroxene and an Aluminous spinel of hercynite-type in addition to basic plagioclases some of which are reversely zoned and have finger-print textures that indicate resorption, compositionally these are andesines, and consequently quite a bit more sodic than the other plagioclases noted. Binns <u>et al</u>.(1970) showed that limited experimental evidence suggested that the liquidus or near liquidus plagioclase crystallising from alkali basalt compositions would get more sodic at high pressure, an effect possibly also enhanced by the entry of the anorthite component in early clinopyroxene. Binns <u>et al</u>. also suggest that for 'spinel' to be preserved from a fractionation event at high pressure, the magma must be silica undersaturated. This is certainly the case for the vast majority of hawaiitic lavas encountered (see also Thompson <u>et al</u>. 1972). However, the presence of an aluminous clino-pyroxene on the liquidus which would have the effect of enriching the residual liquid in silica, would necessitate that the liquid was almost basanitic (c.a. 10% normative Nepheline) or else the spinel phase would react with the liquid to yield either $Mg_2Si_2O_6$-$MgAl_2O_6$ enrichments in the sub-calcic clinopyroxene phase or an aluminous orthopyroxene. Within the composite hawaiite of Dun Ard an-t-Sabhail some 'xenocrysts' approximating to the latter are found (see Chapter 8).

In addition strange, enigmatic pyroxene intergrowths are a rare occurrence in this flow and may be relicts of the sub-calcic phase. Thus, this particular flow, although of only limited and local occurrence may supply crucial evidence for the genesis of the intermediate lavas. In analogous assemblages elsewhere such phenocryst assemblages have been interpreted as cognate xenocrysts from higher pressure fractionation events e.g. Binns et al. (1970); Wilkinson and Binns (1969); Wright (1968). In contrast to Skye (and indeed the rest of the British Tertiary Igneous Province) these other occurrences are commonly associated with the appearance of dunite or lherzolite nodules. If these are high-pressure phases rather than a break-up product of the basement then they are further evidence for the derivation of the hawaiitic magma at depth. Indirect evidence that clinopyroxene is probably important at some stage in the genesis of all the Hebridean alkalic rocks perhaps may be gleaned from the studies of several other alkaline and mildly alkaline suites e.g. East Otago Province, New Zealand (Coombs and Wilkinson, 1969), Aden (Cox et al. 1970) Madiera (Hughes and Brown 1972) and Deccan (e.g. Krishnamurthy and Cox 1977) which have broadly similar geochemical characteristics and differentiation sequences. The basalts of these suites carry clinopyroxene (augite) as a phenocryst phase whereas the Hebridean examples do not and in the former it is easily demonstrated to be an important fractionating phase.

No such elaborate high-pressure origin seems necessary in order to explain the sequence hawaiite - mugearite - benmoreite - (trachyte). As stated earlier, the removal of the low-pressure phenocryst phases in these rocks is adequate to demonstrate the transition with possible additional fractionation of zircon at the latest stage, but other mechanisms such as differential partial melting, crustal contamination or both should be considered. It has already been demonstrated that the west-central Skye Alkalic Suite series basalt-mugearite cannot have originated by differential partial melting, with some subsequent fractional crystallisation, of a garnet-lherzolite mantle as proposed for the 'equivalent' suite in Mull by Beckinsale <u>et al</u>. (1978), Pankhurst and Beckinsale (1979). Neither can it have originated by a similar process at shallower depths in a plagioclase-lherzolite mantle since although Sr behaves mostly in a similar fashion to Beckinsale <u>et al</u>'s Group II Mull lavas the Sr/Ba ratios are markedly different. Furthermore, some plagioclase fractionation is demonstrable in the Skye suite but apparently not in Mull. Yttrium in behaving similarly to Mull Group III basalts suggests either that magma mixing has occurred or that crustal contamination was possibly an important factor especially during the early volcanic history of west-central Skye. There is some supporting evidence for this from the work of Moorbath and Thompson (1978) which reveals that $^{87}Sr/^{86}Sr$ correlates negatively with total Sr confirming previous Pb-isotope evidence of interaction with Lewisian upper crust (Moorbath and Welke, 1968). Hence crustal contamination cannot be ruled-out as a major contributory factor in Skye. The genesis of the Alkalic Suite can be represented diagrammatically as shown in Figure 46. The spectrum of lava compositions (of all Suites) observed at the surface implies a complex mechanism or perhaps several mechanisms of formation. In part this variation could be due to a heterogeneous source or by different degrees of partial melting followed by polybaric crystal fractionation. Rates of ascent and lengths of residence times in variously sited magma chambers, perhaps interconnected allowing a certain amount of batch mixing to occur, would also affect the compositions seen. Some degree of polybaric control is evidenced by the range of phenocrysts and xenocrysts in the lavas. The Dun Ard an-t-Sabhail composite if considered in conjunction with the other composites of Roineval and Drum na Criche (Harker 1904; Kennedy 1931; Anderson and Dunham 1966; Boyd 1974) show a range of high pressure phases. Lavas more evolved than hawaiite would then be derived from a heterogeneous spectrum of hawaiite compositions; their final products perhaps being largely controlled by the splitting of the low-pressure thermal divide in the system olivine - clinopyroxene - plagioclase - (quartz or nepheline) as mentioned previously.

Finally, not only does the composite flow (above) appear to be very important in any consideration of the genesis of the Alkalic Suite but, could also be important in explaining certain features of the Talisker low-alkali tholeiite (see later). Assuming that compositional gradients exist in magma chambers given enough time then, in composite bodies in general the expulsion of a more basic component (often porphyritic) after the first eruption of slightly more evolved lava (e.g. Boyd 1974) could also explain the slight internal differences in character between the Preshal More and Preshal Beg outliers as is considered more fully in 9.3.iv).

9.3.ii) The Sub-Alkalic Suite

Although as stated in 9.3.i), Thompson et al. (1972) were able to subdivide their Skye Main Lava Series (SMLS) into two lineages from basalt towards either benmoreite or trachyte via relatively Si-poor, Fe-rich and Si-rich, Fe-poor intermediates respectively on the basis of major element geochemistry and petrography, there appears to be little supporting evidence for such a well-defined splitting of the Alkalic Suite in west-central Skye. One reason for this discrepancy, accepting that two lineages do exist, is that few lavas more evolved than mugearite are found in west-central Skye in contrast to the area of Thompson et al's study in northern Skye where such lavas are well developed around the Bracadale region (see figure 15). Consequently it cannot be unequivocably be stated that such lineages are present or absent, but there is limited evidence in support of some divergence of trends in the mugearites of west-central Skye. In figures 29, 32 and 33 this limited divergence is noted and where suitable, trend lines have been drawn to bring attention to it. Less than 5% of the total intermediate rocks analysed conform to this sub-Alkalic Suite and there is little apparent difference in the petrography of the rocks concerned save perhaps, that to a limited extent, titaniferous magnetite dominates over olivine here whereas the reverse is more applicable to the Alkalic Suite. Also apparent is the inescapable fact that many of the analyses concerned belong to the upper parts of the Arnaval Lava Group (see Chapter 6) and especially those lavas directly underlying the Talisker Group in Glen Oraid and Sleadale. They are interbedded with lavas of the Alkalic Suite but certainly appear more common in this region. This includes the intermediate trachyte (CPX-phyric) of Sleadale which is quite distinct from the alkali trachyte of Cnoc Scarall as mentioned in Chapter 7 and 8 and is possibly the strongest evidence for a second lineage. In addition to the restrifted number of lavas, this Sub-Alkalic Suite is defined by a few intrusions, notably dykes as shown in figure 33.

Variation in terms of both Differentiation Index and iron/magnesium ratio of both major and trace elements (figures 29, 30 and 36) does not readily distinguish between the Alkalic and sub-Alkalic Suites and for the most part their variation is similar. However, accepting that two lineages exist and that their end members (at least as far as west-central Skye is concerned) are the Cnoc Scarall and Sleadale Trachytes, the latter relative to the former is depleted in Al_2O_3?, total Fe, Na_2O and

K_2O (ie. total Alkalis), Nb, Zr and Rb with corresponding enrichments in CaO, MgO, TiO_2, P_2O_5, Ba, Sr and Zn. There is little or no appreciable difference between the remainder. Thompson et al. (1972) and Thompson (1974) regarded the two lineages of intermediate lavas within the Skye Main Lava Series (S.M.L.S.) as having been derived from relatively iron-rich, silica-poor nepheline normative basalts and iron-poor, silica-rich hypersthene normative basalts respectively and that their differences could be traced back to small differences in the chemistry of these basalts. This has not been found possible for the lavas and intrusions of west-central Skye. However, fractionation at relatively low-pressures of titaniferous magnetite, plagioclase feldspar and at a later stage of alkali feldspar and apatite seems to explain the variation in the Sleadale Trachyte compared to the sub-Alkalic hawaiites and mugearites and it still seems likely that differences in the parental basalts is the source of variation between the Alkalic and sub-Alkalic Suites. It is possible that the near aphyric, low MgO basalts constituting the Transitional Suite are the progenitors of the sub-Alkalic intermediate lavas, and this is considered later.

9.3.iii) The Transitional Suite

A small group of hypersthene-normative basaltic lavas and possibly related intrusions (e.g. the sills at Geodh'a'Ghamhna and Allt Gearraidh Dhroighinn) interbedded with predominantly nepheline-normative alkali-olivine basaltic and hawaiitic lavas belonging to the Bualintur and Cruachan Groups (see Chapter 6) have characteristics which set them aside from both the Alkalic and Tholeiitic Suites.

Petrographically (see Chapters 7 and 8) they are either essentially aphyric or relatively poor in fresh groundmass olivine but with the appearance of a brownish, sub-calcic clinopyroxene as a major, possibly micro-phenocrystic, phase often accompanying plagioclase feldspar. In these rocks which have Differentiation Indices equivalent to the most basic basalts of the Alkalic Suite, olivine appears to have been supressed as a major phenocryst phase.

The basaltic rocks of this suite are characterised by intermediate values of Na_2O, K_2O, total Fe, TiO_2 and CaO as shown in figures 29, 30, 33, 36 and 39, and have Ti/Zr, Zr/Nb and Zr/Y ratios distinct from and intermediate to both the Alkalic and Tholeiitic Suites (see Table 8). Some, although not of a low-alkali type do

FIGURE 39

Plot of Ti versus Zr for the basaltic lavas of west-central Skye and the associated intrusions, showing that the latter mainly fall within the low-alkali, high-calcium olivine tholeiite or Preshal More Magma Type of Mattey et al. (1977)

Symbols for intrusions as used in figure 29.

In addition: o Alkali olivine basalts (Alkalic Suite)

+ Transitional basalt

⧫ Low-alkali, high-calcium olivine tholeiite of Preshal Beg

◊ Low-alkali, high-calcium olivine tholeiite of Preshal More

A —·—·— Fairey Bridge Magma Type (Mattey et al.,1977)

B ----- Preshal More Magma Type " " "

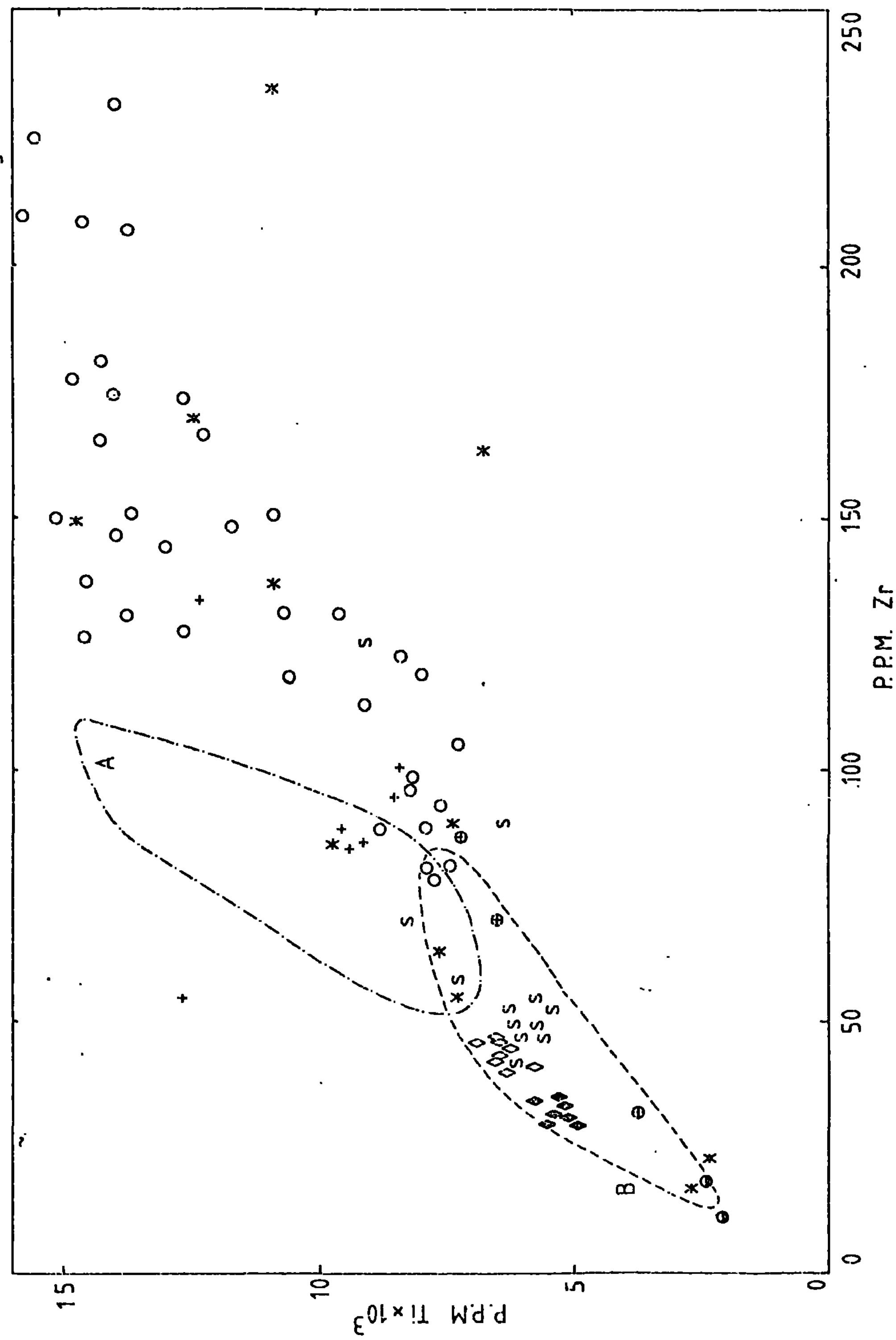


Figure 39

carry very high CaO (10% to 12.5%) similar to the low-alkali, high-calcium, olivine tholeiites, compared to the Alkalic Suite and are easily distinguished from these basalts in figures 36 and 40. Also, in considering their near-aphyric, relatively olivine-poor status, they retain values of MgO at around 8% to 9% equivalent to the distinctly olivine porphyritic nepheline- and hypersthene-normative basalts of the Alkalic Suite. Their pyroxene is relatively diopsidic (see Chapter 8, Figure 22) and this, apart from completely altered and barely recognisable groundmass olivine, is the only other possible site for the MgO. Figures 39 and 40, plotting Ti against Zr and Ti against Fe/(Fe+Mg) respectively, distinguish the various volcanic suites in west-central Skye and show the basalts of the Transitional Suite broadly similar to the Fairey Bridge/Preshal More magma types of Mattey et al. (1977) in the former but distinct in the latter and truly transitional between the Alkalic and Tholeiitic Suites. This figure illustrates well the multilineate variation of the Skye basalts. In figures 29, 36 and 40 the Transitional Suite appears to lie on a trend close to the low-alkali tholeiites in the Tholeiitic Suite, suggesting some genetic connection. This is especially well shown by the elements SiO_2, MgO,

FIGURE 40

Plot of TiO_2 versus the ratio iron/iron + magnesium for the various basaltic lavas and intrusions of west-central Skye. Also shown are the plutonic intrusions. This figure very neatly distinguishes between the various suites or magma types recognised. Symbols as used in figure 39.

In addition:

F Fairey Bridge Magma Type of Mattey *et al*. (1977)

Trend lines:

1. Alkalic Suite
2. Transitional Suite
3. Fairey Bridge Magma Type trend
4. Tholeiitic Suite (equivalent to Preshal More Magma Type trend)

The vectors indicate the maximum effect of the removal of olivine or plagioclase phenocrysts.

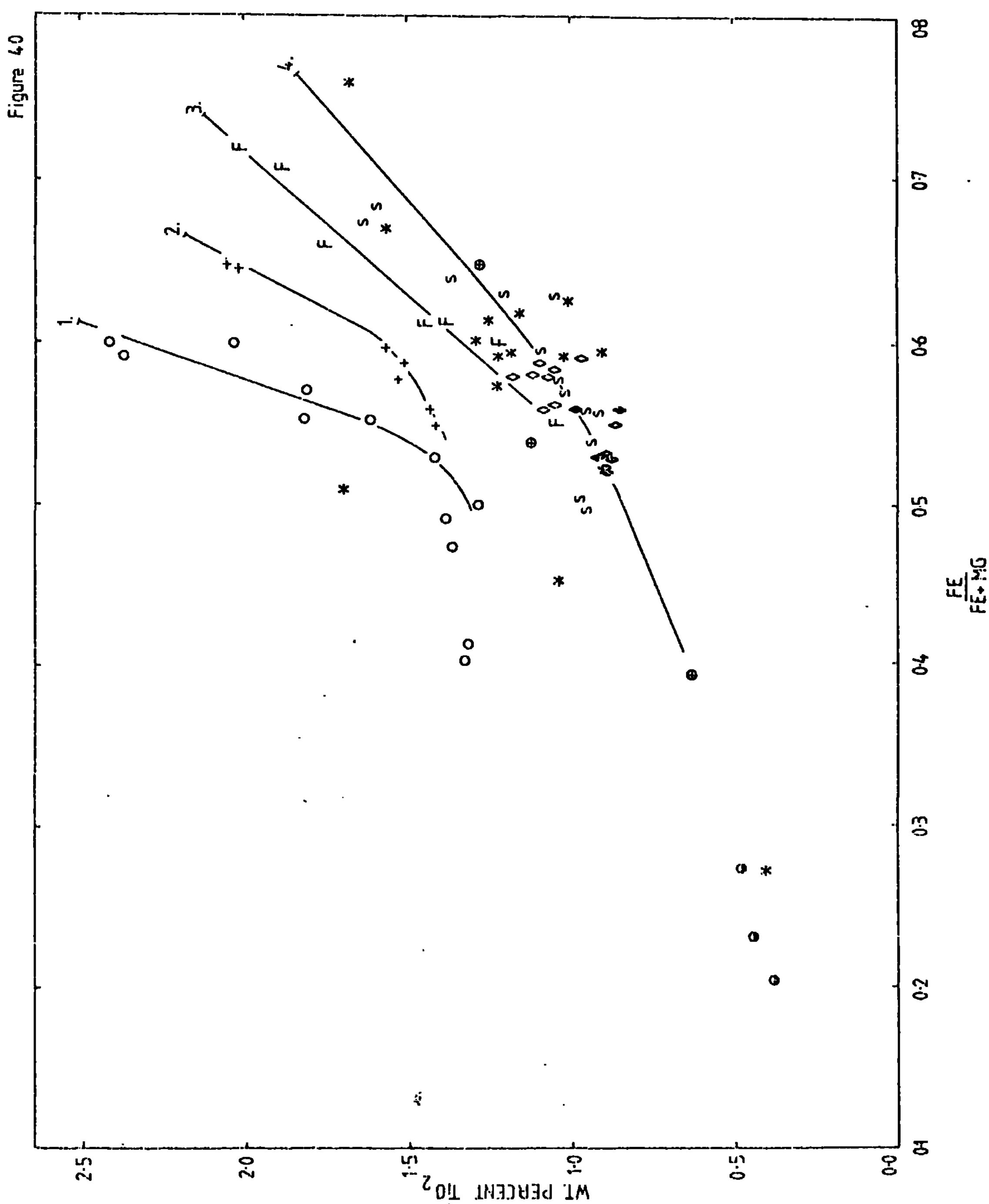


Figure 40
1.
2.
3.
4.
WT PERCENT TiO_2
2.5
2.0
1.5
1.0
0.5
0.0
FE / FE+MG
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

CaO, Ni and Cr but in detail the Ti/Zr ratios of basalts in this suite having equivalent iron/magnesium ratios (Table 7, figure 36) are lower than both the Fairey Bridge and Preshal More magma types ie. the Tholeiitic Suite. Absolute values of the incompatible trace elements eg. Zr, Rb, Y and Nb are of the same order of magnitude as Mattey et al's Fairey Bridge magma type, but there are slight differences and some degree of overlap with the Tholeiitic Suite.

The sills quoted in Chapter 7, and mentioned above appear to be petrographically related to at least a few of these lavas having sub-calcic clinopyroxene as an increasingly important phase mostly at the expense of olivine and the presence of predominantly interstitial titaniferous magnetite. In terms of their geochemistry they lie on trends towards the Tholeiitic Suite eg. Alkalis versus SiO_2 (figure 33) and this coupled with the petrography sets them aside from the Alkalic and Sub-Alkalic Suites. They have on this basis been asigned to the Tholeiitic Suite and are considered in more detail later.

In summary, relative to the predominantly nepheline-normative Alkalic Suite with which they are associated, the few lavas and intrusions of the Transitional Suite are depleted in total iron, MgO, Na_2O, TiO_2, P_2O_5, Sr, Ni and Cr and possibly also Al_2O_3, K_2O and Zr with enrichments in SiO_2, CaO and Y. In direct comparison with the hypersthene-normative basalts which form the basis of Thompson _et al_'s (1972) Si-rich, Fe-poor basalt to trachyte lineage within the S.M.L.S. the Transitional Suite has much the same variation relative to the nepheline-normative basalts. These Transitional basalts have roughly comparable ranges of SiO_2, K_2O, TiO_2, P_2O_5 and Nb, Rb and Zr (see table 8). In these respects, it is possible that they are themselves the basaltic parents of the intermediate lavas in the Sub-Alkalic Suite although they differ from Thompson _et al_'s hypersthene normative basalts in possessing considerably higher CaO (values ranging 10-12.5 wt.% against 9.3-10.3 wt.%) and in being depleted in Sr. Thompson _et al_'s hypersthene-normative basalts on average contain more K_2O than their nepheline-normative counterparts and although there is some overlapping of data the same is basically true of the Transitional Suite. Hence it is altogether very tempting to link these relatively MgO-poor, hypersthene-normative basalts with the intermediate lavas of the Sub-Alkalic Suite.

In contrast to the basalts of the Alkalic Suite, the Transitional Suite basalts plot in a cluster around the piercing point in figure 35 which represents the locus of liquids in equilibrium with olivine, plagioclase and spinel, and show no 'olivine control' at low pressures, thus bearing close similarities to many of the Small Isles 'basalts' discussed by Ridley (1973). This suggests fractional crystallisation has been important in their ascent, and most likely at low pressures.

Comparisons of stratigraphically connected Transitional and Alkali Suite basalts such as specimens Sk751216 and Sk751208 respectively from the Cruachan Lava Group Group reveal that the transitional basalt is relatively depleted in FeO, MgO, K_2O, TiO_2, Zr, Y and Sr, possibly due to having been derived by a more substantial partial melting event followed by some fractionation of olivine and plagioclase. That these basalts are allied also to the low-alkali, high-calcium olivine tholeiites is shown by their abnormally high CaO values and the extremely depleted trace element contents. Thus they could be transitional because of the degree of partial melting producing them, or perhaps even a intermixing of primitive MgO-poor Alkalic and low-alkali tholeiite magmas in the intricate reservoir plexus envisaged, although this would be difficult to check and as with a model proposing that they could be the products of a low-pressure differentiation process of the low-alkali tholeiite magma type, this would necessitate the introduction of that magma at a relatively early stage in the volcanic cycle. This possibility is considered subsequently.

9.3.iv) The Tholeiitic Suite

The division of basaltic and gabbroic rocks into alkali and tholeiitic types within each centre in the Tertiary Igneous Province has been known for some time. Bailey et al. (1924) called these the 'Plateau' and 'Central' Magma Types respectively and although recent research is revealing the multilineate nature of the basaltic and related rocks throughout the Province, in Skye as elsewhere there is still a fairly clear-cut division between the two. In west-central Skye those rocks considered here under the heading of the Tholeiitic Suite range from the low-alkali, high-calcium olivine tholeiites to 'andesitic' intermediates, various gabbros and ultrabasics associated with the Central Complex and a few acidic minor intrusions. Their variation in terms of major and trace element chemistry is shown by figures 29, 33, 36, 39 and 40.

9.3.iv)A. The Low-Alkali Olivine Tholeiites

In west-central Skye the low-alkali olivine tholeiites are represented by the lava flow forming the two outliers of Preshal Mor and Preshal Beg near Talisker and by several minor intrusions referred to as sheets in this study. The flow is one of only two flows possessing this unusual composition (Thompson et al., 1972; Esson et al., 1975) so far discovered within the Tertiary Igneous Province although the 'magma type' is known to be well represented in the regional dyke swarms of Skye, Mull, Islay-Jura, Arran and Antrim (Mattey et al. 1977; Lamacraft 1978; Turner pers. comm. in Mattey et al.; Patterson 1955). The intrusions of this composition are mainly inclined basic sheets (low-angle dykes) or cone-sheets; the latter associated with the margin of the Cuillin Hills Intrusive Complex.

Compared to the basaltic members of the Alkalic Suite described previously these low-alkali tholeiites show considerable depletion in total iron content, MgO, Na_2O, K_2O (total alkalis), TiO_2 and P_2O_5 as well as the trace elements Ba, Nb, Zr, Sr and Rb as shown in figures 29, 30 and 37. They also have distinctive Zr/Nb, Zr/Y, Ti/Y and Ti/Zr ratios. In this respect only the highly magnesian olivine + spinel porphyritic basalts of the Alkalic Suite approach them in having such depletion patterns but as mentioned previously (Chapter 7 and 9.3.i) these are easily distinguished both petrographically and by their high levels of Cr and Ni. These olivine-tholeiites are possibly the most 'primitive' of all the basaltic rocks found in west-central Skye by virtue of their abnormally high CaO wt.% (12-13 wt.%), exceptionally low K_2O wt.% (generally 0.1 wt.%) and low values of incompatible trace elements compared to the Alkalic Suite. They plot as a distinct group on the Ternary AFM plot (figure 31) and in figure 32 are characterised by feldspar in the bytownite range. The total alkalis against silica plot of figure 33 reveals them to be tholeiitic although mineralogically they are olivine tholeiites, containing substantial hypersthene + olivine in their norms. The normative projections of figures 34 and 35 set them aside from the Alkalic Suite. Intragroup variation is restricted in west-central Skye when shown against the fields of the Preshal More Magma type defined by Mattey et al. in figures 39 and 40. Table 10 shows that the low-alkali, high calcium olivine tholeiites are distinct in trace element pattern from both hypersthene- and nepheline-normative representatives of the Alkalic Suite and the Transitional Suite lavas. Esson et al. (1975) and Mattey et al. (1978) liken the chemistry of these rocks to that of ocean floor tholeiites or mid-oceanic ridge-type basalts. Indeed, when plotted in terms of the ratios Zr/Y and Ti/Y (see Table 10) as used by Pearce and Gale (1977) to discriminate between 'within-plate basalts' from 'other basalt types' and also used by Beckinsale et al. (1978) for Mull, Tertiary lava data (fig.44) the low-alkali tholeiite and the gabbro plot in field A while the Alkalic-suite basalts fall into field B in figure 44, and are neatly separated from one another. The Transitional Suite basalts plot within field B but seemingly intermediate to the Tholeiite and Alkali Suites reafirming their truly 'transitional' nature. Another feature of this diagram is that the hy-normative alkalic basalts have apparently higher Zr/Y but smaller Ti/Y ratios relative to the ne-normative alkalic basalts.

In considering the Talisker Lava Group, the analyses (Appendix 1) plot close to one another suggesting that only analytical and sampling variations have produced the slight scatter of data observed from what is considered to be a single flow, but in detail, small and possibly important differences exist between the two outliers. When the data for each is plotted against height within the flow, the variation between them is more obvious as shown in figure 41. From this it appears that Preshal Beg is relatively depleted in total alkalis, TiO_2, P_2O_5, total iron and SiO_2 and has correspondingly a lower iron/magnesium ratio and Differentiation Index. Only CaO and MgO seem on average to be higher. Also, the chilled, basal contact of the Preshal Beg section (specimen Sk750809) appears to be the most primitive rock sampled having a Differentiation Index of 13.3 and an iron/magnesium ratio of only 0.52. In terms of trace elements the two outliers are again quite distinct. This is true of Y, Sr, Cu, Ba and Ni (figure 41) and especially Zr (figure 39), which for the Alkalic Series was found to be a reasonable indicator of the degree of differentiation. Preshal Beg is depleted in these elements relative to Preshal More and the adherence of this pattern of variation,coupled to that of the major elements,with the pattern produced by differentiation, argues against the inter-outlier variation being due to analytical scatter and compositions close to the detection limits but rather suggests that for some reason, the tholeiite of Preshal Beg, situated closer to the assumed positioning of the vent which gave rise to it and the underlying pyroclastics, is slightly more basic than Preshal More. Variation within the Preshal More magma type of Mattey et al. was attributed to fractional crystallisation of the observed phenocrysts (olivine + plagioclase) in approximately their modal proportions at comparatively low pressures. This seems also to be likely for the example discussed here considering the subtraction vectors in figures 38 and 40.

Another, as yet unmentioned but predictable variation within the low-alkali tholeiite flow is noted in figures 41, 42 and 'averaged-out' in figure 43. This reveals that the internal chemistry is slightly variable with height and position within the respective zones of figure 18 as described in Chapter 6. When it is considered that the flow is over 100 metres thick, it is not altogether surprising to find that some differentiation similar to that within a thick sill has occurred, always assuming however that the main bulk of the flow was erupted more or less simultaneously. Disregarding the upper or zone of contorted, irregular columns which show a random variation due to more rapid cooling, the main columnar zone (2) and the basal parts (1) possess an apparent systematic variation. Compared to the lower zones the central portion of the main columnar zone which would probably be the latest to crystalise is slightly but significantly enriched in total alkalis, TiO_2, P_2O_5, SiO_2, total iron, iron/magnesium, Differentiation Index, Ba, Nb?, Zr, Y, Sr and Cu and correspondingly depleted in CaO , Ni and Cr. This pattern of variation is identical to that shown above to exist between Preshal Mor and Preshal Beg and reveals that the central columnar zone is slightly more evolved than the base and the fine-grained junction

FIGURE 41

Major element variation with height in the flow of low-alkali, high-calcium olivine tholeiite that forms the twin outliers of Preshal More and Preshal Beg.

- ● Preshal Beg
- o Preshal More

zone

1. Chill zone and contact
2. Main regular volumns
3. Fissile-laminar contact zone
4. Upper, less regular to highly contorted fan-shaped columns

Figure 41

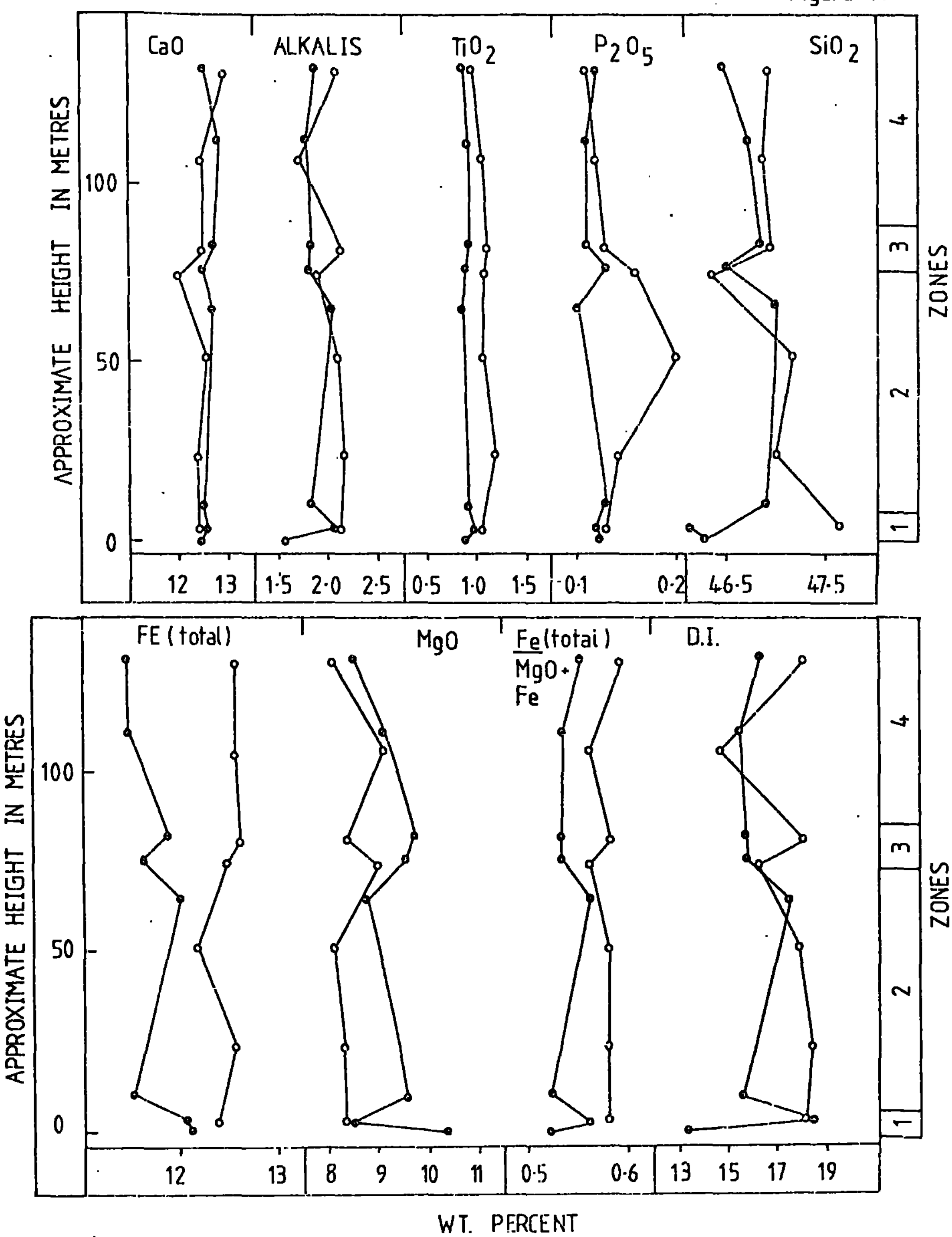

CaO
ALKALIS
TiO 2
P2 O5
SiO 2
APPROXIMATE HEIGHT IN METRES
100
50
0
12 13
1·5 2·0 2·5
0·5 1·0 1·5
·0·1 0·2
46·5 47·5
ZONES
4
3
2
1
FE (total)
MgO
Fe(total) / MgO+Fe
D.I.
12 13
8 9 10 11
0·5 0·6
13 15 17 19
WT. PERCENT

FIGURE 42

Trace element variation with height in the flow of low-alkali, high-calcium olivine tholeiite that forms the twin outliers of Preshal More and Preshal Beg. Symbols as for figure 41.

Figure 42

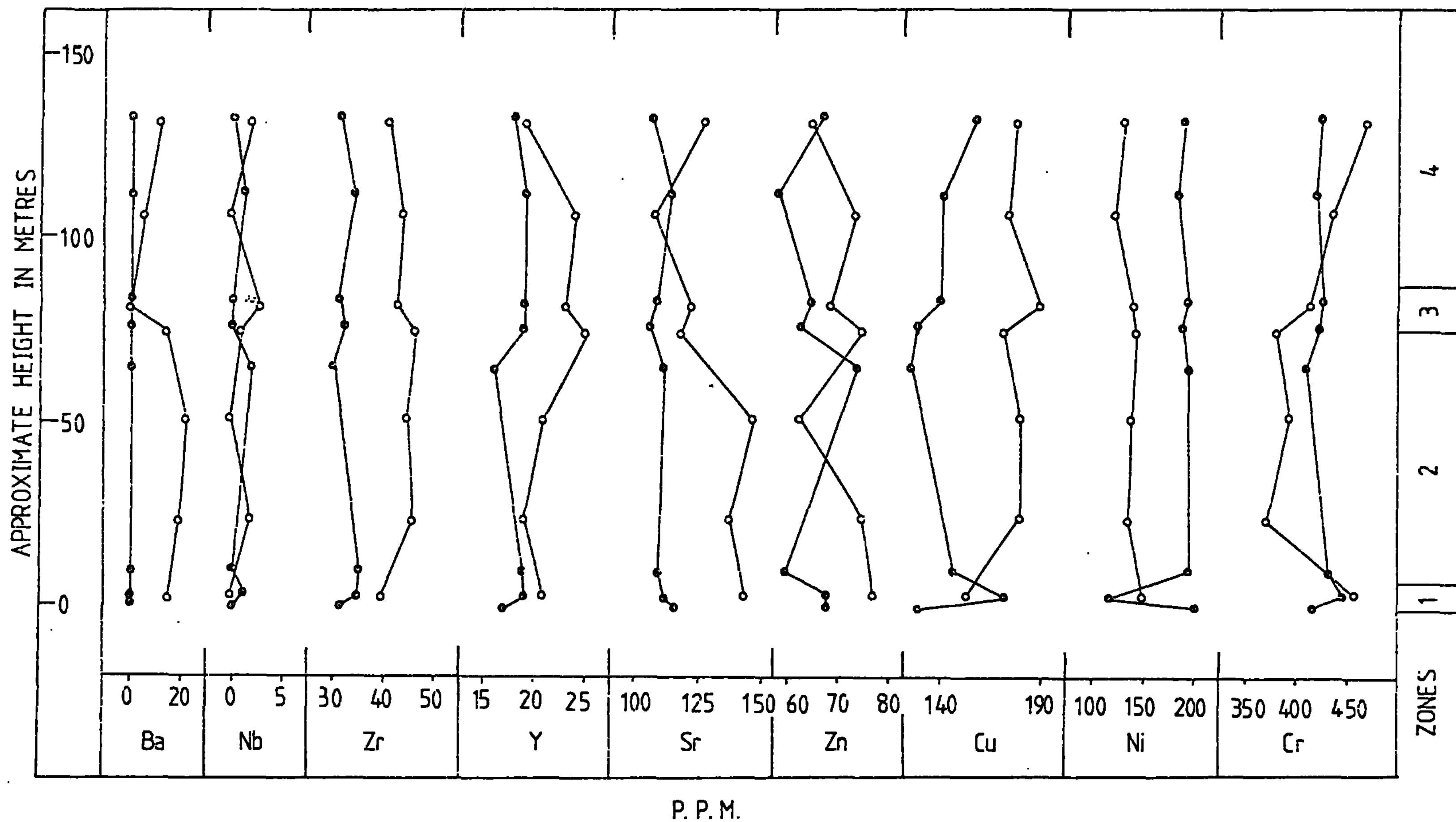
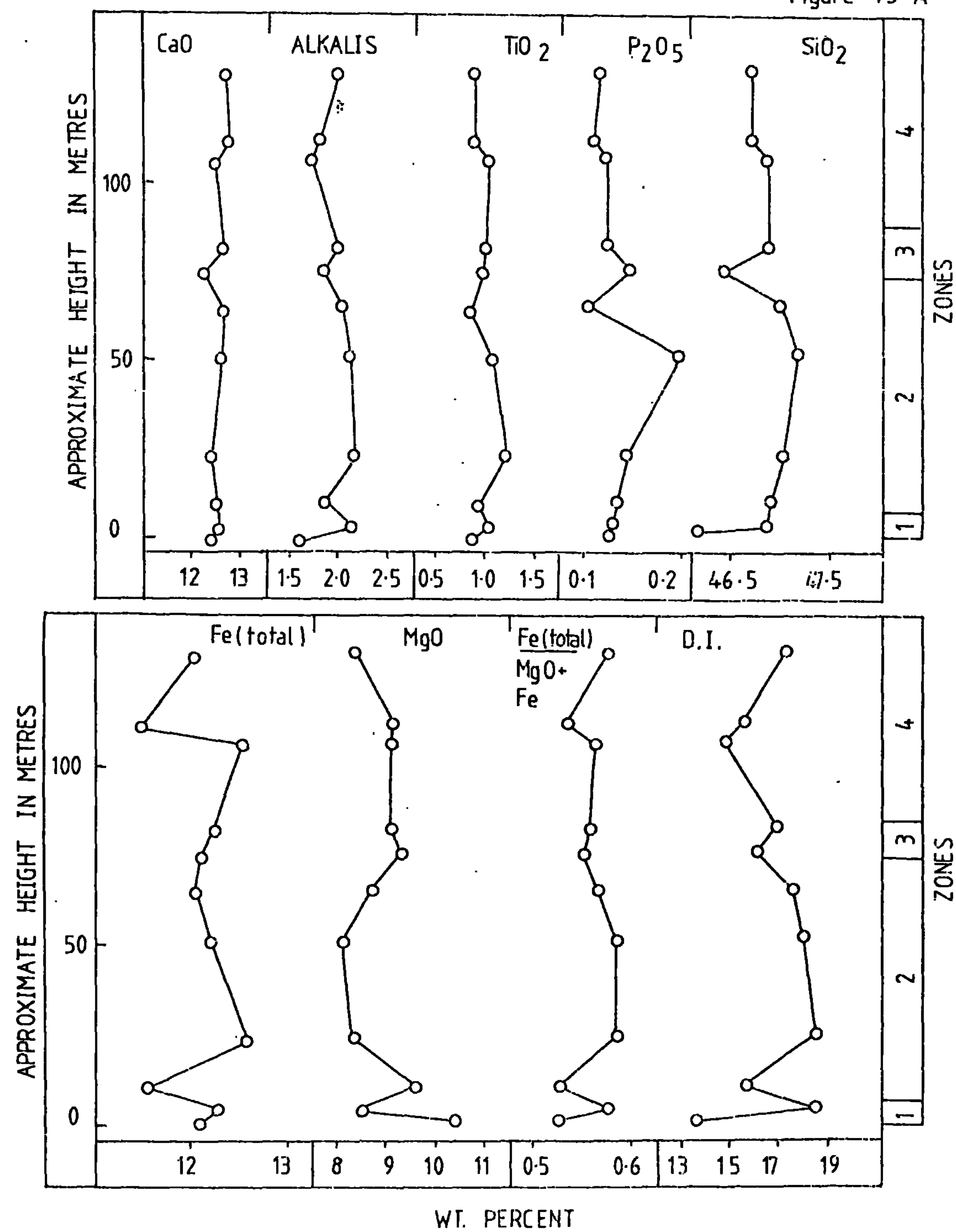

APPROXIMATE HEIGHT IN METRES
150
100
50
0
0 20
Ba
0 5
Nb
30 40 50
Zr
15 20 25
Y
100 125 150
Sr
60 70 80
Zn
140 190
Cu
100 150 200
Ni
350 400 450
Cr
ZONES
1
2
3
4
P. P. M.

FIGURE 43

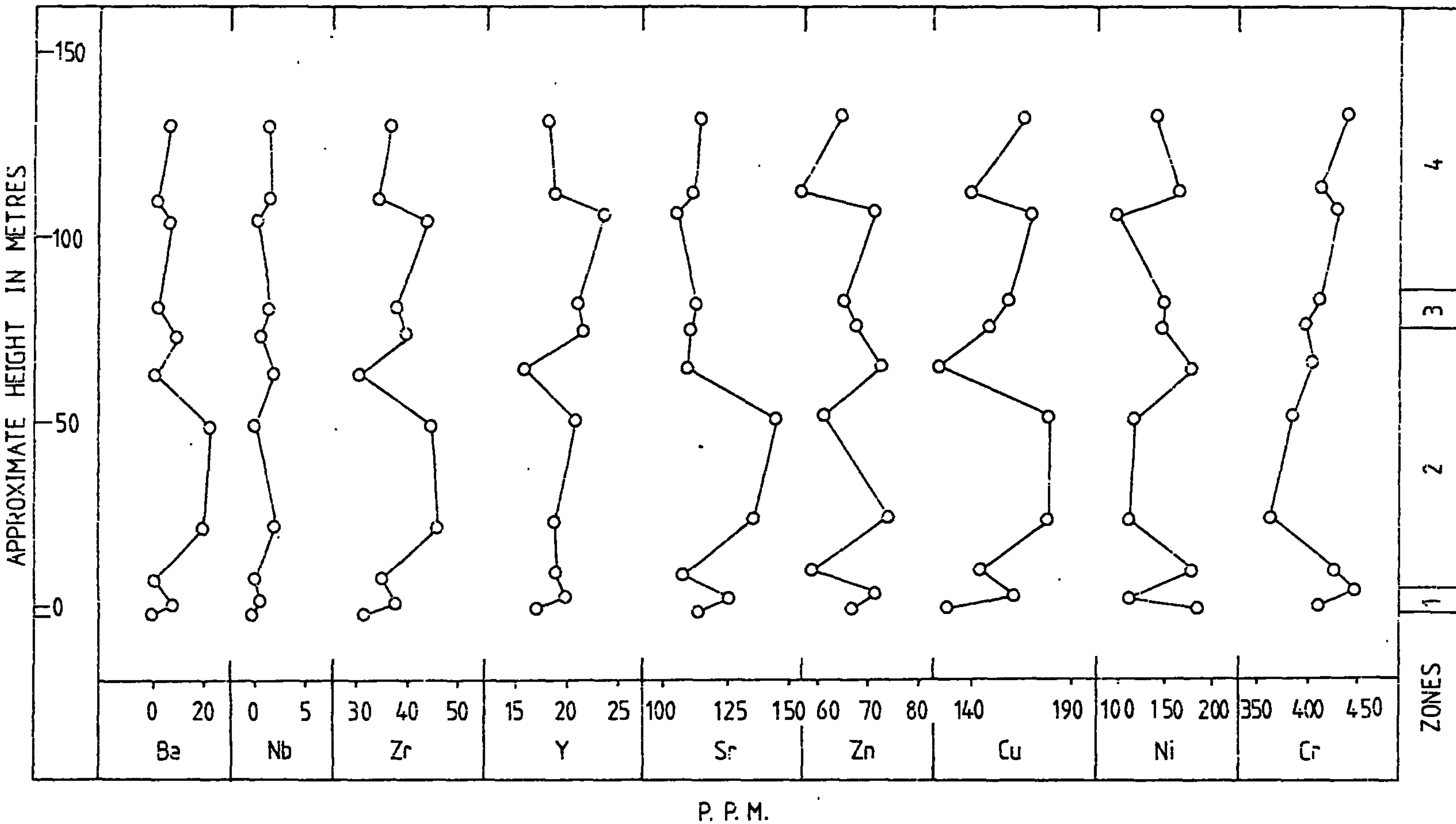
'Average' major and trace element concentrations with height in the low-alkali, tholeiite of the Talisker Group (based on figures 41 and 42). Zones as identified in figure 41. A-majors B-traces.

Figure 43-A



CaO
ALKALIS
TiO 2
P2O5
SiO2
APPROXIMATE HEIGHT IN METRES
100
50
0
12
13
1·5
2·0
2·5
0·5
1·0
1·5
0·1
0·2
46·5
47·5
ZONES
4
3
2
1
Fe(total)
MgO
Fe(total)
MgO+
Fe
D.I.
8
9
10
11
0·5
0·6
13
15
17
19
WT. PERCENT

Figure 43-B



APPROXIMATE HEIGHT IN METRES
150
100
50
0
0 20
Ba
0 5
Nb
30 40 50
Zr
15 20 25
Y
100 125 150
Sr
60 70 80
Zn
140 190
Cu
100 150 200
Ni
350 400 450
Cr
ZONES
1
2
3
4
P. P. M.

FIGURE 44

Plot of the ratios Zr/Y against Ti/Y for the basaltic rocks of the west-central Skye lavas.

● Nepheline-normative alkalic basalt.

O Hypersthene-normative alkalic basalt (sub-alkalic?)

+ Transitional Suite basalt

♦ Low-alkali, high calcium olivine tholeiite

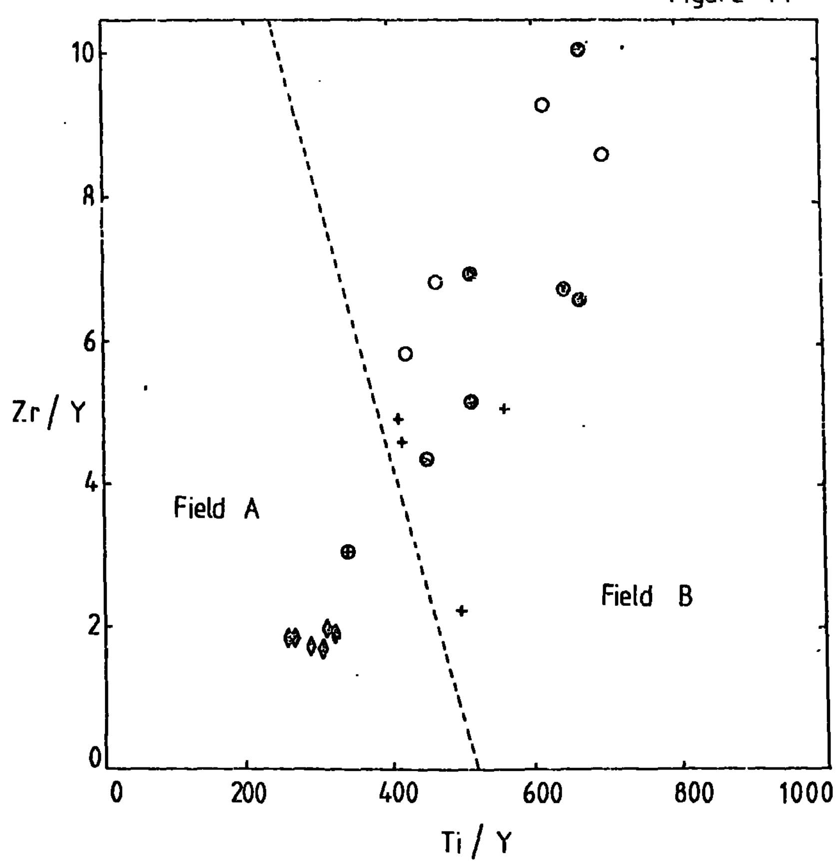
Field A. Ocean Floor basalts, Low K tholeiites and calc-alkaline basalts

B. Within-plate basalts

Source: Pearce and Gale (1977)

⊕ Gabbro

Figure 44



(fissile-laminar zone 3) with the overlying irregular columnar zone (4). In most instances there is a slight reversal of this simple pattern towards the base but in general the main variation is easily explained considering that in a shallow intrusive environment as must have existed within the central, more slowly and regularly cooling portions of the flow, elements such as K_2O, Na_2O, SiO_2, P_2O_5, TiO_2, Ba, Sr, Rb and the incompatible trace elements Nb, Zr and Y would be preferentially excluded from early crystallising phases becoming progressively concentrated in later fractions; the cooling rate however being rapid enough to ensure that differentiation did not proceed beyond a very embryonic stage. No more 'evolved' basalts or leucocratic veining was encountered during this study which might have represented the final residuum.

9.3.iv)b. The Gabbros

As shown in figure 39, the gabbroic rocks sampled are closely allied to the low-alkali, high-calcium olivine tholeiites of the Talisker Group and the inclined basic sheets in that they virtually all fall within the field of the Preshal More magma type of Mattey *et al*. However, for the most part they do not possess identical characteristics to this group, especially in trace element patterns, suggesting that although large batches of such a magma type were readily available during the peak of activity in Skye as suggested by Thompson _et al_. (1972) and Esson _et al_. (1975) few crystallised directly into the intrusive (plutonic) counterpart of the lava flow. Only specimen Sk760808 has the characteristic low K_2O (0.09 wt.%) and high CaO(11.54 wt.%) coupled with TiO_2, Zr, Y and perhaps Sr and Rb within the ranges of Mattey _et al_'s magma type. Specimen Sk751105-A from the gabbroic plug noted near Glen Brittle also has these characteristics (see Appendix 1). The former gabbro appears only as discrete lensoid bodies within the main gabbro and on petrography alone appears noritic in type while the outer gabbro has been classed as a eucrite (Weedon 1961; Hutchison 1966, 1968) and is chemically quite distinct, possessing much higher SiO_2, Na_2O, K_2O, TiO_2, MnO and P_2O_5 as well as Ba, Nb, Zr, Y, Sr, Rb, Zn and Cu than the norites. Despite these variations the intrusive rocks of west-central Skye almost all tend to form a single 'tholeiitic' lineage as shown in figures 29, 33 and 36, excepting Sk760803 representing a leucocratic variant of the outer eucrite which resembles the Sub-Alkalic Suite.

9.3.lv)c. Intermediates

The most evolved members of the Tholeiitic Suite apart from the rare acidic intrusions are represented by either a single- or two-sills intruding the lava sequence close to the junction between the Bualintur and Cruachan lava groups, west of the mouth of Glen Brittle, and by a few scattered dykes. They are probably best termed basaltic andesites indicating their oversaturated nature.

In contrast to the intermediate rocks of the Alkalic and Sub-Alkalic Suites these rocks plot well below the Hawaiian division line in figure 33, and show depleted variation patterns for SiO_2, MgO, TiO_2 (total alkalis) P_2O_5, Nb, Zr, Y, Sr, and possibly Cr and Ni. The ratios of these elements vary accordingly. Of these elements it is the low values of the incompatible trace elements and the lack of extreme enrichment in TiO_2 in the intermediates that characterise these rocks. Most are olivine + hypersthene normative but some are more oversaturated and carry a few percent of normative quartz.

9.3.iv)d. <u>The Ultrabasics</u>

Rocks having an ultrabasic composition are restricted to the area of and around the immediate margins to the Cuillin Hills Intrusive Complex. As is typical of such rocks they are depleted very much in the incompatible trace elements, SiO_2, TiO_2, alkalis, CaO, P_2O_5 and Al_2O_3 but strickingly rich in MgO, Cr and Ni, reflecting the predominance of Mg-rich olivine, clinopyroxene and spinels with subsidiary plagioclase feldspar. They thus appear very strongly controlled by the modal percentage of olivine and a cumulate origin is most likely and possibly from liquids approximating to the primitive tholeiites discussed earlier. Subtraction of olivine, clinopyroxene, orthopyroxene, chrome-spinel and anorthitic plagioclase would result in large bodies of cumulus gabbros, peridotites and allivalites etc. as indeed is the case in Skye. Suitable olivines (maximum Fo_{91} - see Chapter 8.1 and Esson et al. 1975), sub-calcic clinopyroxene and bytownitic/anorthitic plagioclase occur as phases within the low-alkali tholeiite rocks giving support to this. If the variation within Mattey et al's Preshal More magma type is indeed caused by subtraction of the observed phenocryst phases (olivine + plagioclase) then it is not too surprising to find that these rocks plot at the extreme basic end of this Magma Type in figures 39 and 40.

9.3.iv)e. The Acidic Rocks

Only two rocks analysed fall within this category and one is compositionally allied to trachyte having several features in common with the trachytic rocks of the Alkalic and Sub-Alkalic Suites but lying on the Tholeiitic Suite trend lines in figure 29. The other, is an example of the granophyric net-veining which

FIGURE 45

The sub-alkalic and alkalic trachytes (Sleadale and Cnoc Scarall respectively) and the granophyric net-veining which characterises the thermally metamorphosed lavas in contact with the Outer Gabbros of the Cuillin Hills Intrusive Complex near An Sguman, plotted in the system Quartz-Albite-Orthoclase.

□	Alkali trachyte of Cnoc Scarall	
■	Sub-alkalic or intermediate trachyte of Sleadale	
◓	Granophyric veining	
L	Lewisian gneisses (Dunham 1968) Rhum	Ridley 1973
†	Torridonian arkoses (Kennedy 1951)	figure 11
⌂	Field of Skye acid intrusions (Thompson 1967)	
....	'Thermal Valley'	

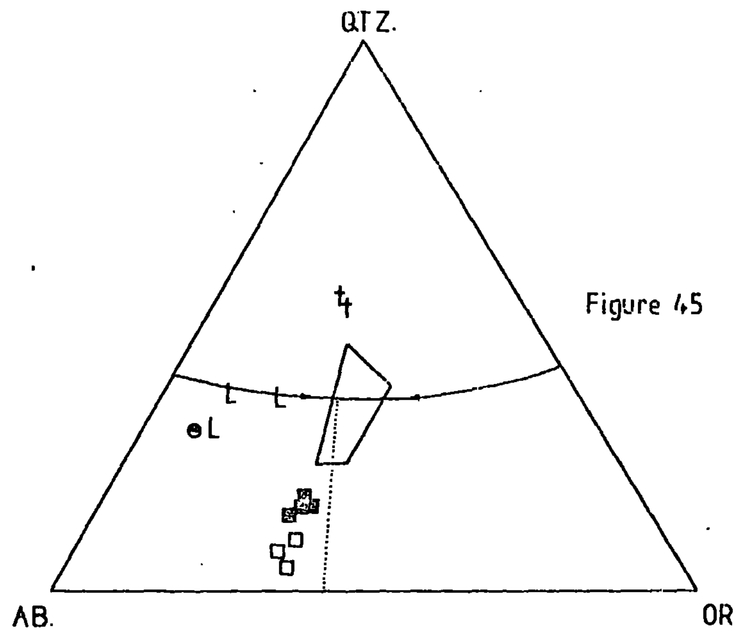


Figure 45

penetrates some of the brecciated basalts near An Sguman and can often be traced back to where it likewise cuts the outer gabbros. This rock also apparently lies towards the end of the Tholeiitic Suite trend in figure 29 and could have been derived via fractional crystallisation of this suite. However, when plotted in the system Quartz-Albite-Orthoclase, it fails to correspond to any previously analysed Skye granites (eg. taken from Thompson 1967) as indicated by figure 45. Rather, it plots close to the position within the feldspar field corresponding to analyses of Lewisian Gneiss from Rhum and could possibly have been derived via the melting and subsequent crystallisation of feldspathic gneiss at a shallow depth during the emplacement of the Intrusive Complex. Lewisian gneiss is known to form the basement to the entire area and in the area of Skye underlies a now relatively thin cover of Torridonian and Mesozoic strata.

9.3.iv)f. <u>Petrogenesis of the Tholeiitic Suite</u>

The extremely low values of many elements and especially the more incompatible trace elements suggests that the basic members of the Tholeiitic Suite ie. the low-alkali tholeiites are the products of the substantial partial melting of the upper mantle from which the olivine + spinel porphyritic alkalic lavas had previously been derived. Thus they represent the substantial melt products of the same spinel lherzolite,but now depleted,upper mantle. Variation within these basalts might result from the fractionation of the observed phenocryst phases ie. olivine and plagioclase in roughly their modal proportions. This was also the conclusion of Mattey et al. (1977) for their Preshal More magma type. With differentiation Ti/Zr falls from over 130 to around 35 (Differentiation Indices 16 to 52) and so separation of these phases alone is insufficient to explain the variation in the intermediate members of the suite. However, limited magnetite (titaniferous) and clinopyroxene also appear as subordinate microphenocryst phases in some of these rocks and they would provide the variation patterns shown.

To test the hypothesis that olivine in the Talisker Group lava may be accumulative,the same method as used for the alkalic rocks was applied, whereby the theoretical liquidus olivine is compared with the observed phenocryst cores. The results are shown in Table 11 Top zone specimen Sk750907 from Preshal Mor shows an excellent correlation of the respective values indicating no accumulation while the contact-chill-breccia Sk750809 on Preshal Beg tends to indicate that as Olivine $Fo_{observed}$

> Olivine $Fo_{calculated}$ (using maximum Fo-content Esson et al. 1975) then some accumulation has taken place. However mean values for the tholeiites olivines suggest no accumulation in the present rocks but unless a primary magma concept is considered then it is likely that at least some segregation has taken place during ascent. The extensive partial melting event visualised as having given rise to the low-alkali tholeiites would produce silica saturated hypersthene-normative picritic liquids at mantle depths. Fractionation of olivine upon ascent would produce the tholeiitic magma; its low trace element and K_2O, TiO_2, Na_2O, P_2O_5 contents etc. being inherited from the picritic magma via its depleted source region. In terms of the normative projection An-Di-Fo, although this represents only part of an analysis, the low-alkali tholeiites cluster near the Ternary piercing point in a similar fashion to the Transitional Suite.

9.3.iv)g. Formation of the Talisker Group

In 9.3.iv)A it was mentioned that the Talisker tholeiite varied both internally and between outliers. If the flow is 'ponded' ie. a valley in-fill then this could be explained by the following sequence of events which are summarised in figure 48.

Event 1. Eruption of tholeiite was preceeded by a phase of violent activity producing the pyroclastics noted beneath both outliers and some reworking by water and extensive weathering took place prior to lava effusion. The source vent for these tuffs and agglomerates was possibly in the vicinity of Preshal Beg as evidenced by particle size and distribution.

Event 2. Eruption of fluid tholeiitic magma with some phenocrysts, some lava flowing into water accumulated on the surface in small depressions. This produced the breccias and 'pillow' or lobate structures commonly associated with the chill zone 1 or A of Preshal Beg.

Event 3. Rapid effusion results in flow down-valley to Preshal More where chilling again occurs at the base of the flow. However, in flowing over a rough surface the effect of friction causes retardation of the basal portion which is progressively over-ridden by the upper parts of the flow. The base and sides are retarded by the contact with the floor and walls of the valley so that the most rapid movement occurs centrewards. Thus later (slightly) magma is transferred to Preshal More and is slightly more 'evolved' with higher alkalis, TiO_2, SiO_2, Fe(total), Fe/(Fe+Mg) and Differentiation Index than the chill of Preshal Beg.

FIGURE 46

A proposed petrogenetic scheme for the evolution of the Skye lavas based on the findings of this study of west-central Skye, Thompson et al. (1972) and Thompson (1974).

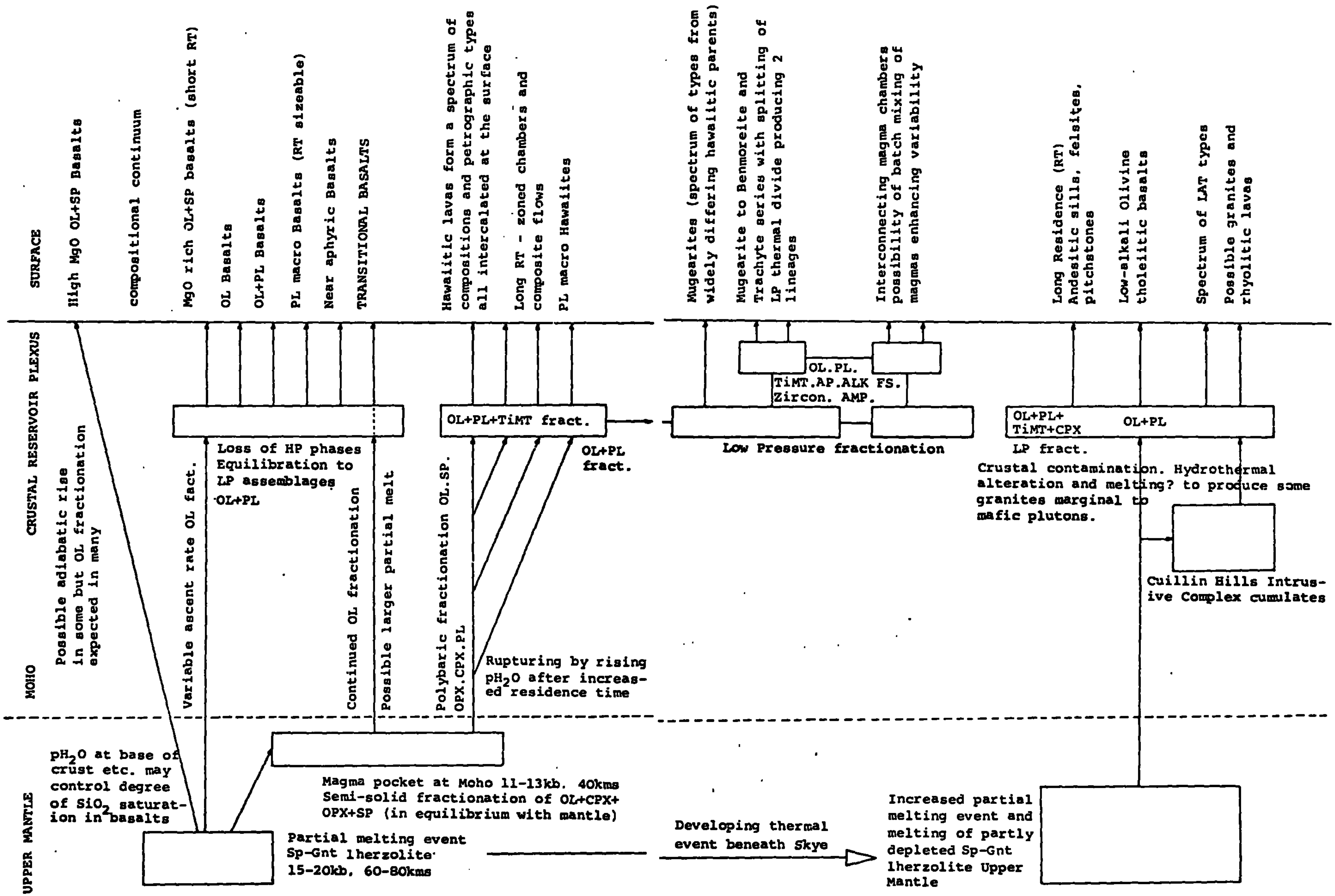


FIGURE 46. PETROGENETIC SCHEME FOR THE TERTIARY VOLCANIC ROCKS OF WEST-CENTRAL SKYE

FIGURE 47

A generalised volcanic and intrusive sequence as observed in west-central Skye showing the critical importance of large erosional breaks in the sequence in producing lavas of different characteristics to those previously erupted.

STRATIGRAPHY	SEDIMENTARY HORIZONS IN SEQUENCE	VOLCANICS ERUPTED	MAIN INTRUSIVE EVENTS AND COMPARISONS
	Agglomerates and intrusion/ explosion breccias at margins of Cuillin Complex	Minor vents and breccias. No record of later lavas	Radial dykes and the Cuillin Hills Complex. NW-SE Regional dyke swarm, cone sheets and plugs. Oseitic dykes of North Skye. Inclined sheets in west-central Skye. Increased partial melting.
Talisker Group	NO RECORD	Low-alkali, high-calcium olivine tholeiite	
	Tuff and agglomerate of Preshal More, Preshal Beg and Beinn Bhreac		
Arnaval and Loch Dubh Groups (equivalent in part)	Carbost Burn beds Ben Scaalan, Biod Mor and Beinn nan Cuithean beds	High% evolved rock types and possibly increasingly sub-alkalic. Thick boles locally. Composite and feldspar macroporphyritic flows	Similar to Beinn Totaig (in part) and Bracadale (in part) Groups in Northern Skye
Tusdale Group		Typical series dominated by cycles of various types of basalts-hawaiite-basalts-hawaiite etc.	Similar to Beinn Edra and Ramascaig groups in Northern Skye.
Cruachan Group (some overlap with Tusdale)	Sgurr an Duine agglomerate and well developed boles beneath many intermediate flows		
		Transitional lavas with feldspar macroporphyritic basalts and some mugearites	?Andesitic sills
	Conglomerates and sandstones of Glen Brittle, Allt Mor and Geodh'a'Ghamhna		Source for clasts perhaps Rhum-Canna region
Bualintur and Meacnaish Groups (equivalent in part)		Early intermediate flows overlain by thick sequences dominated by olivine-rich types. In part may be more transitional than later Skye series. Some basalt-hawaiite cycling.	Lavas involved in later aureole of Central Complex but may have some similarities to Small Isles types.
	Fine basal ash and agglomerates of Soay Sound	Limited explosive activity	Partial melting event. Slow restricted rise from undepleted mantle followed by rapid ascent prior to reservoir plexus establishing itself.
Mesozoic	Thick sedimentary sequences developed with unconformities exposed along Soay Sound.		Rather condensed sequence from Permo-Trias to Cretaceous compared to Strathaird or NE Skye.
Torridonian			Also well developed in Rhum 12-13 kms distant

FIGURE 47. A GENERALISED IGNEOUS-SEDIMENTARY SEQUENCE AS OBSERVED IN WEST-CENTRAL SKYE

FIGURE 48

Postulated series of events in the formation of the Talisker lava group in diagrammatic form, based upon field observations and its geochemical characteristics.

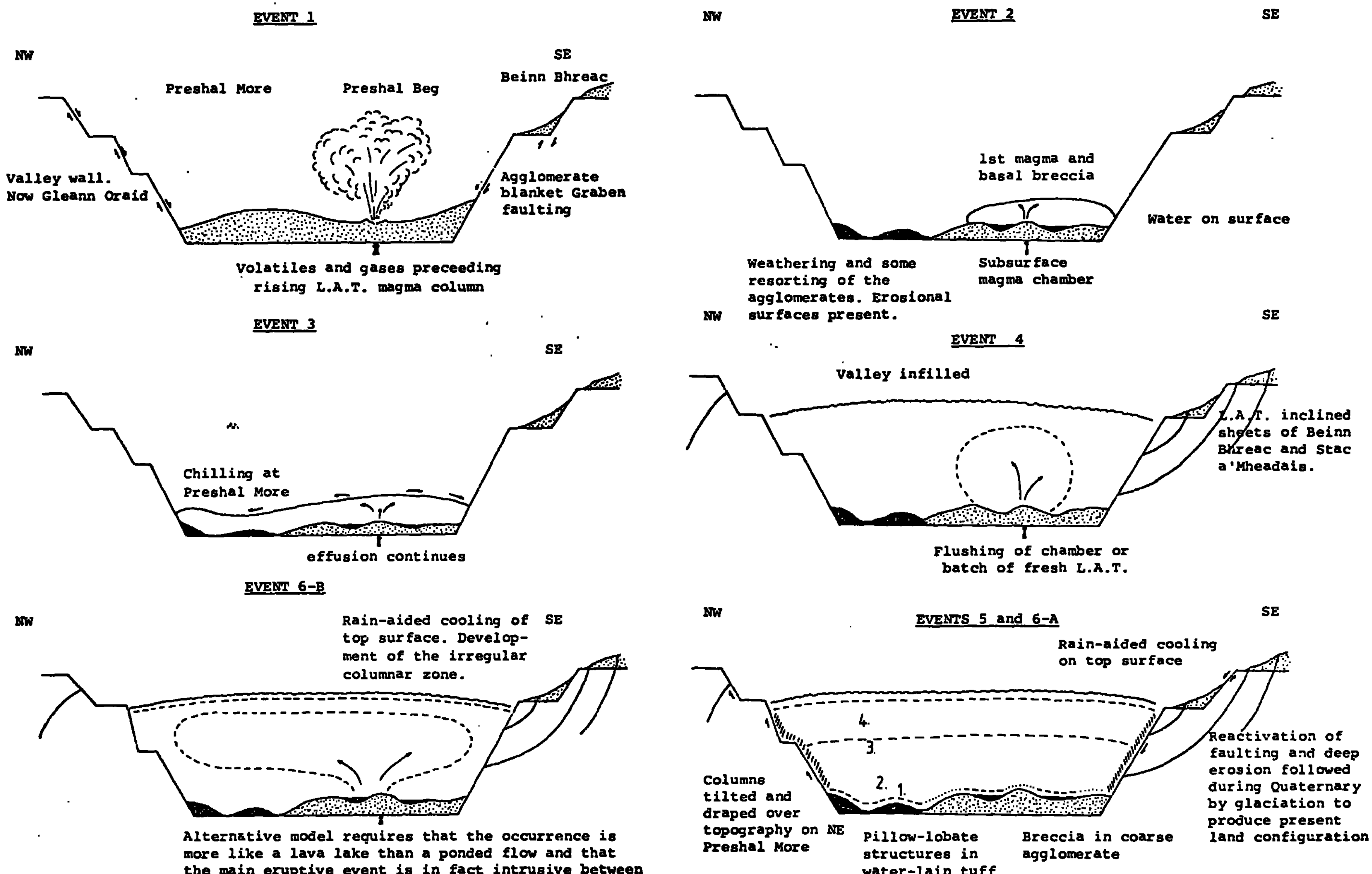


FIGURE 48. DIAGRAMMATIC REPRESENTATION OF THE SEQUENCE OF EVENTS WHICH MAY HAVE PRODUCED THE TALISKER GROUP

Event 4. Steady effusion now fills the valley rapidly to a depth of over 130 metres. The later magma to reach the surface could be more basic than that preceding it if the magma chamber below is being flushed out and the small amount of olivine accumulation found perhaps to be present now reaching the surface. Also, fresh batches of low-alkali magma from below may be more primitive consequent upon the still rising degree of partial melting which produces them.

Event 5. A lava-lake is established with semi-molten rock. Compositional gradients exist both vertically and laterally. The mass at Preshal Beg is more basic than Preshal More as it is closer to the source and cools last.

Event 6. Cooling and solidification possibly aided by water percolating from above (rain-water?) now occur resulting in the Zones A-D or 1-4 mentioned in Chapters and 7 and also .3.iv)a, figures 41, 42 and 43.

Alternatively, the top columnar zone was forming prior to when the main mass was erupted. This would result in Preshal More and Preshal Beg late magmas being 'intrusive' between the upper and lower chills. The second pulse of magma would behave much as the first with the Preshal Beg end less evolved than that of Preshal More. This could also help to explain the following observations:

i) the chilling effect between the main and top columnar zones 2 and 4 at zone 3.
ii) the flow texture which is a delectable feature in parts of zone 3.
iii) the slight change in chemistry at this junction.

9.4. The Igneous Sequence in West-Central Skye

The preceding section has shown that in the area under consideration there is considerable diversification amongst the rocks encountered both petrographically and chemically. The following paragraph is an attempt, in a simplified fashion, to fit these rocks into a logical sequence of events based upon the established stratigraphy of the lavas and intrusions.

The lowest stratigraphic lava group - the Meacnaish Group - is characterised by the appearance of early differentiates followed by olivine-rich basalts. Evolved rocks might be expected at the beginning of the volcanic history in a region primarily because of the time taken and subsequent fractionation for the early magmas to reach the surface. Also, the first melts might sample an undepleted source, hence their relatively evolved chemistry upon eruption. Once established, the conduits would rapidly erupt primitive more magnesian basalts, and a system of near-surface probably interconnecting reservoirs would be established. Later differentiates such as hawaiites would not be common occurrences as indeed appears to be true. However, if the mechanism for the generation of hawaiites outlined previously is accepted then the basalt-hawaiite-basalt-hawaiite sequence of the Bualintur (in part equivalent to the top Meacnaish lavas) and Cruachan Groups would be explained. This sequence is complicated by the occurrence of intra-formational conglomerates, big-feldspar basalts, transitional basalts and a tholeiitic andesite flow/sill all at approximately the same horizon or fairly close to one another. This association is possibly not accidental, if it is considered that a hiatus in activity accompanied by deep erosion and weathering to produce the conglomerates, might allow time for alkalic magmas to equilibrate and evolve in near-surface reservoirs and for an increased degree of partial melting at source to take place. Eruption of this magma at a later date could force out ahead of it both evolved lavas and feldspar-macrophyric basalts and hawaiites. Such lavas directly succeed the conglomerates near Glen Brittle and south-east of Loch Eynort. Also, whether by mixing with aphyric alkali-basaltic magma or by some fractionation process, rocks akin to the Transitional Suite could be formed and erupted locally; their evolved products later, but perhaps almost simultaneously intruding the sequence especially at weak horizons such as the intergroup boundary. A waning in the thermal gradient would presumably be necessary to enable the alkalic suite to re-establish itself, but this is not impossible. Some of the Transitional and Tholeiitic dykes and gabbroic plugs around the Glen Brittle area could have been emplaced during this period. The Cruachan and Tusdale groups show broadly similar characteristics again of basalt-hawaiite-basalt type sequences similar to those of the Beinn Edra and Beinn Totaig groups (Anderson and Dunham 1966, and figure 10-11). After a significant pause in activity which produced the sediments of Ben Scaalan, the subsequent flows of the Arnaval Group are notably the most evolved in the area. With the waxing of the thermal event in Skye, more silica saturated rocks would be once more produced but still dominated by the Alkalic Suite. These could then be represented by the mugearites and trachyte of the Sub-Alkalic Suite at the top (or close to it) of the Arnaval Group. Breaks in activity now and before e.g. as at Ben Scaalan, might be the reasons for the appearance once more of big-feldspar hawaiites and mugearites belonging to the Arnaval, Loch Dubh, Beinn Totaig and Bracadale Groups such as the composite flows of Dun Ard an-t-Sabhail and Roineval. That a long period of relative quiescence and deep weathering then took place is evidenced by the nature of the unconformity beneath the Talisker Group. This pause was shattered by explosively violent activity to produce the pyroclastic accumulations of Beinn Bhreac, Preshal Beg and Preshal Mor. Some delay was then experienced prior to the eruption of the Talisker Group as the pyroclastics are weathered and partially reworked in places by water; the presence of which is also evidenced by the pillow-like breccia beneath Preshal Beg. The chemistry of the Talisker Group (low-alkali olivine-tholeiite) possibly indicates the setting-up of an eruptive centre in the Talisker-Loch Bracadale region from which a considerable thickness of such magmas may have been erupted and subsequently lost by erosion. The inclined basic sheets encountered in fair numbers north of Loch Eynort and sometimes inclined towards the Talisker region are also thought to belong to this period. Meanwhile, the Central Complex was developing at this 'thermal climax' and so was the regional dyke swarm which is made up from over 70% Preshal Mor ie. low-alkali tholeiite type dykes (Mattey et al. 1978). Mattey et al. in reviewing the extent to which this magma type figures prominently in the dyke-swarms and minor intrusions of several other Hebridean centres and the fact that it bears close resemblance to mid-oceanic ridge basalts (Esson et al. 1975) in both major and trace element (including rare-earth) abundances suggest that this phase of magmatism in the British Tertiary Igneous Province was connected intimately to 'genuine, but abortive, attempts to produce oceanic crust'.... near the continental margins of the forming north-Atlantic Ocean.

The igneous sequence outlined above is summarised in figure 47.

9.5. Chemical variation and origins of amygdaloidal zones and boles

9.5.i) Amygdaloidal zones and the effects of widespread zeolitisation

Even in the apparently freshest lava centre, microscopic examination reveals that there is often considerable interstitial zeolite, chlorite and secondary amphibole, produced by the circulation of hydrothermal solutions producing low-grade zeolite facies metamorphism throughout the lava pile subsequent to extrusion. As a consequence, all analyses will tend to vary and be affected depending upon the abundance and species of the secondary minerals present. In an attempt to assess the role played by these minerals in influencing the analyses of lavas previously considered fresh, two flows, one an olivine +

spinel porphyritic basalt from the north shore of Talisker Bay and the other a fine-grained hawaiite from Ardtreck, were selected for study. Relevant analyses are presented in Table 12.

The former flow, specimen Sk750301, has a well developed massive central portion as well as a thick upper amygdaloidal zone and associated bole, or fossil soil. The zeolites present in considerable quantities are:

1. Analcite $NaAl(SiO_3)_2.H_2O$
2. Natrolite $Na_2Al_2Si_3O_{10}.2H_2O$
3. Thomsonite $NaCa_2Al_5(SiO_4)_5.6H_2O$

Hence, unless the depositing solutions are closely related to the actual compositions of the lavas themselves, the analyses should reflect relative enrichments in these elements and most especially in Na_2O and Al_2O_3. Relative to the central portion analysis (Sk750301) the amygdaloid (Sk750303) is depleted in SiO_2, MgO, CaO, MnO, P_2O_5, Ba, Sr, Cu, Ni and Cr, with constancy or corresponding enrichments in Al_2O_3, Fe_2O_3(total) Na_2O, K_2O, TiO_2, Nb,Zr,Y and Zn. Therefore it is possible that the above zeolites have significantly influenced the analyses. However, the other enrichments appear to mainly reflect the weathering process and most especially the presence of oxidised titaniferous magnetite not removed by the

TABLE 12

Representative major and trace element analyses of lavas, scoria and derived boles from west-central Skye. Titles and specimens (see written copy).

	Ol+Sp basalt	Scoria	Derived Bole	Ol+Sp basalt	Derived Bole	Hawaiite	Scoria
	750301	750303	750302	740106	750310-B	740108-A	740109
wt.%							
SiO_2	44.31	43.67	34.27	46.30	41.13	48.68	44.56
Al_2O_3	14.50	18.53	26.53	16.07	24.20	15.88	18.89
Fe_2O_3	1.25	1.75	-	2.00	-	2.00	1.50
FeO	10.82	11.47	-	9.00	-	12.48	13.27
Fe_2O_3*	12.07	13.22	27.60	11.00	19.86	14.48	16.10
MgO	13.35	8.83	1.61	11.04	2.29	4.03	3.32
CaO	8.33	4.94	0.64	8.26	0.50	6.30	5.00
Na_2O	2.02	4.07	6.10	3.54	5.57	4.60	2.80
K_2O	0.49	0.60	0.08	0.87	L.76	0.71	0.72
TiO_2	1.36	1.94	5.74	1.32	6.34	3.02	5.39
MnO	0.19	0.16	0.08	0.18	0.03	0.26	0.27
P_2O_5	0.19	0.11	0.08	0.42	0.03	0.55	0.47
ppm							
Ba	114	41	65	153	168	252	173
Nb	1	6	21	3	111	27	4
Zr	165	128	176	120	862	461	140
Y	18	23	27	20	43	55	23
Sr	705	136	57	717	170	677	295
Rb	2	3	3	11	6	4	4
Zn	73	87	105	67	64	62	81
Cu	79	86	180	82	38	14	77
Ni	680	269	132	543	119	9	20
Cr	1014	285	2008	1144	2532	77	120

*Total iron as Fe_2O_3 as in X.R.F. Analyses. Other data: 'standard' values (see Chapter 9.1).

leaching solutions.

The hawaiitic example from the west-side of the Ardtreck peninsula contains a lesser proportion of zeolites revealing the tendency for zeolites and related species to be more commonly associated with silica-poor environments; in this case, basaltic lavas which also tend to be generally more 'open' structured allowing easier penetration. The species present are:

1. Analcite $NaAl(SiO_3)_2.H_2O$
2. Thomsonite $NaCa_2Al_5(SiO_4)_5.6H_2O$
3. Chabazite $(Ca,Na_2)Al_2(SiO_3)_6.6H_2O$
4. Stilbite $H_4(Ca,Na_2)Al_2(SiO_3)_6.4H_2O$
5. Calcite $CaCO_3$

Relative to the fresh hawaiite flow (Sk740108-A), the amygdaloid (Sk740109) shows decreases in SiO_2, MgO, CaO, Na_2O, P_2O_5, Ba, Nb, Zr, Y and Sr, with significant rises in Al_2O_3, Fe_2O_3(total, TiO_2, Zn, Cu, Ni and Cr. With the exception of Al_2O_3 there is no apparent enrichment in those elements present in the zeolites and indeed, more often than not decreases. This could be explained by a combination of factors. Firstly, weathering to leave residual Fe-Ti and Al oxides and associated sulphides is dominant, other elements being leached away and secondly the chemistry of the flow may itself be influencing the species deposited. In the north-east of

Skye, the hawaiites capping the Beinn Edra Group (mugearites of Anderson and Dunham 1966) contain considerable interstitial and amygdaloidal analcite despite the observation that they are within a chabazite-rich zone; the analcite-natrolite zone ending some depth below (P.M. King, pers. comm.).

Another characteristic of the amygdaloids is their weathered and much altered nature as hinted above. Chlorite, amphibole, magnetite, biotite, unidentified clay minerals and some sulphides are common occurrences and olivine is almost never found in a fresh state. Likewise, the clinopyroxenes are altered mostly to amphibole. The weathered crust of Sk750301 relative to the unweathered basalt shows an increase in ferric iron combined with a loss of SiO_2, Na_2O, K_2O and some MgO and this ought to be taken into consideration in comparing the analyses with several percent zeolites present. Anderson and Dunham (1966) report significant increases in Ferric Iron at the expense of Ferrous Iron and in combined water content in amygdaloids with relative decreases in SiO_2, CaO and perhaps the alkalis.

In conclusion, the presence of minor amounts of zeolite probably has little effect on the overall chemical analysis of individual flows. The effects are only really obvious and of critical importance in the badly weathered and altered amygdaloidal zones. Where amygdales exist in the centres of flows and are sampled (as in this study) the chemical characteristics of the flow are more likely to be influenced by weathering effects or alterations around the amygdales rather than by the zeolites themselves. In some cases, the combined effects of using both slightly weathered and amygdaloidal specimens in distinguishing geochemical trends and affinities is important as it results in false 'norms' which are widely used in classification schemes. Flows obviously badly affected in this manner were not generally considered in establishing the various lineages discussed in Chapter 9.3. but no flow or intrusion was completely free of either deuteric, zeolite facies, thermal-hydrothermal or weathering induced alteration.

Wood et al. (1976) have recently considered the mobility of both major and trace-elements during zeolite facies metamorphism of Icelandic lavas and report many features similar to those discussed here; significant mobilisation is noted in the cases of Si, Mg and Sr with constant or slightly increased values of Ti, P, Zr, Y and Nb. In considering the hawaiitic flow from Ardtreck, the trace element results are at variance with the depletions of these authors. The Sr data for both

Icelandic and Hebridean basalts suggests that caution should be applied when considering Sr isotopic data in such terrains.

9.5.ii) Boles and interlava related sediments

9.5.ii)A Boles: Chemistry and Formation

The red-brown and purple boles frequently associated with the contemporaneously weathered upper amygdaloidal zones of many of the lavas were also studied. Their outline petrography is dealt with in Chapter 7.

Chemically, these rocks bear little or no resemblance to the parent lavas (Table 12) and in the examples studied, Sk750302 (developed upon Sk750303) and Sk750310-B (developed upon another nepheline-normative olivine + spinel porphyritic basalt Sk740106 from Ardtreck) there is a consistent picture of element depletion and enrichment during the weathering process which produces sueh fossil soils and weathered crusts.

In both instances the major elements SiO_2, MgO, CaO, K_2O, MnO and P_2O_5 are depleted in the boles while Al_2O_3, total iron as Fe_2O_3, Na_2O and TiO_2 are markedly increased. The trace elements show a less consistent trend but there is consistent loss of Ba, Sr and Ni and gain of Nb, Y and Cr: Zn, Cu and Rb are variable. Since most of the Ni and MgO are combined in the forsteritic olivines, the early breakdown of this phase will result in their release to the system, where they are apparently leached from these fossil soils by meteoric waters and once buried, by percolating meteoric and groundwaters. Much the same process is accountable for the loss of CaO, K_2O, P_2O_5, Sr and Ba which are held in the clinopyroxenes, feldspars and apatites and usually form secondary soluble carbonates which will be removed in solution leaving relative concentrations of Na_2O and Al_2O_5. SiO_2 is lost to the system from all silicates and may be in a gel-like form or in colloidal suspension. Some boles eg. specimen Sk750305 contain large patches of amorphous or isotropic 'glass-like' substances which may represent this. The heavier mafic phases of the respective basalts, namely the chrome-spinels and titaniferous magnetites will tend to remain residual minerals although oxidation may be intense and consequently there are substantial increases in Cr, TiO_2, Fe_2O_3, Zr and Nb. The highly coloured nature of these rocks is primarily due to oxidation of iron-bearing phases. In general, ferromagnesian phases degrade to clay minerals of the montmorillonite and illite groups, silica and soluble carbonates of magnesium, calcium and iron. The latter is subsequently oxidised to haematite and limonite group oxides and hydroxides. The increase in Na_2O is probably mostly accountable by the presence of analcite or other zeolites in small irregular veins. In the examples quoted in Table 11, there is contrasted behaviour of Cu and Zn. In Sk750302 these are enriched relative to the parent basalt but are slightly depleted in Sk750310-B. Both trace elements are only commonly held in the sulphide phases infrequently encountered in these lavas and their relative distribution in these rocks appears to reflect the occurrence of minute quantities of bronze-yellow coloured inclusions (sulphides?) within analcite crystals in the amygdaloid Sk750303.

9.5.ii)B Boles as fossil soils: A comparison with present-day processes

Boles are often referred to as fossil lateritic soils implying a long uninterupted period of intense weathering in 'humid' conditions, and indeed a lateritic horizon is today formed where the ground-water movements and the effects of leaching meteoric water down to the water table within the soil, concentrate iron and aluminium oxides in a restricted layer. These concentrations often form as nodular or cellular, slag-like masses and may, upon drying, become irreversibly hard. These features fit many of the boles examined. However humid or tropical conditions need not be prevalent as high heat-flow on the lava surface combined with substantial rainfall would produce much the same effect and indeed there is little evidence for an extensive vegetation cover. High rainfall is also implied by the presence of fluvial conglomerates as discussed in Chapters 3 and 7. Overall, the chemical process which appears to have formed the boles and some of the sedimentary formations such as those at Ben Scaalan, is similar in many ways to Ferrallitization; a process by which parent rock weathers to kaolinite plus Fe-Al sequioxides, through the loss of Si, N, Ca^{++}, Mg^{++}, Na^{+} and K^{+} (Bridges 1970). Alternatively, sub-tropical red-purple soils developed upon basic igneous parents known as Krasnozem soils also tend to have these characteristics of the minor interflow boles. At present, such soils are known from the type-locality in the southern U.S.S.R., Australia and the Hawaiian Islands (Bridges 1970).

9.5.ii)C <u>Interflow sediments distinct from the red boles</u>

The tuffaceous sediments, ironstones and boles on Ben Scaalan and those similar types from Beinn nan Cuithean, differ in several respects from the red boles developed upon the lavas. Some horizons are very iron-rich with very little silica; X-ray Diffraction analyses revealing a preponderance of Limonite eg. Sk750308 and especially Sk750310-A. These could represent the ultimate products of lava weathering in this area. Alternatively, the latter in being very depleted in most trace elements (see Appendix 1, Table 6) many elements being on or below the detection limits could conceivably represent the horizon at which the Al-Fe sequizoides from the leaching of other horizons were deposited forming a hard, indurated iron-pan. Its low total indicates considerable combined water and carbon dioxide. Analyses of Sk750307 and Sk750309 (Appendix 1, Table 6); the laminated white, ashy or tuffaceous mudstone-like rocks from Ben Scaalan show that the former has an unusually high concentration of Al_2O_3 and SiO_2 with very low total iron. This does not resemble a typical bole or lateritic ironstone but rather some type of feldspathic tuff, possibly trachytic. Derivation from earlier trachytic rocks was also suggested for these horizons in Chapter 7.3.iii). The latter shows only a slight increase in Al_2O_3 and total iron relative to basalts or hawaiites but has low CaO and MgO presumably due to loss through solution: Na_2O and TiO_2 are higher than in normal hawaiites due to concentration in residual oxides and secondary minerals which occur as veins throughout these rocks.

Superimposed upon the lavas and their secondary mineralisation is a thermal aureole developed around the Cuillin Hills Central Intrusive Complex. Its effects in terms of petrography, mineralogy and geochemistry are discussed in Chapter 10.

CHAPTER 10

THE CONTACT AUREOLE OF THE CUILLIN HILLS INTRUSIVE COMPLEX

10.1 Introduction

Subsequent to the extrusion and zeolite facies metamorphism of at least the presently exposed remnants of the Skye lava succession, the major gabbroic, eucritic and ultrabasic plutonic intrusions of the Cuillin Hills Intrusive Complex were emplaced. Their intrusion and the extensive hydrothermal and in part pneumatolytic or metasomatic aureole developed around them has affected the adjacent lavas (Meacnaish, Bualintur and Cruachan lava groups) texturally, mineralogically and perhaps chemically.

Almond (1960,1964) studying the broadly equivalent Lower Eocene lavas in Strathaird, to the south-east of the Cuillins, also investigated the thermal and hydrothermal effects of the intrusions upon the lavas and recognised an inner hornfels zone and an outer amphibole zone which gradually gives way outwards to a zone of 'normal' post-consolidation alteration. To a large extent the same concentric zonal arrangement is applicable to west-central Skye (figure 49) but in contrast to the Strathaird area the aureole, especially the inner zones, seems more restricted in width. This may be due to a number of controlling factors such as the degree of tectonic movements or disturbance

Figure 49

Map of west-central Skye in the vicinity of the Cuillin Hills Intrusive Complex showing the arrangement of the metamorphic zones developed in the lavas by its emplacement.

Zones:	1a and 1b	Outer Zone
	2	Middle Zone
	3	Inner and Hornfels Zone

Localities:	A	Beinn a'Bhraghad
	B	Beinn Staic
	C	An Cruachan
	D	Truach Mheall
	E	Creag na Laire
	F	Allt a'Choire Gheadaidh at the Glen Brittle youth hostel
	G	Beinn an Eoin
	H	An Sguman
	I	Ceann na Beinne
	J	Rubh'an Dunain

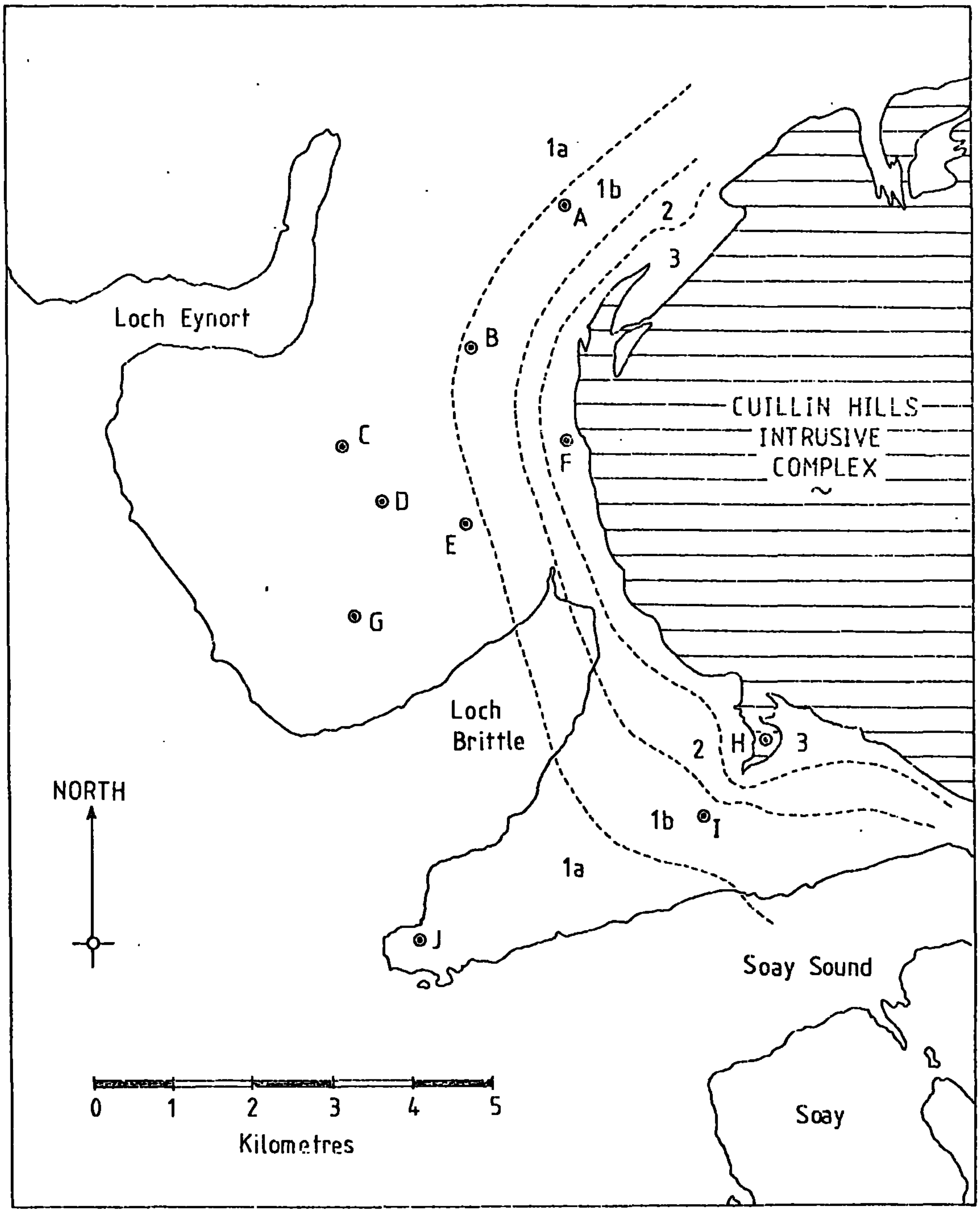

1a
1b
2
3
A
B
C
D
E
F
G
H
I
J
Loch Eynort
Loch Brittle
CUILLIN HILLS
INTRUSIVE
COMPLEX
2
3
1b
1a
NORTH
Soay Sound
Soay
0
1
2
3
4
5
Kilometres

Figure 49

during the emplacement of the Complex, the presence of more permeable pre-Tertiary sediments close by, the proximity of the Camasunary-Skerryvore fault or to the angle of contact with the lavas. In Strathaird, but not in west-central Skye, the lava-gabbro contact is characterised by a small anticlinal structure and this, in conjunction with the above-mentioned factors may have allowed the easier access to the lavas of water and various volcanic gases and volatiles thus producing a more extensive amphibole or 'wet' zone. The hornfels zone (by contrast a 'dry' zone) is also more restricted in west-central Skye and a little different in that orthopyroxene, a common phase developed in the Strathaird rocks is relatively rare. This however probably merely reflects the preponderance of originally olivine-rich basalts in west-central Skye and no pre-Tertiary strata immediately adjacent to the intrusions although it must occur at no great depth below.

The meta-lavas of west-central Skye have been divided into three zones: Outer Zones (1a,1b), Middle Zone (2) and Inner Zones (3a,3b,3c). The main features of the aureole are considered in two parts, petrography and geochemical characteristics.

10.2 Petrography and general characteristics of the lavas involved in the contact aureole

10.2i) The Outer Zones

The outer zones (1a,1b) of the thermal and metasomatic aureole developed in the lavas in the vicinity of the Cuillin Hills Intrusive Complex are characterised by predominantly olivine-porphyritic basalts with lesser numbers of olivine + plagioclase porphyritic and plagioclase macroporphyritic basalts and rare hawaiites, all of which in the field show very little sign of increased secondary or tertiary alteration or pneumatolysis, other then that of zeolite facies-type metamorphism and deuteric alteration found to be pervasive in even those lavas far removed from the Complex (see Chapter 6.3).

Those lavas of subzone 1a are often considerably hydrothermally altered with significant amounts of groundmass chlorite and subsidiary fibrous amphibole developed in the groundmass, but for the most part the ferromagnesian phases and feldspars remain surprisingly fresh except for those weathering and deuteric alteration products seen throughout the area ie. iddingsite or serpentinous pseudomorphs after olivine and associated rare pale green chlorites. The occurrence of apparently fresh lavas amongst the successions characterising Beinn Staic, Beinn a'Bhraghad, part of An Cruachan, Truagh Mheall, Beinn an Eoin and Creag na Laire (Bualintur and Cruachan groups) and Creag Mhor and Sgurr nan Cearcall (Meacnaish group) suggests that on the whole these lavas have only been marginally affected by the aureole. Zeolites are recorded in the amygdaloidal zones of zome of these flows but there is a tendency for yellow-green pleochroic acicular or black lustrous flakes of chlorite, amorphous clay minerals and calcite to be present in the amygdales instead. Sparse epidote + prehnite + chlorite + natrolite examples are found close to those lavas assigned to subzone 1b (Sk751306). Chlorite may also be abundant in the groundmass surrounding amygdales and vacant vesicles e.g. Sk751502, Sk751503. Pale green amphibole becomes increasingly common inwards towards subzone 1b but is irregularly developed as the zones may overlap in some characteristics. The overall thickness of subzone 1a is indeterminate as it grades outwards into 'normal' lavas.

The lavas of subzone 1b are somewhat poorly exposed over much of the area of Glen Brittle but appear to constitute a zone up to a kilometre wide. In general they are dark, patchily altered basalts characterised by occasional sealed joints and veins of epidote and calcite and in thin section by orange-pink to colourless or pale green pleochroic mica or talc pseudomorphs after olivine although pseudomorphs of bowlingite and chlorite are also present(e.g. Sk751002, Sk751101-A, Sk751103, Sk751104.)

Similar pseudomorphs are only found outside the aureole in limited numbers in the olivine-tholeiite lava of the Talisker group and some low-alkali tholeiite minor intrusions. In some, the cores of the larger phenocrysts may still be fresh. The usually deep mauve-pink-brown pleochroic titaniferous augites are commonly fringed or partially pseudomorphed by a pleochroic fibrous actinolite amphibole but it is never abundant and the original textures of the basalts remain intact. Even the plagioclases show only the first signs of clouding by minute inclusions of magnetite and perhaps white mica or albitisation or re-sorption (e.g. Sk751101-A, Sk751101-B, Sk751103). Primary magnetite is commonly rimmed by a red-brown pleochroic biotite while some ilmenite exsolution lamellae and possibly haematite and titanohematite are observed. Some of these changes are attributable to deuteric processes. Ade-Hall et al. (1971) report a number of alteration products from the deuteric and hydrothermal alteration of magnetite and titaniferous magnetite, including sphene, ferri-rutile, titanomaghemite and polycrystalline titanohematite, under conditions which may have been operating in the outer zones of the aureole. Likewise, some olivines also show only deuteric or low-grade metamorphic to hydrothermal effects ie. iddingsite and chlorite with minor magnetite. Amygdales and cavities are infilled with epidote, chlorites and green fibrous bundles and terminated prisms of amphibole and clay minerals. The only zeolite species remaining is scolecite developing centrally to the other minerals and possibly therefore not a first-generation zeolite. In some lavas e.g. those along the coast of Loch Brittle, geopetal structures are well developed with thin needles of amphibole growing on a clay-mineral base.

10.2.ii) The Middle Zone

Between the lavas of the outer zones and those in relatively close proximity to the intrusions is a transitional or middle zone varying between 100 and 400 metres wide. In their field characteristics the lavas of this zone resemble the predominantly aphyric ophimottled (poikilitic augite) and olivine $\pm$ plagioclase porphyritic basalts of the inner zones in retaining to a certain extent classic 'trap-featuring' and still recognisable bright red inter-lava boles. They are often deeply weathered. However, the assemblage of secondary minerals and their often characteristic leucocratic greenish or pink-grey colour mostly distinguishes them from the adjacent zones although coloured or variagated specimens are also found in the latter. In thin section clinopyroxene is retained in its original poikilitic or sub-ophitic texture but is extensively replaced by green chlorite and fibrous amphibole with subsidiary euhedral magnetite. Olivine phenocrysts are variously altered to or pseudomorphed by iddingsite, chlorite and magnetite or a core of pale-green to pinkish pleochroic mica or talc rimmed by chlorite and magnetite. Very little fresh olivine is present in the groundmass(e.g. Sk760204;) its place being taken by mixtures of talc and bowlingsitic or chloritic material. Both groundmass and phenocrysts of plagioclase are commonly corroded or patchily resorbed, slightly clouded and not infrequently partially altered, especially along fractures, to coarse aggregates of albite, calcite and sericite with rare epidote. Amygdaloidal specimens are generally much more altered and coloured green or pink due to a high modal percentage of chlorite and amphibole in the groundmass than the massive flow centres. In these, green to colourless pleochroic chlorite or spongey yellow epidote rimming central sheaf-shaped prehnite aggregates with accessory actinolitic amphibole, acicular epidote, calcite or quartz is a common assemblage. A relatively sodic plagioclase is also found occasionally within or projecting from the rims of amygdales into their centres and large geodes and geopetal structures floored by microcrystalline clay minerals are not uncommon.

Those lavas slightly closer to the intrusions, grade in most characteristics with those above (Sk760201 to Sk7660208) but are commonly much more indurated and toughened. A reddish-pink-grey or more rarely a greenish colour is common (e.g. Sk760504, Sk760505) due to an increasingly high modal percentage of chlorite and haematite in the groundmass. Olivine is now replaced by a low birefringent chlorite and numerous, small euhedral magnetite octahedra and any feldspar is invariably clouded by opaque inclusions and altered to aggregates of epidote + albite + calcite ± zoisite ± sericitic mica. Sodic plagioclase (andesine to oligoclase and only rarely albite) and epidote are common amygdaloidal fillings while calcite is a very rare accessory and perhaps a retrograde metamorphic product.

10.2.iii) <u>The Inner Zones</u>

The inner zone of the aureole exhibits a variety of metalavas varying from recognisable basalts which although extensively altered retain the textural relations between the main constituents, through basalts in which there is evidence of the onset of melting and recrystallisation to completely recrystallised granoblastic aggregates of plagioclase + olivine + clinopyroxene + magnetite ± orthopyroxene. These are met with progressively towards the gabbro-lava contact and are referred to as subzones 3a, 3b and 3c respectively. The zone varies in width between about 75 and 700 metres grading into the middle zone.

Subzones 3a and 3b are not separable in the field both being characterised by dark, often greenish, much altered, ophitic (ophimottled textures of Almond, 1960, 1964) alkali-olivine basalts. In this respect they appear gradational with the innermost lavas of the middle zone. Terraced featured formed by successive flows are evident in the well exposed sections at An Sguman and the Allt a' Choire Ghreadaidh above the Youth Hostel but are not common in the intervening relatively poorly exposed ground, although these are also well developed to the east towards the head of Loch Scavaig. Those lavas close to the small peridotite intrusion at An Sguman are extensively traversed by veins and flats of coarsely crystalline green and yellowish-green epidote and amygdaloidal structures are common. The stratigraphy of these sections is considered in Chapter 6.2. and they are assigned to the Meacnaish lava group as are the hornfels of subzone 3c.

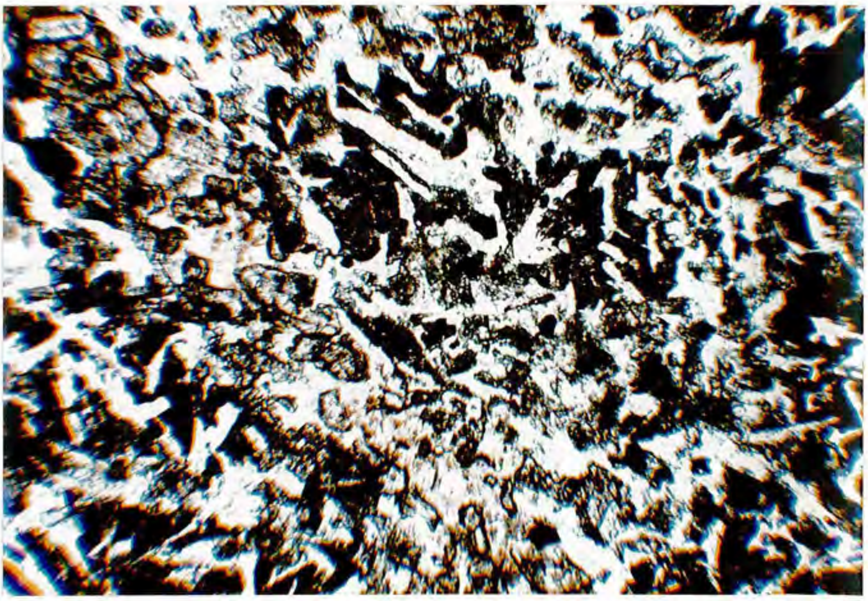
Even in thin section these subzones are virtually identical, the main differences being that the inner sub-zone 3b contains large subophitic titaniferous augites and recognisable olivines whose margins are recrystallised to small granular aggregates e.g. Sk751608, and the degree of opaque-inclusion clouding of both groundmass and phenocryst feldspars is greater than in subzone 3a (Sk751611, Plate 100). In addition, many of the clinopyroxenes of subzone 3b show some exsolution of magnetite and the development of a pale-green uralitic amphibole at their borders. Olivines are generally totally pseudomorphed by chlorite along with rare bowlingite and strings of small octahedra of magnetite especially at the margins and along fractures but one example from subzone 3a, specimen Sk751604, remains relatively fresh with a reaction rim of biotite, hornblende and magnetite (Plate 99). Where in association with glomero-porphyritic plagioclase the olivines have a different reaction rim characterised by a pale-green biotite and magnetite. The alteration and mineralogy of the olivine + plagioclase + clinopyroxene porphyritic basalt Sk760814/Sk7725 has been already described (Chapter 7.1.i)E) and the tendency for plagioclase to form aggregates of albite + epidote ± zoisite ± calcite ± sericite or white mica - a process known as saussuritisation - is a noted feature. The groundmass of these basaltic rocks (Sk751608, Sk751611, Sk760811, Sk760812, Sk760814, Sk760815, Sk7619, Sk7623, Sk751901-06) is typically very altered with substantial heamatite, chlorite, bowlingite?, talc?, some early-formed iddingsite? and widely distributed secondary as well as primary titanif-erous magnetite. Magnetite fringes biotite and clay minerals and white mica are also present. The mineralogy of the amygdales is considerably different from those of the 'normal' lavas but braodly similar to that of the middle zone; zeolite assemblages having been replaced by a new

PLATE 99

Photomicrograph of a slightly thermally metamorphosed olivine + plagioclase porphyritic basalt Sk751604 showing reaction rims around the olivine phenocrysts of biotite and magnetite. The groundmass is severely hydrothermally altered and only the small plagioclase laths remain relatively fresh.

PLATE 100

Photomicrograph of a more thermally metamorphosed lava Sk751611 from near Glen Brittle House showing the pervasive clouding of the groundmass feldspars by minute granules of magnetite. The rock is traversed by a thin vein of clinopyroxene + epidote which in this photograph can be seen sloping from left to right.



suite of minerals. There is no real evidence to show that zeolites were ever present in these lavas. The assemblages seen in both subzones 3a and 3b are virtually identical but in the inner lavas of 3b plagioclase aggregates are found. The amygdales are often beautifully zoned e.g. Sk760812 (Plate 101), Sk7623 with such assemblages as:

A. Epidote-rich basalt - biotite and magnetite rim - chlorite rosettes and needles - magnetite - epidote centre

B. Basalt - magnetite rim - prehnite and epidote - pale green chlorite/amphibole with opaque inclusions

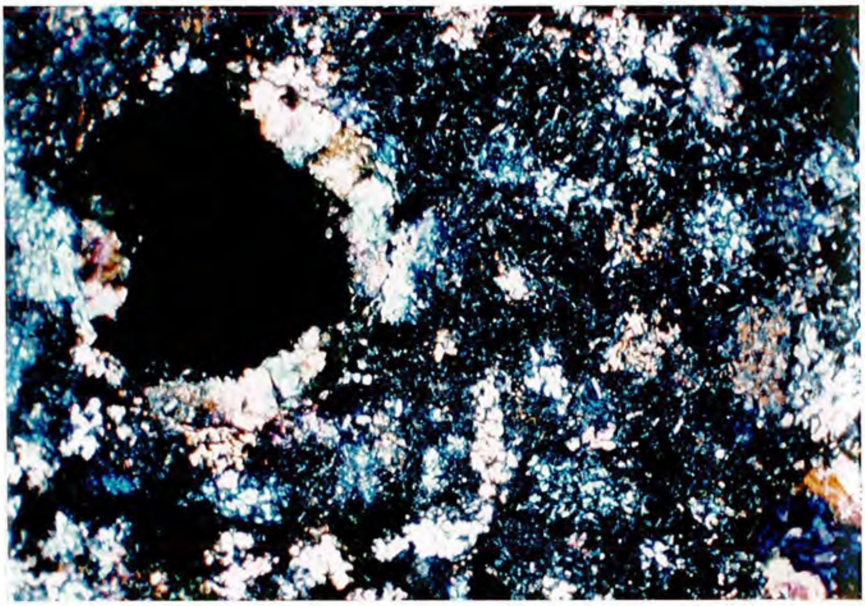
C. Basalt - magnetite rim - anomalous blue birefringent chlorite after amphibole? - spongey epidote with rare amphibole needles - purple/blue to brown anomalously birefringent chlorite centre.

D. Increasingly epidotic basalt - biotite and magnetite rim - bowlingsite-like material - plagioclase with epidote and garnet - prehnite, epidote and calcite centre.

In rocks close to the hornfels subzone 3c (e.g. Sk 760815), the ophimottled texture of the basalts is still

PLATE 101

Photomicrograph of the thermally and hydrothermally altered aphyric basalt lava Sk760812 from near An Sguman showing masses of small subophitic clinopyroxenes in an 'ophimottled' texture. The large amygdale contains aggregates of epidote, plagioclase, clinozoisite/zoisite? chlorite and uralitic amphibole. The felsic constituents are completely degraded.



retained although the pyroxene is marginally recrystallised to small granules of pale-brown augite and not uncommonly magnetite. Magnetite is abundant in the ground-mass. The innermost amygdales tend to be free of chlorite and prehnite but still contain aggregates of albite or zoned distributions of albite + epidote + actinolitic ampihbole and calcite.

The high grade basaltic and intermediate (hawaiite?) granular hornfels (3c) occur only in contact with, as xenoliths within or as a thin, irregular 'skin' up to 5 metres wide, to the outer gabbros of the Intrusive Complex, and are best exposed at the localities of An Sguman and the Allt a'Choire Ghreadaidh where they are easily distinguished from the adjacent lavas and gabbros by their tough nature and leucocratic, rough and granular appearance. Amygdaloidal structures are still evident but no zeolites or hydrous minerals are present, their place being taken by plagioclase feldspar. The preservation of most of the basaltic mineralogy, the incipient melting and recrystallisation of the major phases in the adjacent subzones, and the reconstitution of earlier amygdaloidal assemblages of various zeolites and related minerals to plagioclase aggregates argues against the metamorphism at least in part, having been a progressive one in which the hornfels and other rocks of the inner zone underwent alterations at various temperatures before finally equilibrating at pressure +

temperature conditions similar to the pyroxene-hornfels facies. Thus these hornfels in most cases are not obviously the direct equivalents of zones 1 and 2 or the subzones 3a and 3b and probably equilibrated rather quickly relative to them.

Almond (1960, 1964) in considering the hornfels near the gabbros in Strathaird and Camasunary, recognised four granoblastic basaltic hornfels assemblages:

1. plagioclase + clinopyroxene + olivine + magnetite.
2. plagioclase + clinopyroxene + orthopyroxene + magnetite.
3. plagioclase + clinopyroxene + olivine + orthopyroxene + magnetite.
4. plagioclase + orthopyroxene + magnetite.

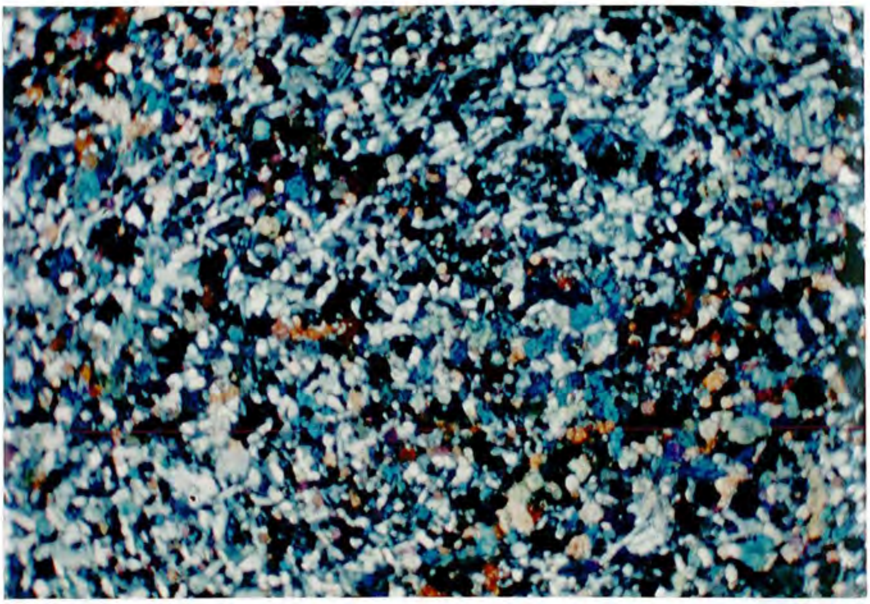
In west-central Skye, orthopyroxene appears to be extremely rare and the majority of completely restructured hornfels are of type 1 above containing substantial olivine often in excess of 15% modal (e.g. Sk751006, Sk751007, Sk760805, Sk760807, Sk7618 Plate 102). In thin section the larger olivines, probably representing original phenocrysts, are often surrounded by thin rims of small magnetite granules suggesting that the original may have been normally zoned with a relatively Fe-rich rim. Only

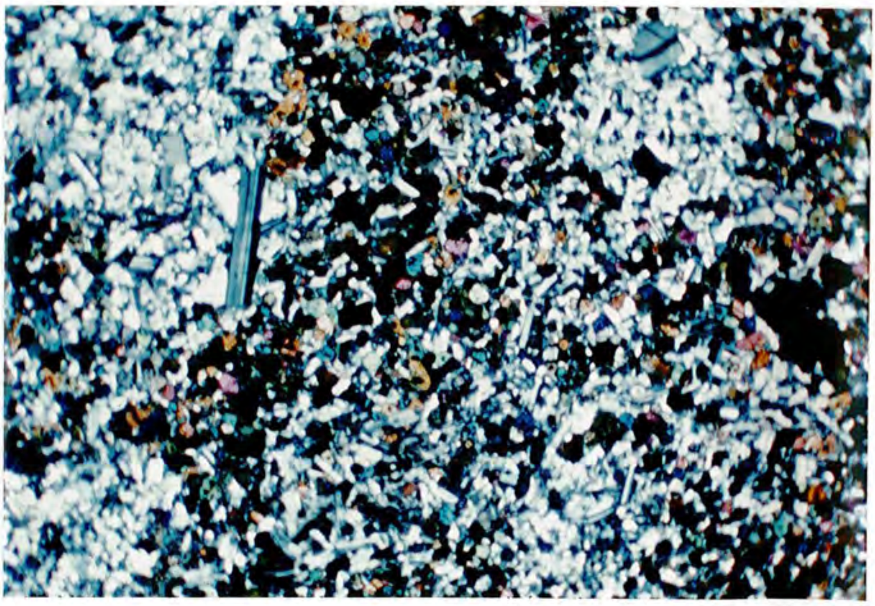
PLATE 102

Photomicrograph of an equigranular olivine + clino-pyroxene + titaniferous magnetite + plagioclase hornfels, originally an olivine basalt Sk760804 from the lava-gabbro contact zone near An Sguman. Local concentrations of the ferromagnesian phases are present but their origin is unknown.

PLATE 103

Photomicrograph of another high grade olivine + clino-pyroxene + titaniferous magnetite + plagioclase basaltic hornfels Sk760805 from the same locality as Sk760804. The clear patches composed of plagioclase aggregates and scattered plagioclase microporphyroblasts mark the sites of former zeolite filled amygdales converted to plagioclase by the elimination of water during intense thermal meta-morphism. Dark patches of aggregated titaniferous magnetite can also be seen in the photograph; some may contain irregular patches of exsolved ilmenite. Little or no ortho-pyroxene was encountered in these high grade hornfels.





one analysis is available (Appendix 3, Table 1, Specimen 51) and seems to be more iron-rich (Fo_{65}) than phenocrysts from 'normal' equivalent basalts but more or less identical to the groundmass phase. Clinopyroxene varies considerably in texture in the hornfels ranging from small equigranular crystals to larger (0.3-0.5mm) relict poikilitic or poikiloblastic crystals enclosing olivine, magnetite and plagioclase (e.g. Sk760804). The cores of many of the larger pyroxene granules are characterised by exsolution lamellae and inclusions of a probably titaniferous magnetite often arranged along cleavage traces. Accompanying this phenomenon the normally pale mauve, titaniferous augites become near colourless or slightly brownish-pink and the analysis (Appendix 3, Table 2, Specimen 33) is correspondingly depleted in iron and titanium relative to 'normal' alkali-basaltic augites (see Chapter 8). Original plagioclase is recrystallised to equigranular crystals of simply twinned labradorite. Larger crystals show complex and often strong zoning and twinning and probably represent original microphenocrysts. These frequently have inclusion-packed margins. In some examples e.g. Sk751004 and Sk751007 some degree of original trachytic texture may be retained by slightly elongated or stumpy laths and in these same rocks, olivine may be less abundant than elsewhere and the hornfels were perhaps more evolved than basalt originally.

The clouding of the groundmass feldspars by myriads of minute magnetite or related opaque inclusions so prevalent in the bordering subzones is absent although inclusions of magnetite, clinopyroxene and possibly olivine are present in the larger crystals as already mentioned although their size makes identification difficult. Titaniferous magnetite is ubiquitous in all basalts from this area and in the hornfels is recrystallised to small equigranular crystals which may form aggregates up to 1 mm in diameter. In a few instances these aggregates give the impression of sizeable poikiloblastic masses (e.g. Sk760805) enclosing stunted plagioclase laths and augite granules. Although of general basaltic composition this rock contains a somewhat TiO_2-poor magnetite (figure 28) when compared with those from other basaltic rocks. This feature is compensated for by the appearance of discrete equigranular crystals of ilmenite-pseudobrookite. Ilmenite lamellae appear more common in hornfels magnetites than in those non-metamorphosed basalts although they are not completely absent in the latter. Biotite may occur as sizeable (up to 1 mm diameter) reddish brown to pale brown pleochroic poikiloblastic crystals but is not abundant.

The amygdaloidal structures seen in relief on many hornfels weathered surfaces are, upon microscopic examination seen to be composed predominantly of granular and stunted plagioclase laths (e.g. Sk760805, Labradorite An_{56-62}) with subsidiary greenish diopsidic clinopyroxene, olivine and sericitic mica (Plate 103). The latter is probably either a weathering induced alteration or retrograde metamorphic effect. Olivine may occur peripherally along with magnetite to many of these structures. The feldspars are generally strongly zoned but simply twinned and were presumably formed by the elimination of water from previously zeolite-filled cavities by the following type of reaction:

$$Na_2Al_2Si_3O_{10}2H_2O \text{ (Natrolite)} + CaAl_2Si_3O_{10}3H_2O \text{ (Scolecite)}$$

$$\longrightarrow 2NaAlSi_3O_8 \text{ (Albite)} + 3CaAl_2Si_2O_8 \text{ (Anorthite)} + 11H_2O$$

Also, the addition of SiO_2 to analcite would produce albite but although analcite is recorded in some of the lavas of the lava groups concerned, this process was probably subsidiary to the main dehydration reaction. Plagioclase could also conceivably be formed by the reverse in the amygdales of assemblages of albite + calcite + epidote replacing feldspar in the inner zones, although this would imply that to some extent the metamorphism was progressive whereas most textural relations of the outer and middle zone rocks tends to suggest otherwise. No metamorphosed boles were found in the present study despite an extensive search. However, Almond reports a cordierite +

potash feldspar (Sanidine?) + magnetite + plagioclase + mullite assemblage produced by intense thermal meta; morphism of such rocks. In Mull and Ardnamurchan plagioclase + spinel + corundum (var. sapphire) assemblages may also represent metamorphosed boles or laterites. Similar rocks are also features of parts of Antrim.

10.2.iv) Summary and Metamorphic Facies

Progressively from the outer parts of the aureole towards the lava-gabbro contact both the primary and amygdale or secondary mineralogy of the lavas changes. Firstly a loss of the lower temperature zeolites is noted and the rocks begin to show groundmass alteration to chlorites and talc which also appear in the amygdales possibly after removal, replacement or instead of zeolites. Olivine next becomes pseudomorphed by orange-pink to green pleochroic micas or talc, and epidote appears firstly in the form of veins and amygdales but gradually also in the groundmass (Zone 1b). Sausuritisation and resorption effects and albitisation of the larger feldspars overlaps with the presence of the above mentioned olivine pseudomorphs (Zones 1b and 2) appearing more common and widespread inwards. Amygdale assemblages commonly consist of chlorites + amphibole + calcite + prehnite + epidote and amphibole is common as a groundmass phase. Thus the regional zeolite facies metamorphism of the lava pile gives way to a zone with assemblages comparable to greenschist or albite-epidote-amphibolite facies types. Inwards through the outer subzones of the inner zone (3a and 3b) prehnite is rare and finally lost in 3b. Striking anomalously birefringent chlorites occur in association with magnetite + epidote + albite $\pm$ garnet $\pm$ calcite in the amygdales. The rocks themselves show a progressive clouding of the feldspar resulting in dark coloured rocks from the outer zones inwards towards the contact and not until the innermost subzone (3c) does the effect eventually disappear. This fact also suggests that the metamorphism was progressive in type. Magnetite exsolution from primary clinopyroxene is important in this zone also and is first prevalent in subzone 3b. These inner rocks have been thoroughly recrystallised to granoblastic aggregates of normal basaltic minerals ie. plagioclase, olivine, magnetite and clinopyroxene with only rare orthopyroxene. Amygdales show only aggregates of plagioclase with rare clinopyroxene and olivine probably developed from original zeolite assemblages rather than those characterising the adjacent zones implying a non-progressive metamorphic event. These rocks are typical of those formed under pyroxene-hornfels facies conditions. There is little evidence of replacement of one amygdaloidal mineral or alteration by another apart from chlorites possibly developing at the expense of amphibole and chlorite + magnetite rimming micaceous olivine pseudomorphs. Thus as readjustment to new conditions and the rate of metamorphic reactions are generally slow, the lavas probably had little time individually to equilibrate properly at a range of temperatures and so the metamorphism was probably non-progressive but much influenced by the roles of water and volatiles in the outer zones.

10.3. The Geochemistry of the Metamorphosed Lavas

Chemical analyses of the metamorphosed lavas are presented in Appendix 1, Table 7. The lavas are extensively altered, often weathered and show considerable development of secondary and tertiary minerals both in the main mass of the rock and the amygdales. Consequently the analyses are highly variable in quality. However, as textures are mostly retained in all but the innermost subzones the still recognisable alkali-transitional basalts can be compared with their equivalents existing outside the aureole. That some chemical change has occurred is revealed by the fact that these meta-lavas are without exception hypersthene + olivine normative and on a plot of total alkalis against silica (figure 50) they occur within the field of tholeiitic or transitional alkali-tholeiitic basalts. There appears to be no consistent overall pattern of major element variation either within or between zones but there are important increases in SiO_2

Figure 50

Total alkalis (Na_2O+K_2O) versus silica plot for those lavas in the vicinity of the Cuillin Hills Intrusive Complex.

○ Outer zone 1b

Δ Middle zone 2

○ Inner zone 3a

□ Inner zone 3b

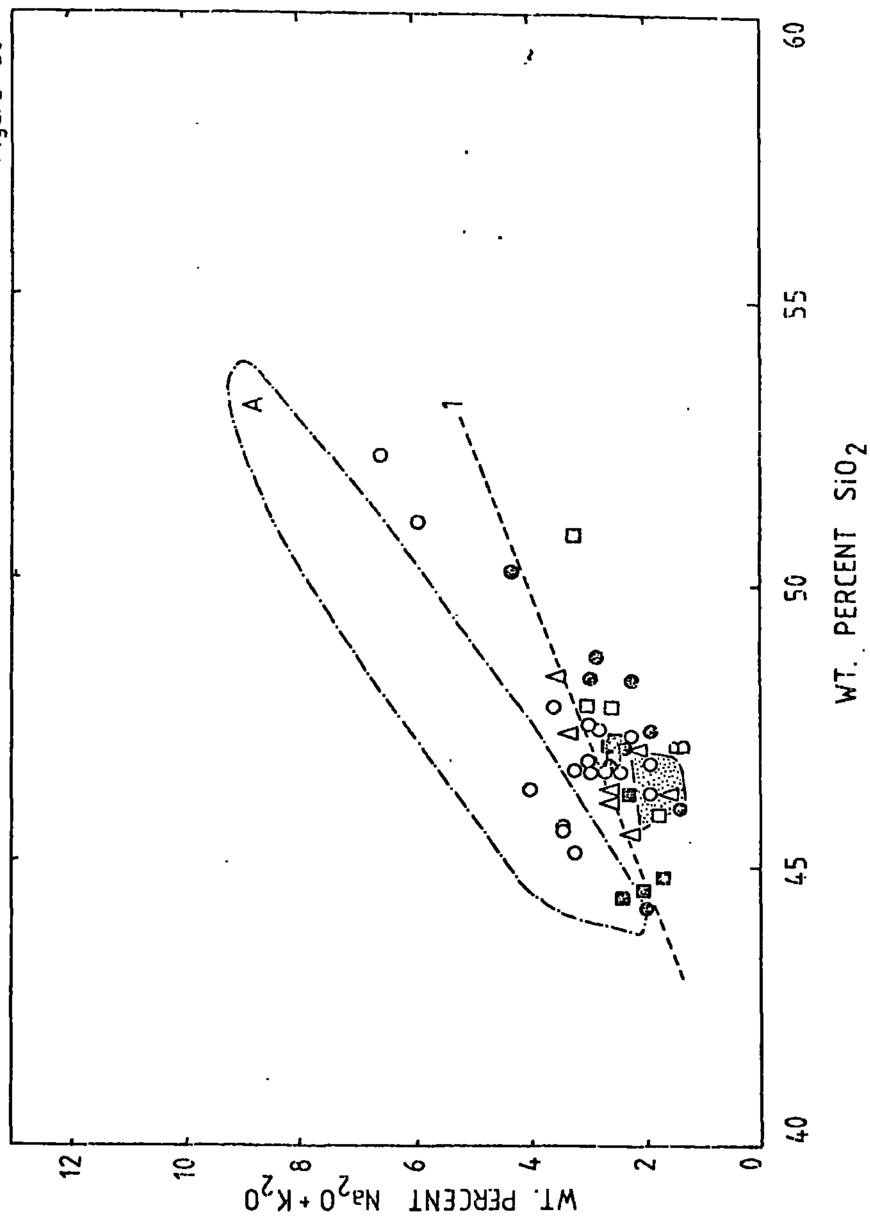
■ Inner zone 3c (hornfels)

Fields: A. basalt-hawaiite-mugearite non-metamorphosed lavas from west-central Skye.

B. low-alkali, high-calcium olivine tholeiite lava (stippled).

Trends: 1. Hawaiian division line separating alkali-olivine and tholeiite lavas (MacDonald and Katsura, 1964).

Figure 50


A
B
1
WT. PERCENT SiO_2
WT. PERCENT $Na_2O + K_2O$
40
45
50
55
60
0
2
4
6
8
10
12

and CaO and occasionally $Fe_{total)}$ and MgO, and corresponding reductions in Na_2O, K_2O? and TiO_2. Al_2O_3 is variable but appears to be substantially reduced in the rocks of the middle (2) and outer (1) zones. This pattern of variation is at variance with that characterising the weathering and bole or laterite forming process (Chapter 9.5) in which SiO_2 is lost and TiO_2 and Al_2O_3 are markedly increased by being held in residual phases. Almond (1960,1964) noted a marked increase in the SiO_2 and alkali content of the hypersthene $\pm$ olivine bearing basaltic hornfels which could be possibly attributed to the effects of partial melting of adjacent sediments (rheomorphism) and the presence of para-metamorphic granitic veins. Granitic veins are rare in the west-central Skye area but are present at An Sguman. Angus (1970) noted that hornfelsed dolerites, in the basic plutonic complex, Co. Tyrone, Ireland, relative to the gabbros, were depleted in SiO_2 and alkalis with enrichments in Fe, Mg, Ti and Ca, in contrast to the Skye examples. SiO_2 could also presumably be made available locally upon exsolution of titaniferous magnetite from the augites and might help produce orthopyroxene in these rocks. In west-central Skye comparison of olivine + spinel porphyritic basalts with the olivine-rich (and possibly chrome-spinel bearing) basaltic hornfels e.g. Sk751006 reveals little or no SiO_2 increase but an overall rise in SiO_2 in the aureole is shown by plotting it against those elements considered by Wood et al. (1976) (Ti,P,Zr,Y,Nb) and Pearce and Norry (1979) (Ti,Zr,Y,Nb) as being relatively immobile during hydrothermal alteration and metasomatism due in part to their high charge:radius ratio (figures 51-A, 51-B). The lavas and especially the high grade hornfels plot outside the fields characterising the normal basalt types and accepting a SiO_2 increase there appears to be relative depletions in these elements also. If no depletion in Zr and Nb has occurred then this would necessitate that most were olivine + spinel porphyritic basalts originally; a feature easily checked by basic petrography and found to be incorrect. Also, figures 52 and 53 reveal that TiO_2 and P_2O_5 must have been removed in some of these rocks. Yttrium is notably depleted in the granular hornfels and possibly also in the adjacent subzones. This situation is opposite to that expected but Pearce and Norry also consider that these elements are only really unaffected in the absence of substantial amounts of ions such as F^- and Cl^- which may have been quite common around the aureole. Other trace elements are variable or little affected e.g. Ni and Cr which indicate no relative enrichments and are of the same order of magnitude as in the unmetamorphosed basalts, but Ba is generally increased

Figures 51-A and 51-B

Silica versus Zr and Nb in the metamorphosed lavas of the aureole around the Cuillin Hills Intrusive Complex. Symbols as used in figure 50 and Transitional Basalts as in figures 29 onwards.

Fields: A. Olivine and olivine ± plagioclase porphyritic basalts (unmetamorphosed)
B. Olivine + spinel porphyritic basalts
C. Low-alkali, high-calcium olivine tholeiite lava.

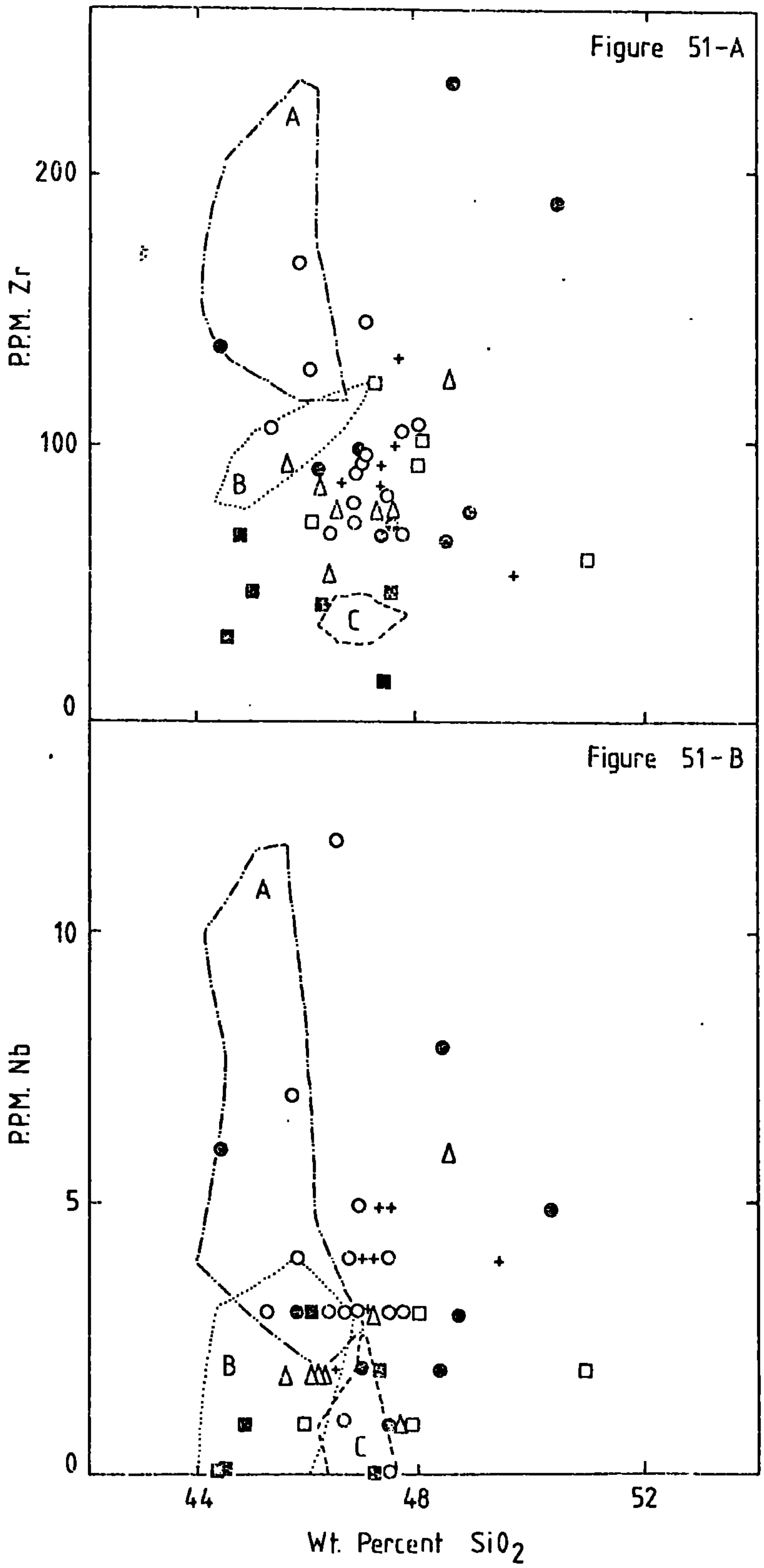


Figure 51-A
A
B
C
200
100
0
P.P.M. Zr
Figure 51-B
A
B
C
10
5
0
P.P.M. Nb
44
48
52
Wt. Percent SiO_2

Figure 52

Plot of Ti versus Zr for the metamorphosed lavas of the Cuillin Hills Intrusive Complex aureole. Symbols as for figures 50 and 51.

Fields: A. olivine and olivine + plagioclase porphyritic basalts (unmetamorphosed)
B. olivine + spinel porphyritic basalts
C. Fairey Bridge Magma Type (Mattey et al., 1977)
D. Preshal More Magma Type " " " "

Figure 52

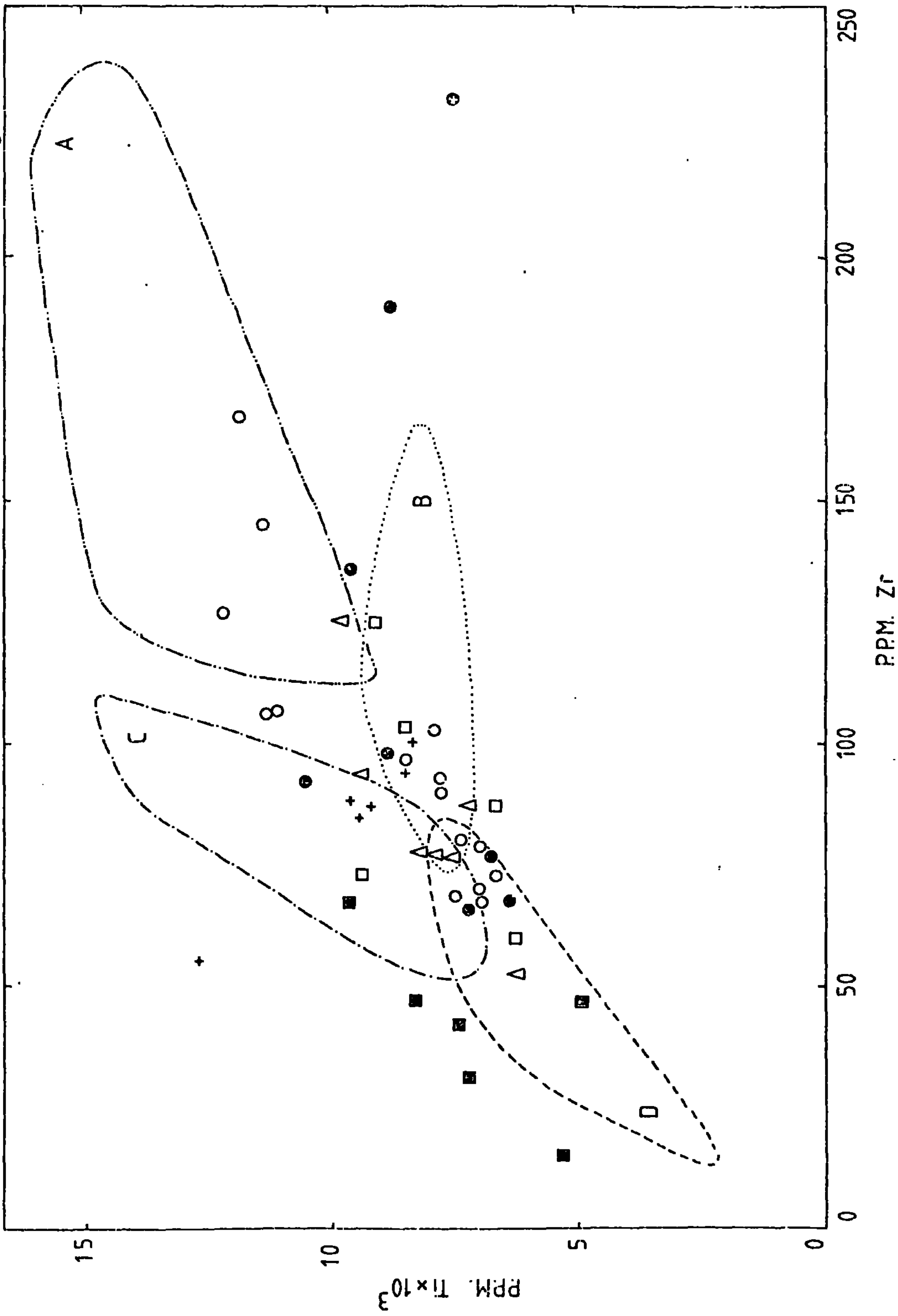


Figure 53

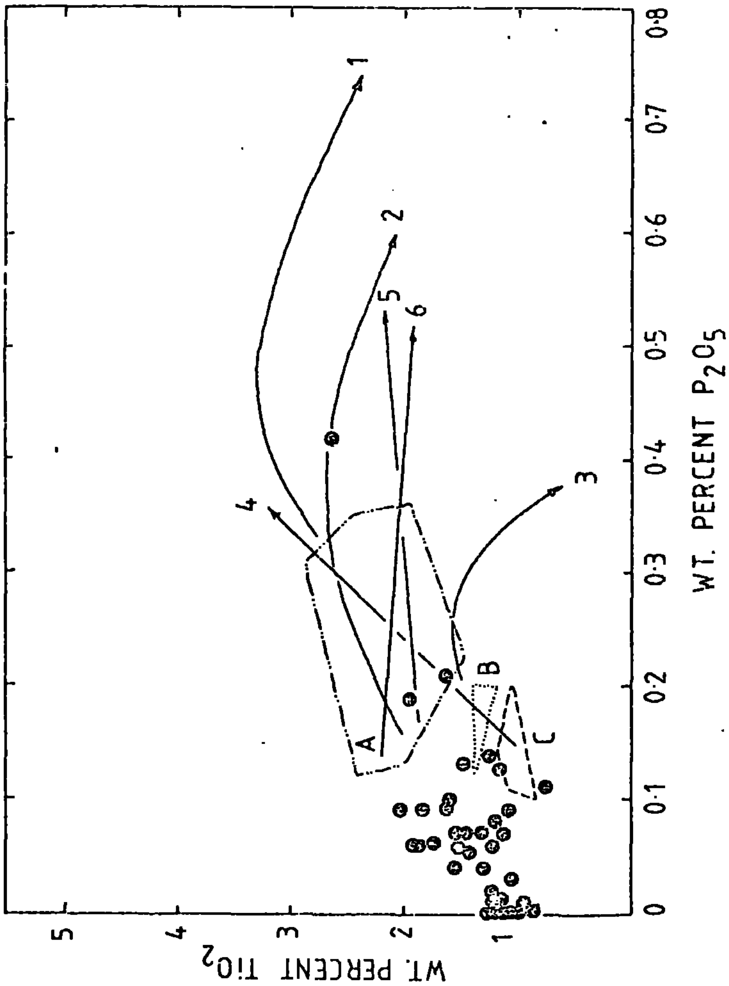
Major element variation plot of P_2O_5 against TiO_2 showing the relative positions of both metamorphosed and unaltered basaltic lavas from west-central Skye.

● Lavas within the aureole of the Cuillin Hills Intrusive Complex.

Fields: A. Olivine and olivine + plagioclase porphyritic basalts (unmetamorphosed)
B. Olivine + spinel porphyritic basalts
C. Low-alkali, high-calcium, olivine tholeiite lava

Trends: 1. Continuation of west-central Skye trend to hawaiites and mugearites
2. Mull lavas Groups I and III: after Beckinsale et al. (1978).
3. Mull lavas Group II: after Beckinsale et al. (1978)
4. Muck lavas: after Ridley (1973)
5. Rhum lavas: " " "
6. Canna lavas: " " "

Figure 53


WT. PERCENT TiO_2
WT. PERCENT P_2O_5
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
1
2
3
4
5
A
B
C
1
2
3
4
5
6

and Rb and Sr show a wide spread of values and so no generalisation can be made. Figure 53 shows that substantial P_2O_5 depletion has occurred. As phosphorus is almost completely locked-up in late-stage apatites and such phases would presumably be the first to undergo changes upon heating, this depletion is logically explained. In addition, this may hold the key to the problem of the apparent depletions in such elements as Zr, Y and Nb, in that both F^- and Cl^- ions are often associated or combined with apatites and would probably be freed upon metamorphism. The presence of these ions in the interstices of the lavas at an early stage could account for the depletion in the incompatible elements mentioned above which would now become mobile rather than immobile in the system as has also been suggested by Pearce and Norry.

Another possibility which should not be overlooked if we consider these incompatible elements to be immobile is that at least some of the lavas may be showing primary chemical characteristics. Thus although alkaline or transitional alkali basalts based upon original petrography, they could be even more transitional towards low-alkali tholeiite or Fairey Bridge magma types (Mattey et al. 1977) (figure 52) than those lavas outside the aureole. In this respect some at least could be broadly similar to those from the Small Isles (Hoey, pers. comm.) but differing in detail e.g. figure 53 TiO_2 against P_2O_5 showing various lineages from the Small Isles (Ridley 1973) and Mull (Beckinsale et al. 1978). Petrographically distinctive transitional basalts do occur within the area of and near the aureole and occur stratigraphically close to the intraformational conglomerates mentioned earlier. The occurrence of Small Isles-type transitional alkali-olivine basalts in the Meacnaish group and adjacent lavas would indicate an interdigitation of these lava sequences (see also Canna Ridge in Binns et al. 1973) possibly suggesting that the lavas of Canna etc. and possibly the Rhum plutonic centre are substantially older than their type-equivalents in Skye. However, substantially more work in this area is necessary to establish the correlation if any.

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APPENDIX 1

Major and Trace element analyses

Table 1. Basalt lavas

2. Hawaiite lavas

3. Mugearite lavas

4. Benmoreite and Trachyte lavas

5. Intrusions

6. Interflow horizons

7. Central Complex Aureole

TABLE 1. BASALTS

Analyses	Division
1-11	Olivine + spinel porphyritic
12-33	Olivine porphyritic
34-48	Olivine + plagioclase porphyritic
49-51	Plagioclase macroporphyritic
52-58	Transitional near aphyric suite
59-66	Aphyric of alkalic suite
67-82	Low-alkali, high-calcium olivine tholeiite

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

Table 1.

	1	2	3	4	5	6	7	8	9	10
	740106	740607	750301	750602	750604	751211	751212	751501	7706	7616
WEIGHT PERCENT										
SIO2	46.30	44.38	44.31	46.03	46.83	44.06	44.12	45.82	44.17	44.80
AL2O3	16.07	15.56	14.53	14.57	14.73	10.92	11.04	14.86	14.14	15.60
FE2O3	2.00	1.25	1.25	1.25	1.25	1.25	1.25	1.50	1.25	1.25
FEO	9.00	10.39	10.82	10.53	10.56	10.48	10.31	10.21	10.56	10.75
MGO	11.04	12.23	13.35	11.83	10.60	17.21	17.18	12.45	14.16	12.05
CAO	8.26	9.32	8.33	10.13	9.50	9.37	9.36	9.91	9.43	9.68
NA2O	3.54	2.11	2.02	2.36	2.55	1.90	1.91	2.43	2.10	2.42
K2O	0.87	0.63	0.49	0.22	0.37	0.17	0.16	0.37	0.18	0.38
TIO2	1.32	1.37	1.36	1.28	1.40	1.30	1.31	1.37	1.33	1.22
MNO	0.18	0.19	0.19	0.19	0.18	0.19	0.18	0.17	0.18	0.19
P2O5	0.42	0.23	0.19	0.16	0.21	0.18	0.18	0.12	0.19	0.20
TOTAL	99.00	98.75	98.01	99.72	99.35	98.14	98.15	99.21	98.86	99.73
PPM										
BA	153	49	114	23	124	0	0	89	25	55
NB	3	3	1	0	3	0	1	4	2	2
ZR	120	96	165	93	122	79	80	98	88	105
Y	20	18	18	18	18	10	12	16	14	17
SR	717	284	705	275	314	185	178	320	220	251
RB	11	9	2	0	0	3	3	6	2	3
ZN	67	71	73	67	78	71	71	77	72	75
CU	82	110	79	144	78	117	119	125	125	122
NI	543	580	680	427	404	963	968	478	751	500
CR	1144	1274	1014	1161	1039	1760	1655	896	1162	1075
APPROXIMATE GRID REFFRENCE										
NG	338360	318343	309308	368268	369269	384225	384225	396212	308308	339248

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

	11	12	13	14	15	16	17	18	19	20
	7717	740305	740306	740402	741001	741002	741103	750118	750203	750501

WEIGHT PERCENT

	11	12	13	14	15	16	17	18	19	20
SIO2	44.56	44.28	44.44	46.41	45.24	46.01	45.95	45.50	45.40	45.39
AL2O3	13.62	15.02	15.87	15.25	16.26	16.20	15.22	16.26	16.05	16.68
FE2O3	1.25	1.25	1.25	1.50	1.50	1.50	1.50	1.50	1.75	1.50
FEO	10.55	12.38	12.77	10.43	11.14	11.30	11.07	11.82	10.61	12.11
MGO	15.43	8.12	7.52	11.16	9.99	8.38	8.13	9.71	7.84	6.84
CAO	9.23	9.17	9.35	9.25	9.04	9.15	9.15	9.75	8.97	9.16
NA2O	1.95	2.49	2.46	2.55	2.65	2.62	2.94	2.71	4.01	3.02
K2O	0.17	0.31	0.35	0.37	0.54	0.40	0.56	0.38	0.54	0.43
TIO2	1.25	2.32	2.47	1.48	1.86	2.06	2.36	2.11	2.30	2.44
MNO	0.18	0.20	0.20	0.19	0.18	0.18	0.19	0.21	0.18	0.19
P2O5	0.16	0.31	0.35	0.23	0.33	0.31	0.32	0.22	0.28	0.28
TOTAL	99.64	97.23	98.55	98.82	98.73	99.36	98.62	101.48	99.33	99.39

PPM

	11	12	13	14	15	16	17	18	19	20
BA	15	117	159	112	170	224	157	85	119	100
NB	2	5	8	2	5	3	7	3	4	12
ZR	80	173	177	114	169	167	232	127	297	126
Y	13	31	31	23	17	29	26	25	28	31
SR	193	434	412	264	438	408	493	356	550	400
RB	2	6	5	8	9	2	8	5	3	9
ZN	70	79	76	85	79	78	85	87	78	76
CU	128	108	107	107	115	103	106	124	84	51
NI	805	151	146	312	294	128	256	154	275	143
CR	1405	72	72	716	343	64	314	72	385	85

APPROXIMATE GRID REFERENCE

	11	12	13	14	15	16	17	18	19	20
NG	308308	322317	322318	302318	322331	322332	362297	315338	378298	353275

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

	21	22	23	24	25	26	27	28	29	30
	751206	751207	751208	751209	751210	751214	751702	751703	760306	760307
WEIGHT PERCENT										
SIO2	44.12	45.66	43.95	44.25	44.46	45.26	45.42	44.97	45.18	44.13
AL2O3	14.41	16.08	14.70	16.07	15.88	15.91	16.04	17.29	15.27	13.87
FE2O3	1.50	1.75	1.25	1.50	1.75	1.75	1.75	1.75	1.75	1.50
FEO	12.27	11.40	14.81	13.06	12.47	12.17	12.19	11.38	12.42	14.79
MGO	9.63	8.39	9.34	6.79	7.36	7.93	6.98	7.32	8.64	8.81
CAO	8.76	8.97	8.86	8.69	8.41	9.08	8.80	9.08	8.57	8.81
NA2O	2.57	3.83	2.55	3.28	3.94	3.82	3.80	4.36	4.07	3.23
K2O	0.43	0.48	0.36	0.34	0.31	0.25	0.22	0.21	0.38	0.47
TIO2	2.34	2.17	2.52	2.88	2.61	2.31	2.64	2.04	2.00	2.42
MNO	0.19	0.17	0.19	0.20	0.21	0.18	0.20	0.17	0.19	0.20
P2O5	0.27	0.20	0.27	0.31	0.31	0.19	0.28	0.16	0.13	0.12
TOTAL	97.85	99.10	98.44	98.82	99.09	98.85	99.67	98.73	98.60	98.35
PPM										
BA	88	72	14	122	49	23	2	37	211	208
NB	5	6	4	5	5	2	5	3	13	10
ZR	146	236	149	203	225	234	258	211	298	293
Y	22	23	23	23	25	21	25	23	26	27
SR	381	525	393	417	550	562	490	463	968	1067
RB	4	6	2	13	10	0	9	2	5	4
ZN	75	75	63	76	71	85	62	82	63	66
CU	105	61	116	102	49	76	82	106	81	86
NI	155	77	161	127	108	121	137	177	202	191
CR	92	135	155	34	85	142	47	213	97	77
APPROXIMATE GRID REFERENCE										
NG	389229	388229	387228	387228	387225	386218	357215	355229	354248	354249

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

	31	32	33	34	35	36	37	38	39	40
	760308	740101	740104	740201	740502	740507	740508	740801	740901	740904
WEIGHT PERCENT										
SIO2	44.24	47.25	45.21	44.02	45.62	45.14	44.73	44.78	44.42	44.42
AL2O3	16.55	13.96	16.30	15.59	17.44	17.02	16.93	16.79	17.26	17.26
FE2O3	1.25	1.75	1.50	1.50	1.50	1.75	1.50	1.50	1.50	1.50
FEO	12.07	9.55	11.52	11.37	12.14	11.07	11.10	13.19	10.72	10.72
MGO	7.58	8.75	9.48	6.69	5.80	7.21	7.05	6.71	8.67	8.67
CAO	9.65	8.60	10.76	8.84	9.98	9.13	9.34	9.39	10.44	10.44
NA2O	2.52	3.67	2.50	3.45	3.32	3.90	3.26	2.79	3.25	3.25
K2O	0.22	0.70	0.23	0.44	0.35	0.49	0.55	0.30	0.33	0.33
TIO2	2.31	2.64	1.75	2.37	1.96	2.17	1.96	2.44	1.77	1.77
MNO	0.21	0.15	0.21	0.20	0.19	0.19	0.20	0.22	0.19	0.19
P2O5	0.26	0.33	0.24	0.29	0.26	0.26	0.28	0.25	0.26	0.26
TOTAL	98.30	98.42	99.70	96.02	98.56	99.56	98.13	99.82	98.81	98.81
PPM										
BA	104	242	78	101	138	113	117	112	140	140
NB	3	6	0	4	5	5	4	4	5	5
ZR	130	170	118	181	142	144	148	137	132	132
Y	24	33	21	32	30	27	30	30	25	25
SR	353	524	312	465	509	414	379	409	388	388
RB	3	10	2	12	5	13	9	4	7	7
ZN	82	75	74	78	66	68	75	71	72	72
CU	127	100	90	103	86	105	128	120	113	113
NI	243	127	254	136	72	148	163	151	360	284
CR	497	420	177	70	166	67	76	94	284	360
APPROXIMATE GRID REFERENCE										
NG	354248	342359	338359	352304	339337	337332	336330	351301	360305	360310

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

	41	42	43	44	45	46	47	48	49	50
	741104	750614	750707	751001	751502	751502	751704	760304	740209	751407
WEIGHT PERCENT										
SIO2	44.76	45.89	46.04	46.36	45.52	45.52	45.68	45.33	47.81	47.43
AL2O3	18.10	16.00	15.20	15.16	16.47	16.47	16.17	15.78	17.68	17.77
FE2O3	1.50	1.50	1.50	1.50	1.75	2.00	1.75	1.50	2.00	1.25
FEO	11.31	11.25	10.56	10.09	11.66	11.46	10.99	11.80	10.61	7.26
MGO	7.40	8.04	9.86	9.40	6.98	6.98	6.54	6.88	4.19	7.05
CAO	9.42	9.04	9.40	10.47	9.42	9.42	9.72	9.79	7.92	14.68
NA2O	3.36	3.18	2.59	2.62	4.08	4.08	3.62	2.75	4.29	1.94
K2O	0.37	0.19	0.55	0.62	0.29	0.29	0.49	0.30	1.06	0.15
TIO2	1.96	2.13	1.82	1.61	2.38	2.38	2.44	2.39	2.44	1.13
MNO	0.19	0.20	0.19	0.19	0.17	0.17	0.20	0.20	0.18	0.13
P2O5	0.36	0.23	0.26	0.20	0.21	0.21	0.23	0.25	0.58	0.03
TOTAL	98.73	100.22	99.25	99.34	98.93	98.99	99.05	98.29	98.76	98.82
PPM										
BA	153	18	234	218	31	75	111	145	514	18
NB	7	2	5	2	0	6	4	4	24	3
ZR	167	173	166	131	251	192	208	165	170	60
Y	30	28	18	19	25	23	25	20	33	14
SR	470	467	438	390	528	579	495	446	683	347
RB	3	5	2	2	3	4	10	5	18	1
ZN	63	80	84	81	76	79	81	72	66	39
CU	98	123	85	114	77	77	81	74	25	77
NI	129	268	289	151	111	111	108	37	7	80
CR	43	469	696	555	69	69	123	180	5	230
APPROXIMATE GRID REFERENCE										
NG	365295	363271	336260	412286	397234	395234	355222	355246	363305	370197

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

	51	52	53	54	55	56	57	58	59	60
	760401	751201	751201	751202	751203	751215	751216	751218	740103	740105
WEIGHT PERCENT										
SIO2	48.51	46.41	47.36	47.37	47.15	47.08	47.12	49.47	46.02	44.27
AL203	12.56	14.95	15.00	14.36	15.33	14.80	14.96	14.35	17.27	16.88
FE203	1.25	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
FEO	10.62	11.22	10.48	12.21	10.59	10.38	10.42	10.53	11.94	12.35
MGO	11.00	9.00	9.72	7.45	9.33	8.56	8.06	6.48	6.84	9.87
CAO	9.90	11.95	11.04	10.39	11.17	12.31	12.22	10.94	9.54	8.45
NA20	2.50	1.91	2.02	2.69	2.03	2.41	2.69	2.92	3.48	2.68
K20	0.45	0.26	0.39	0.63	0.31	0.22	0.22	0.16	0.23	0.24
TIO2	1.30	1.51	1.41	2.06	1.43	1.53	1.57	2.10	2.29	1.92
MNO	0.17	0.18	0.17	0.19	0.16	0.17	0.18	0.19	0.22	0.20
P205	0.04	0.08	0.10	0.14	0.10	0.08	0.08	0.15	0.29	0.25
TOTAL	98.30	98.97	99.19	98.99	99.10	99.04	99.02	99.70	100.95	98.62
PPM										
BA	247	73	125	153	94	49	66	60	77	84
NB	3	2	5	5	4	4	3	4	4	7
ZR	140	88	102	134	95	86	85	55	150	151
Y	17	23	21	27	21	19	17	25	26	22
SR	375	199	188	260	204	260	259	131	404	376
RB	7	3	4	6	3	0	2	2	8	4
ZN	80	74	73	81	69	65	66	70	82	78
CU	59	106	104	112	90	125	130	114	109	54
NI	126	133	157	35	106	111	65	83	121	36
CR	147	258	290	152	286	347	364	178	68	138
APPROXIMATE GRID REFERENCE										
NG	409187	409240	408240	407239	406238	385207	384206	384203	341356	339359

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

	61	62	63	64	65	66	67	68	69	70
	760404	740606	740608	750105	750111	751302	750807	750808	750809	750810
WEIGHT PERCENT										
SIO2	48.82	47.01	48.40	44.27	47.26	45.18	46.88	46.12	45.25	46.97
AL2O3	13.94	15.98	17.06	16.88	16.43	15.14	15.98	15.21	15.03	16.39
FE2O3	1.50	1.50	1.25	1.25	1.50	1.50	1.00	1.25	1.00	1.25
FEO	11.37	9.79	10.69	12.10	12.17	11.91	9.44	9.69	9.96	9.67
MGO	9.27	8.54	6.23	9.87	6.94	10.79	9.52	8.43	10.32	8.68
CAO	9.95	9.23	9.87	8.45	7.57	8.93	12.48	12.55	12.48	12.63
NA2O	2.93	2.79	2.05	2.68	2.92	2.49	1.72	2.01	1.45	1.95
K2O	0.37	0.73	0.92	0.24	1.01	0.46	0.09	0.09	0.11	0.09
TIO2	1.25	1.82	1.58	1.92	2.35	2.27	0.89	0.96	0.89	0.84
MNO	0.19	0.18	0.15	0.20	0.21	0.16	0.19	0.19	0.20	0.18
P2O5	0.05	0.26	0.32	0.26	0.26	0.20	0.13	0.12	0.12	0.10
TOTAL	98.74	98.92	98.82	98.12	98.62	98.73	99.37	97.70	98.92	99.82
PPM										
BA	277	264	258	84	373	91	0	0	0	0
NB	6	4	3	7	22	7	0	1	0	2
ZR	86	150	179	151	227	249	35	35	32	30
Y	18	26	22	22	38	24	19	19	17	16
SR	457	431	857	376	311	486	109	112	116	111
RB	3	4	12	4	15	3	0	0	0	0
ZN	83	78	71	78	79	88	60	68	68	74
CU	47	89	118	54	12	71	156	176	142	138
NI	123	128	94	138	60	252	196	119	203	194
CR	55	404	249	36	206	367	431	449	417	411
APPROXIMATE GRID REFERENCE										
NG	404178	318343	319343	340360	310320	409263	331279	331279	325279	326278

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

	71	72	73	74	75	76	77	78	79	80
	750811	750812	750813	750814	750906	750907	750908	750909	750910	750911
WEIGHT PERCENT										
SIO2	46.47	46.85	46.73	46.48	46.86	46.92	46.69	46.96	46.34	47.17
AL2O3	15.81	15.81	16.07	15.53	15.08	15.64	15.17	15.62	15.64	15.51
FE2O3	1.00	1.00	1.00	1.00	1.00	1.25	1.00	1.25	1.00	1.25
FEO	9.53	9.77	9.41	9.38	10.55	10.17	10.37	10.22	10.31	9.82
MGO	9.48	9.58	9.06	8.48	7.91	8.08	9.08	8.34	8.92	8.05
CAO	12.47	12.68	12.76	12.46	12.98	12.93	12.44	12.52	12.01	12.61
NA2O	1.72	1.75	1.71	1.80	1.83	2.01	1.63	1.98	1.78	1.90
K2O	0.10	0.09	0.08	0.07	0.10	0.08	0.08	0.13	0.10	0.20
TIO2	0.87	0.91	0.88	0.86	1.09	0.95	1.06	1.10	1.07	1.05
MNO	0.18	0.20	0.19	0.18	0.22	0.21	0.21	0.21	0.19	0.21
P2O5	0.13	0.11	0.11	0.12	0.11	0.11	0.12	0.13	0.16	0.20
TOTAL	98.82	99.83	99.04	98.40	98.90	99.56	99.22	99.59	98.66	99.06
PPM										
BA	0	0	0	0	0	12	6	0	15	23
Nd	0	0	1	0	5	2	0	3	1	0
ZR	32	31	34	31	47	41	44	43	46	45
Y	19	19	19	18	22	19	24	23	25	21
SR	106	108	113	106	130	127	107	121	118	147
RB	0	0	0	0	0	0	0	0	0	0
ZN	63	65	58	67	73	65	73	69	75	62
CU	142	150	151	164	172	180	176	189	165	182
NI	190	194	182	190	138	130	121	138	143	141
CR	424	425	419	425	429	467	433	412	381	393
APPROXIMATE GRID REFERENCE										
NG	330277	330277	330277	328278	334300	331300	331299	332288	332288	332288

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

	81	82
	750912	750915
WEIGHT PERCENT		
SIO2	47.01	47.64
AL2O3	15.41	15.28
FE2O3	1.25	1.25
FEO	10.15	10.01
MGO	8.24	8.30
CAO	12.39	12.43
NA2O	2.01	1.98
K2O	0.13	0.15
TIO2	1.17	1.06
MNO	0.21	0.21
P2O5	0.14	0.13
TOTAL	99.24	99.55
PPM		
BA	20	16
NB	2	0
ZR	46	40
Y	19	21
SR	137	143
RB	0	0
ZN	75	77
CU	182	161
NI	134	149
CR	370	457

APPROXIMATE GRID REFERENCE

NG	332288	329300

TABLE 2. HAWAIITES

Analyses	Division
83-96	Olivine + plagioclase + magnetite microporphyritic
97-98	Loch Dubh type olivine + plagioclase + magnetite microporphyritic
99-111	Olivine + plagioclase + magnetite microporphyritic
112	Loch Dubh type plagioclase macro-porphyritic, olivine + plagioclase + magnetite microporphyritic
113	Loch Dubh type olivine + plagioclase microporphyritic
114-118	Olivine + plagioclase microporphyritic
119	Plagioclase macroporphyritic
120-131	Olivine + plagioclase + magnetite microporphyritic with rare plagioclase macrophenocrysts
132,134	Composite of Dun Ard an t-Sabhail Upper Unit
133	Composite of Dun Ard an t-Sabhail Lower Unit
135-152	Coarse-grained or basaltic
153-158	Aphyric

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES Table 2

	83	84	85	86	87	88	89	90	91	92
	740108	740202	740203	740206	740207	740301	740304	740308	740406	740512
WEIGHT PERCENT										
SIO2	48.68	45.71	46.90	49.01	49.51	47.81	47.66	46.48	47.25	47.87
AL2O3	15.86	15.89	16.75	16.82	16.38	15.67	16.47	16.46	15.80	17.61
FE2O3	2.00	1.75	2.00	2.00	2.00	1.75	2.00	1.75	1.75	2.00
FEO	12.48	12.34	10.06	10.16	10.15	12.85	12.20	12.20	13.01	10.63
MGO	4.03	4.69	4.73	4.80	5.04	4.58	4.05	4.37	4.75	4.15
CAO	6.30	7.60	7.07	6.67	6.77	6.38	7.16	7.41	7.97	7.44
NA2O	4.60	3.62	4.72	4.10	3.91	4.01	4.42	3.93	3.51	4.66
K2O	0.71	0.62	0.99	1.42	1.35	0.95	1.13	1.04	0.66	1.14
TIO2	3.02	3.20	3.14	3.01	2.92	2.79	3.13	3.33	3.21	3.17
MNO	0.26	0.20	0.19	0.20	0.18	0.23	0.22	0.20	0.20	0.19
P2O5	0.55	0.43	0.47	0.50	0.50	0.63	0.54	0.50	0.43	0.40
TOTAL	99.85	97.42	98.80	99.82	99.84	99.08	100.34	99.03	99.99	100.44
PPM										
BA	252	225	486	572	541	467	471	380	354	428
NB	27	12	25	32	31	21	23	16	12	26
ZR	461	263	270	304	286	412	352	294	257	276
Y	55	44	42	44	42	52	50	42	46	50
SR	677	719	742	724	697	628	772	642	665	681
RB	4	16	24	29	27	20	22	20	11	22
ZN	62	77	54	59	59	70	58	63	78	58
CU	14	35	65	33	29	26	62	89	39	53
NI	9	26	25	11	13	0	7	31	34	20
CR	77	7	16	3	2	0	10	15	15	15
APPROXIMATE GRID REFERENCE										
NG	336362	352305	352306	347313	345316	335319	332318	318319	302318	338325

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

	93	94	95	96	97	98	99	100	101	102
	740802	741107	741108	741112	750104	750105	750403	750506	750801	750815
WEIGHT PERCENT										
SIO2	47.06	46.94	47.89	49.26	48.00	47.76	46.46	46.80	46.41	46.78
AL2O3	16.85	17.12	17.17	17.76	16.12	16.53	16.74	16.42	16.28	15.72
FE2O3	1.75	1.50	1.75	2.00	2.00	1.75	2.00	1.75	1.75	1.75
FEO	12.76	13.04	12.78	10.53	12.42	11.97	12.52	12.46	13.10	12.94
MGO	4.51	5.01	5.07	4.14	3.78	4.39	4.55	4.89	4.55	4.93
CAO	7.43	7.56	7.00	7.15	7.00	7.57	7.78	7.00	8.23	8.33
NA2O	4.00	3.09	3.07	4.48	4.75	3.79	3.90	3.74	3.85	3.98
K2O	0.64	0.64	0.93	1.13	1.09	1.01	0.64	0.97	0.88	0.74
TIO2	3.33	2.76	3.00	2.96	2.83	3.14	3.17	3.37	2.73	2.70
MNO	0.19	0.21	0.21	0.19	0.23	0.21	0.21	0.21	0.22	0.23
P2O5	0.51	0.41	0.40	0.52	0.57	0.42	0.43	0.40	0.31	0.28
TOTAL	100.45	99.73	100.69	101.29	100.17	99.87	99.79	99.39	98.31	99.82
PPM										
BA	214	285	346	450	299	287	202	240	325	356
NB	12	8	5	25	26	19	15	18	12	10
ZR	329	257	258	308	380	352	275	344	228	206
Y	40	35	55	43	53	55	45	47	37	32
SR	747	517	571	711	709	733	666	713	649	655
RB	19	13	13	28	23	21	17	15	23	14
ZN	68	72	61	64	60	73	67	68	87	89
CU	37	36	30	52	46	37	55	53	100	80
NI	20	26	20	21	15	25	50	17	2	6
CR	6	73	40	15	3	10	20	0	33	14
APPROXIMATE GRID REFERENCE										
NG	352300	361295	359294	354293	308332	308331	345286	350270	331289	329275

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

	103	104	105	106	107	108	109	110	111	112
	750816	750817	750819	750918	750919	750920	750921	750922	751213	7634
WEIGHT PERCENT										
SIO2	46.89	46.83	47.37	47.98	48.12	48.49	48.22	47.82	47.22	47.23
AL2O3	15.83	15.69	16.22	16.30	16.02	15.63	15.64	15.74	16.57	16.03
FE2O3	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.00	2.00	2.00
FEO	12.77	12.73	12.93	10.89	10.36	12.85	10.93	12.47	11.52	12.16
MGO	5.29	5.29	4.81	5.58	5.33	3.75	3.86	4.11	5.60	4.71
CAO	8.26	8.23	8.00	7.25	7.34	6.89	7.03	7.22	7.32	7.79
NA2O	3.63	3.87	3.72	3.87	3.96	4.28	4.59	4.32	4.14	4.45
K2O	0.77	0.74	0.54	1.14	1.12	0.90	0.81	0.80	0.93	0.60
TIO2	2.62	2.50	2.55	3.10	3.31	3.21	3.03	3.00	3.11	3.09
MNO	0.22	0.21	0.20	0.20	0.19	0.24	0.22	0.22	0.18	0.21
P2O5	0.30	0.33	0.29	0.43	0.40	0.58	0.49	0.54	0.46	0.37
TOTAL	99.75	99.58	100.12	99.95	99.30	100.25	100.03	99.63	100.33	99.99
PPM										
BA	393	383	414	504	518	580	322	330	132	229
NB	8	9	16	30	31	28	26	26	9	15
ZR	205	205	215	304	295	459	427	410	350	237
Y	35	32	38	39	40	57	64	50	34	42
SR	641	645	669	655	659	708	706	626	1000	630
RB	13	12	15	16	18	22	27	14	2	12
ZN	81	93	84	60	63	61	64	75	63	60
CU	110	90	93	11	18	14	31	53	70	76
NI	14	8	8	0	1	1	10	10	47	35
CR	17	15	11	5	0	0	0	10	18	30
APPROXIMATE GRID REFERENCE										
NG	328275	328273	328272	329302	329302	329302	329304	329305	381225	313309

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   HAWAIITES

	113	114	115	116	117	118	119	120	121	122
	740405	750116	750117	750512	750606	750818	740311	740409	740511	740705
WEIGHT PERCENT										
SIO2	47.26	48.06	48.17	46.96	46.95	47.37	50.62	47.54	46.81	46.65
AL2O3	15.69	16.47	17.04	16.79	16.95	15.93	16.65	17.00	17.01	17.35
FE2O3	1.75	2.00	2.00	2.00	2.00	1.75	2.00	2.00	2.00	1.75
FEO	12.11	12.06	11.39	11.33	11.92	12.38	11.06	11.80	11.60	11.83
MGO	5.47	4.96	4.05	5.26	4.35	4.81	4.87	4.16	4.29	5.05
CAO	7.57	6.97	6.87	7.24	7.42	8.11	6.90	6.88	6.79	7.59
NA2O	3.50	4.62	5.10	4.28	5.10	4.15	4.19	4.71	4.56	4.03
K2O	2.66	0.97	0.53	1.04	0.65	0.79	1.65	0.91	0.97	0.51
TIO2	2.90	3.16	2.88	3.21	3.03	2.80	1.81	3.10	3.17	3.01
MNO	0.19	0.21	0.17	0.21	0.20	0.22	0.17	0.19	0.21	0.19
P2O5	0.38	0.53	0.40	0.42	0.40	0.30	0.83	0.36	0.50	0.46
TOTAL	98.83	101.32	98.70	100.00	100.29	99.98	100.75	98.65	99.20	98.42
PPM										
BA	394	387	169	381	196	405	962	316	417	239
NB	12	24	22	22	18	15	7	25	24	12
ZR	242	270	375	302	316	209	201	357	327	243
Y	43	53	42	44	45	34	35	49	54	42
SR	588	658	783	742	641	664	744	640	690	577
RB	10	20	20	17	19	19	23	14	23	7
ZN	77	69	64	64	64	91	91	72	62	59
CU	30	41	48	51	53	92	27	37	64	26
NI	17	12	8	13	11	9	4	6	9	48
CR	13	20	30	4	10	19	3	0	84	10
APPROXIMATE GRID REFERENCE										
NG	302318	302333	306320	345272	369272	328272	312323	344285	339326	317291

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   HAWAIITES

	123	124	125	126	127	128	129	130	131	132
	740706	740902	740903	750101	750103	750108	750503	750605	750610	741004
WEIGHT PERCENT										
SIO2	46.13	47.12	46.75	48.30	48.30	48.54	47.17	47.54	47.59	49.87
AL2O3	17.15	17.68	17.34	17.23	17.59	17.28	16.73	16.66	16.16	19.07
FE2O3	1.75	2.00	2.00	2.00	2.00	2.00	1.75	1.75	1.75	2.00
FEO	12.00	11.21	11.25	11.20	10.53	10.63	12.59	12.11	11.76	8.06
MGO	4.96	3.64	4.76	4.60	4.32	4.72	4.78	5.38	4.90	3.92
CAO	7.50	7.56	7.21	6.60	7.25	7.00	7.46	7.36	7.52	8.10
NA2O	3.96	4.90	4.55	4.47	5.30	4.24	4.05	3.99	3.97	4.86
K2O	0.92	0.82	0.83	1.09	0.63	1.12	0.64	0.53	0.86	0.51
TIO2	3.34	3.06	3.41	2.62	2.43	2.73	2.69	2.57	3.22	2.14
MNO	0.19	0.18	0.19	0.19	0.17	0.19	0.20	0.19	0.19	0.14
P2O5	0.49	0.54	0.44	0.41	0.29	0.35	0.29	0.28	0.40	0.39
TOTAL	98.39	98.71	98.73	98.71	98.22	98.80	98.31	98.36	99.63	99.06
PPM										
BA	365	423	354	414	152	240	206	192	463	195
NB	24	15	20	29	10	35	15	15	24	9
ZR	280	301	273	381	292	334	328	305	349	197
Y	43	49	42	49	40	40	44	42	49	33
SR	647	615	622	725	639	683	690	597	751	752
RB	17	19	16	18	9	19	7	4	22	8
ZN	62	59	70	69	58	67	70	69	67	42
CU	54	31	55	48	13	47	25	20	30	27
NI	26	28	29	3	0	0	0	19	8	30
CR	7	13	8	0	0	0	0	3	0	21
APPROXIMATE GRID REFERENCE										
NG	316288	364307	363308	315328	313332	309328	352274	369269	368277	319332

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

	133	134	135	136	137	138	139	140	141	142
	760702	760703	740404	740501	740504	740605	750205	750206	750207	750401
WEIGHT PERCENT										
SIO2	48.42	49.96	47.63	47.95	47.53	45.28	48.82	48.48	48.21	45.32
AL2O3	16.50	18.28	17.23	15.58	16.57	16.15	15.98	16.35	15.75	15.19
FE2O3	2.00	2.00	1.75	1.75	2.00	2.00	1.50	2.00	1.75	1.50
FEO	9.94	8.27	10.92	9.52	10.92	10.82	9.20	8.85	9.19	13.01
MGO	5.06	4.39	6.48	6.39	4.78	9.13	7.90	7.30	7.48	5.85
CAO	8.17	8.16	6.58	9.01	6.95	9.03	10.12	10.09	9.16	7.51
NA2O	4.69	5.09	3.79	3.72	4.05	4.27	3.14	3.29	3.74	3.25
K2O	0.49	0.42	0.66	0.81	1.01	0.44	0.57	0.73	0.65	0.67
TIO2	2.76	2.18	3.07	2.76	3.11	1.83	1.41	1.57	1.73	3.19
MNO	0.18	0.14	0.16	0.16	0.19	0.18	0.16	0.17	0.17	0.20
P2O5	0.35	0.35	0.49	0.32	0.48	0.25	0.15	0.15	0.34	0.47
TOTAL	99.65	100.26	98.78	99.03	98.80	99.38	98.95	98.98	98.17	97.61
PPM										
BA	224	149	211	268	576	206	234	705	225	167
NB	12	10	11	7	26	5	2	3	3	11
ZR	224	177	329	168	277	143	174	172	196	256
Y	37	27	40	24	38	24	22	22	33	43
SR	660	770	782	524	854	456	477	501	495	641
RB	13	9	12	14	23	6	1	9	6	13
ZN	65	55	54	74	57	80	70	71	79	78
CU	90	40	24	112	49	93	113	79	97	28
NI	15	5	14	77	20	245	436	173	227	3
CR	0	0	12	234	8	459	170	447	364	15
APPROXIMATE GRID REFERENCE										
NG	319332	320329	303315	337340	339334	318344	384296	386297	386292	336298

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   HAWAIITES

	143	144	145	146	147	148	149	150	151	152
	750802	750803	750901	750902	750904	750905	750913	750916	751204	751205
WEIGHT PERCENT										
SIO2	46.67	46.52	46.85	48.26	47.00	47.08	47.04	46.33	45.29	46.00
AL2O3	16.15	15.51	16.63	16.12	15.19	15.81	15.59	15.59	16.13	15.86
FE2O3	1.75	1.75	1.75	2.00	1.75	1.75	1.75	1.50	2.00	2.00
FEO	13.10	13.09	12.00	10.89	13.33	13.02	12.77	13.51	10.82	11.05
MGO	5.20	5.67	5.02	5.31	5.66	4.92	5.29	5.74	7.24	7.95
CAO	7.72	7.95	7.08	6.88	7.71	8.14	7.88	7.86	8.04	8.42
NA2O	3.52	3.39	4.10	3.86	3.50	3.42	3.79	3.11	3.45	4.58
K2O	0.81	0.77	0.78	1.19	0.82	0.83	0.84	0.75	0.65	0.50
TIO2	2.75	2.63	3.24	2.87	2.63	2.65	2.64	2.66	2.71	2.29
MNO	0.22	0.23	0.19	0.19	0.23	0.22	0.23	0.23	0.18	0.16
P2O5	0.34	0.32	0.47	0.48	0.35	0.32	0.32	0.32	0.39	0.26
TOTAL	99.69	99.28	99.44	99.26	99.65	99.61	99.56	99.10	96.90	99.09
PPM										
BA	388	414	352	506	432	300	444	401	83	78
NB	14	20	20	28	20	11	21	8	7	10
ZR	221	209	334	298	207	221	311	209	320	228
Y	33	34	47	43	37	33	32	33	25	23
SR	709	658	624	648	672	614	650	569	622	551
RB	13	15	12	20	16	16	15	15	18	6
ZN	87	88	64	63	82	96	72	88	78	86
CU	28	38	89	24	24	94	40	10	81	90
NI	5	8	27	3	0	17	4	22	145	140
CR	5	33	4	0	2	10	40	50	107	154
APPROXIMATE GRID REFERENCE										
NG	330288	330288	334301	334301	335300	335300	328296	329301	389230	389230

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

	153	154	155	156	157	158
	740208	740303	740703	750606	750708	750924
WEIGHT PERCENT						
SIO2	46.90	48.01	48.41	47.82	48.32	46.35
AL2O3	16.54	15.38	15.89	17.10	16.07	15.58
FE2O3	1.75	2.00	2.00	2.00	2.00	1.75
FEO	11.97	12.46	12.08	11.62	11.44	12.78
MGO	5.21	4.39	4.73	3.91	4.80	5.34
CAO	7.97	6.43	6.76	7.32	6.75	7.48
NA2O	3.71	4.60	4.37	5.15	4.55	3.85
K2O	1.00	0.98	0.70	0.65	0.73	0.63
TIO2	2.82	2.91	3.36	2.64	3.01	3.48
MNO	0.20	0.24	0.19	0.18	0.20	0.21
P2O5	0.34	0.59	0.54	0.28	0.61	0.56
TOTAL	99.74	99.37	100.37	98.67	99.75	99.43
PPM						
BA	350	462	232	196	234	220
NB	10	25	23	18	5-	16
ZR	173	421	354	318	166	374
Y	38	63	42	45	18	52
SR	657	726	780	641	438	785
RB	15	22	9	19	2	2
ZN	75	74	57	64	84	70
CU	95	43	30	53	85	78
NI	82	12	16	11	289	43
CR	20	5	19	10	696	82
APPROXIMATE GRID REFERENCE						
NG	346316	333318	314297	368275	336261	331307

TABLE 3. MUGEARITES

Analyses	Division
159-172	Olivine + plagioclase + magnetite microporphyritic
173-178	Olivine + magnetite microporphyritic with rare plagioclase microphenocrysts
179-181	Coarse-grained to doleritic
182-186	Rare plagioclase macrophenocrysts
187-188	Aphyric

TERTIARY LAVAS FROM WEST-CENTRAL SKYE MUGEARITES Table 3

	159	160	161	162	163	164	165	166	167	168
	740401	740302	740510	740513	740701	741101	750914	750208	750405	760301
WEIGHT PERCENT										
SIO2	51.00	49.55	49.00	48.36	50.05	51.73	49.73	49.85	47.19	50.82
AL2O3	16.00	15.20	16.37	17.07	16.79	16.42	16.39	16.81	16.96	14.74
FE2O3	2.50	2.25	2.25	2.25	2.00	2.50	2.00	2.25	2.00	2.50
FEO	10.55	12.10	11.12	10.52	11.30	10.19	9.90	10.93	11.99	11.53
MGO	3.72	3.86	3.51	4.34	3.79	2.82	4.12	3.38	4.21	3.40
CAO	6.16	5.99	6.38	7.07	6.29	5.86	6.85	6.15	7.19	6.46
NA2O	6.30	5.17	5.44	5.33	5.12	6.01	4.81	5.47	4.84	4.85
K2O	0.81	0.97	1.15	1.08	0.75	1.75	1.16	0.84	1.11	2.19
TIO2	2.50	2.53	2.61	3.03	2.72	1.69	2.79	2.23	3.34	2.02
MNO	0.27	0.23	0.24	0.19	0.26	0.25	0.19	0.24	0.20	0.30
P2O5	0.68	0.64	0.58	0.43	0.71	0.76	0.43	0.57	0.46	0.78
TOTAL	101.66	99.83	99.89	100.84	101.04	99.98	99.47	98.72	99.49	100.87
PPM										
BA	382	364	387	496	212	328	537	228	456	386
NB	15	23	23	28	32	13	29	19	24	22
ZR	485	463	457	373	456	593	310	552	348	571
Y	60	65	67	54	53	61	43	55	50	59
SR	562	582	666	721	670	620	681	738	681	722
RB	11	35	28	25	28	12	22	2	29	13
ZN	88	74	72	63	74	97	74	85	59	95
CU	15	27	33	56	12	9	43	0	40	19
NI	10	1	5	23	6	11	0	2	11	0
CR	0	0	0	7	0	7	0	1	0	0
APPROXIMATE GRID REFERENCE										
NG	302318	334318	338328	337325	313299	370300	330296	387297	335300	374284

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   MUGEARITES

	169	170	171	172	173	174	175	176	177	178
	7602	7624	740509	740905	750201	750202	750204	750703	750703	751801
WEIGHT PERCENT										
SIO2	49.52	49.00	48.47	49.19	50.25	50.74	50.91	48.46	48.58	52.10
AL2O3	15.92	15.80	16.48	17.81	16.73	15.97	16.00	16.60	16.59	15.91
FE2O3	2.25	2.25	2.25	2.25	2.25	2.50	2.75	2.25	2.25	2.75
FEO	10.51	9.98	11.97	9.51	10.58	10.06	9.68	10.59	10.63	8.89
MGO	4.50	4.44	3.35	3.74	3.89	3.44	2.78	4.11	4.25	3.16
CAO	6.53	7.39	6.48	6.59	5.35	5.27	5.46	6.95	7.00	5.45
NA2O	5.19	5.00	5.48	5.42	5.81	6.61	6.51	6.11	5.68	6.36
K2O	1.33	1.00	1.06	1.28	1.00	1.95	1.58	0.46	0.70	2.25
TIO2	3.12	3.19	2.61	2.73	1.97	2.19	2.05	2.77	2.73	1.92
MNO	0.19	0.18	0.24	0.18	0.25	0.28	0.26	0.15	0.15	0.24
P2O5	0.68	0.71	0.54	0.57	0.68	0.72	0.92	0.35	0.30	0.92
TOTAL	100.31	99.75	100.26	100.33	98.76	99.73	98.90	98.80	98.86	99.95
PPM										
BA	461	395	385	438	308	321	248	110	134	324
NB	29	31	32	30	19	14	14	11	9	18
ZR	433	303	444	413	613	602	615	414	416	607
Y	69	44	67	59	59	59	58	27	29	59
SR	625	600	633	638	708	598	543	1099	1209	611
RB	31	35	25	34	6	4	4	0	0	13
ZN	67	68	74	68	106	105	111	62	68	98
CU	26	34	31	27	0	0	0	24	21	0
NI	0	10	4	3	0	1	0	21	17	0
CR	0	0	0	2	0	0	0	3	1	0
APPROXIMATE GRID REFERENCE										
NG	344322	348295	338328	359310	378293	378293	381297	333255	333255	373310

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   MUGEARITES

	179	180	181	182	183	184	185	186	187	188
	740204	740205	740810	740407	750607	750608	750609	750923	750903	750917
WEIGHT PERCENT										
SIO2	48.97	48.29	48.84	47.18	49.21	49.08	48.78	50.70	50.78	51.37
AL2O3	17.11	16.75	16.97	18.06	16.48	17.05	17.08	15.62	16.00	16.26
FE2O3	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.50	2.25	2.50
FEO	9.89	9.50	10.13	10.54	11.85	12.20	11.00	10.49	8.77	7.86
MGO	4.37	4.67	3.83	3.92	4.45	3.62	3.92	4.06	3.68	3.54
CAO	6.71	6.29	7.34	6.80	5.36	6.66	6.29	6.29	6.25	6.45
NA2O	5.10	4.94	4.08	5.47	5.08	5.00	5.34	5.02	4.60	5.19
K2O	1.31	1.50	1.41	0.94	0.99	1.25	1.18	2.10	2.25	2.73
TIO2	2.84	2.90	2.84	3.21	2.62	2.47	2.53	2.61	2.71	2.19
MNO	0.19	0.18	0.19	0.18	0.21	0.19	0.19	0.20	0.20	0.20
P2O5	0.51	0.47	0.50	0.53	0.38	0.44	0.44	0.50	0.60	0.66
TOTAL	100.35	98.79	100.10	99.08	98.88	100.21	99.00	100.09	98.09	98.96
PPM										
BA	499	521	492	359	330	398	433	431	463	355
NB	31	32	28	27	25	29	33	27	25	15
ZR	405	419	358	281	404	426	405	450	399	557
Y	54	53	53	45	61	56	52	59	63	60
SR	641	639	624	505	640	779	698	637	699	653
RB	32	37	28	24	21	27	30	19	39	23
ZN	60	64	57	57	74	76	75	66	102	93
CU	41	28	27	63	19	36	34	36	10	8
NI	12	7	2	34	0	0	0	5	0	0
CR	0	10	13	10	0	0	0	5	0	0
APPROXIMATE GRID REFERENCE										
NG	349308	349310	351296	304314	370273	371273	369277	329306	328302	334300

TABLE 4. BENMOREITES AND TRACHYTES

Analyses	Division
189-190	Near aphyric benmoreite of Portnalong
191-194	Intermediate, sub-alkalic trachyte of Sleadale
195-197	Alkali trachyte of Cnoc Scarall

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BENMOREITES AND TRACHYTES   Table 4

	189	190	191	192	193	194	195	196	197
	77010	77011	750804	750805	750806	7625	7603	7604	7605
WEIGHT PERCENT									
SIO2	53.77	53.62	62.69	62.25	62.16	62.97	62.36	61.88	62.40
AL2O3	16.30	16.55	15.51	15.05	15.15	15.45	15.95	15.65	15.99
FE2O3	2.75	2.75	3.00	2.75	2.75	2.75	3.00	3.00	3.00
FEO	8.23	8.78	2.34	3.26	3.14	3.07	3.75	4.12	3.61
MGO	2.63	2.34	1.55	2.06	1.96	2.31	1.05	0.97	0.97
CAO	3.74	4.10	2.30	2.94	3.04	2.25	1.78	1.62	1.80
NA2O	6.23	6.27	5.08	4.95	4.97	4.86	6.11	5.98	6.31
K2O	2.50	2.61	4.36	3.87	3.81	4.12	4.66	4.51	4.44
TIO2	1.25	4.37	1.65	1.64	1.68	1.62	0.56	0.57	0.57
MNO	0.20	0.21	0.18	0.14	0.19	0.25	0.21	0.24	0.21
P2O5	0.79	0.85	0.66	0.58	0.63	0.61	0.47	0.50	0.47
TOTAL	98.39	99.15	99.58	99.85	99.85	100.60	100.32	99.50	100.17
PPM									
BA	1299	1273	3880	3852	3872	3929	1699	1737	1654
NB	62	62	17	18	16	16	76	73	76
ZR	393	405	379	470	472	380	595	597	599
Y	61	59	64	54	62	55	55	64	52
SR	742	717	614	614	625	520	340	352	350
RB	60	58	85	84	83	74	90	88	92
ZN	111	108	155	145	136	119	101	96	104
CU	2	0	0	0	0	0	0	0	0
NI	0	0	0	0	0	0	0	0	0
CR	0	0	0	0	0	0	0	0	0
APPROXIMATE GRID REFERENCE									
NG	350345	349343	328282	329281	330280	331285	385287	387285	389285

TABLE 5. INTRUSIONS

Analyses	Division
1-20	Dykes
21-29	Inclined sheets and thin sills
30	Creagan Dubh sill
31-32	Andesitic sill of Bualintur region
33-35	Cone-sheets
36-37	Gabbroic plug of west Loch Brittle
38-39	Outer Cuillin gabbros
40-41	Peridotite of An Sguman
42	Granophyre veining

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE Table 5

	1	2	3	4	5	6	7	8	9	10
	DY001	DY002	DY003	DY004	DY005	DY006	DY007	DY008	DY009	DY010
WEIGHT PERCENT										
SIO2	52.34	52.04	50.32	56.43	52.62	47.81	59.73	48.80	45.98	43.06
AL2O3	11.45	9.59	8.06	9.70	8.55	10.56	15.97	10.06	11.01	4.01
FE2O3	2.50	1.50	2.00	2.00	2.00	1.50	2.50	1.50	1.50	1.00
FEO	10.45	11.54	17.15	9.17	13.04	12.32	2.78	12.56	12.37	11.13
MGO	6.89	8.55	5.38	6.93	6.94	10.50	1.38	9.46	13.70	32.99
CAO	5.95	10.42	8.15	8.17	8.04	12.13	7.25	12.35	9.71	5.48
NA2O	4.49	3.06	3.56	3.70	3.86	2.33	4.67	2.27	2.11	0.43
K2O	2.55	0.54	0.51	1.54	0.99	0.02	3.93	0.08	0.30	0.00
TIO2	1.68	1.23	2.45	1.13	2.07	1.23	1.18	1.29	1.68	0.47
MNO	0.15	0.24	0.28	0.18	0.20	0.22	0.10	0.23	0.18	0.19
P2O5	0.38	0.01	0.19	0.04	0.23	0.00	0.20	0.00	0.08	0.00
TOTAL	98.83	98.72	98.05	98.99	98.54	98.62	99.69	98.60	98.62	98.76
PPM										
BA	897	181	213	522	542	38	2732	43	106	33
NB	8	5	10	7	9	0	15	0	4	0
ZR	235	89	150	164	170	55	381	64	137	17
Y	30	25	49	29	36	26	43	29	23	8
SR	523	194	154	249	413	107	550	120	389	51
RB	38	19	12	32	6	1	36	4	9	0
ZN	103	80	123	77	102	66	74	72	77	87
CU	65	157	94	86	129	186	2	171	131	52
NI	17	57	4	69	33	104	0	91	348	1895
CR	59	81	17	313	129	378	0	363	312	3115
APPROXIMATE GRID REFERENCE										
NG	378320	381317	382316	384316	351352	413200	412194	412191	412192	393167

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

	11	12	13	14	15	16	17	18	19	20
	DY011	DY012	DY013	DY014	DY015	DY016	DY017	7638	7620	DY020
WEIGHT PERCENT										
SIO2	47.72	49.38	44.99	46.60	50.30	46.86	47.21	48.46	41.25	51.20
AL2O3	15.92	15.13	12.03	14.90	13.97	13.99	15.83	15.85	10.62	14.27
FE2O3	1.50	1.25	1.00	1.25	1.50	1.25	1.25	1.50	1.00	2.25
FEO	10.83	11.44	11.87	9.68	9.23	11.45	10.04	10.97	8.79	9.05
MGO	7.43	6.92	15.43	7.62	6.41	8.70	7.90	5.99	26.25	3.46
CAO	9.52	10.10	8.93	13.15	9.93	12.20	11.88	8.25	6.27	7.71
NA2O	3.06	2.35	1.41	2.20	2.61	2.28	2.32	3.39	0.75	5.02
K2O	0.58	0.45	0.04	0.24	0.58	0.15	0.11	0.42	0.01	1.88
TIO2	1.25	1.00	1.03	1.03	1.02	1.19	0.90	1.59	0.41	1.68
MNO	0.20	0.20	0.17	0.13	0.20	0.20	0.19	0.18	0.14	0.15
P2O5	0.20	0.37	0.21	0.05	0.30	0.18	0.10	0.43	0.67	0.32
TOTAL	98.21	98.59	97.21	96.85	96.05	98.45	97.73	98.25	97.14	96.99
PPM										
BA	170	84	25	15	176	16	22	297	33	563
NB	4	2	1	0	3	0	1	6	5	20
ZR	162	68	20	50	91	65	93	86	23	378
Y	30	25	13	22	25	25	24	27	9	49
SR	372	165	77	140	189	139	112	305	52	553
RB	8	3	2	2	5	1	2	9	2	31
ZN	80	80	62	75	77	79	78	83	59	113
CU	120	149	103	140	143	165	161	63	120	56
NI	151	126	203	75	54	130	124	99	1350	10
CR	50	202	762	320	190	412	400	106	2674	15
APPROXIMATE GRID REFERENCE										
NG	325345	312300	334253	335356	335356	335355	334351	326345	438191	335356

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

	21	22	23	24	25	26	27	28	29	30
	7408-I	741105	750502	750507	750511	750603	750701	751701	760305	7615
WEIGHT PERCENT										
SIO2	46.37	46.47	48.16	47.58	46.90	48.85	47.42	50.00	47.58	47.69
AL2O3	15.41	15.90	14.37	14.62	15.99	14.88	15.72	15.25	15.98	16.11
FE2O3	1.25	1.25	1.25	1.25	1.00	1.25	1.00	1.50	1.25	1.50
FEO	10.75	9.96	11.44	11.05	10.04	9.49	10.09	8.62	9.57	8.19
MGO	7.17	8.85	7.16	7.32	9.44	8.23	8.06	6.93	7.42	7.49
CAO	11.23	12.85	10.91	11.32	11.43	11.74	11.54	10.70	10.96	12.40
NA2O	2.33	2.05	2.23	2.32	1.65	2.22	1.71	2.52	2.06	2.90
K2O	0.08	0.05	0.22	0.05	0.05	0.04	0.09	0.62	0.34	0.24
TIO2	1.04	0.95	1.38	1.21	0.93	1.02	1.04	1.07	1.52	1.17
MNO	0.22	0.19	0.21	0.23	0.20	0.20	0.21	0.18	0.19	0.19
P2O5	0.16	0.22	0.16	0.15	0.12	0.12	0.12	0.15	0.17	0.32
TOTAL	97.20	99.85	98.74	98.33	98.85	99.12	98.12	98.50	98.10	99.11
PPM										
BA	28	10	27	2	19	15	0	139	419	50
NB	0	1	2	0	2	0	2	2	3	7
ZR	52	49	70	58	47	49	43	89	125	68
Y	25	26	28	24	20	22	23	24	25	16
SR	114	122	133	106	113	107	117	203	152	256
RB	0	0	0	0	0	0	0	5	6	2
ZN	72	65	65	81	65	58	76	67	70	49
CU	176	163	193	190	181	162	198	146	139	90
NI	100	173	97	65	207	115	109	64	100	248
CR	378	423	378	396	427	456	412	216	260	120

APPROXIMATE GRID REFERENCE

	21	22	23	24	25	26	27	28	29	30
NG	352293	361295	353274	349260	345270	368268	359268	364204	355246	349243

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

	31	32	33	34	35	36	37	38	39	40
	7626	7629	751005	760802	760813	751105	751105	760803	760808	760806
WEIGHT PERCENT										
SIO2	54.29	54.26	45.35	47.24	47.18	48.80	51.48	50.10	47.28	41.23
AL2O3	14.35	14.52	15.53	13.36	11.34	15.00	14.94	8.88	11.85	1.06
FE2O3	1.75	1.75	1.50	1.50	1.50	1.50	1.50	2.00	1.50	1.00
FEO	8.08	8.30	11.54	10.12	11.16	9.07	8.71	13.86	8.73	9.81
MGO	4.87	4.70	10.49	11.57	12.38	9.07	5.55	6.06	15.86	43.10
CAO	7.98	8.32	12.40	11.99	12.43	12.06	12.15	8.82	11.54	3.17
NA2O	3.74	3.51	1.09	1.89	1.52	1.96	2.53	4.75	1.41	0.07
K2O	1.12	1.18	0.49	0.08	0.07	0.17	0.66	0.53	0.09	0.00
TIO2	1.65	1.60	0.91	0.95	0.97	1.07	1.21	2.95	0.63	0.36
MNO	0.22	0.22	0.21	0.18	0.20	0.17	0.17	0.26	0.16	0.17
P2O5	0.63	0.64	0.07	0.00	0.02	0.09	0.09	0.24	0.00	0.00
TOTAL	99.58	99.92	99.38	98.88	99.77	98.96	98.99	98.45	99.02	99.97
PPM										
BA	337	371	137	10	58	130	136	320	96	33
NB	9	12	0	3	0	1	0	8	2	3
ZR	283	285	51	54	46	71	89	191	33	12
Y	40	38	29	23	24	23	30	54	11	4
SR	301	245	245	120	111	187	222	283	149	43
RB	37	17	4	3	4	1	15	11	4	2
ZN	100	82	79	76	80	59	58	116	96	72
CU	44	42	164	155	169	161	184	122	86	11
NI	10	10	128	200	151	94	33	42	362	2995
CR	0	5	379	458	416	523	79	38	616	5235
APPROXIMATE GRID REFERENCE										
NG	399207	369196	412225	431196	435188	397198	397198	430194	434191	434192

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

	41	42
	760809	760816
WEIGHT PERCENT		
SIO2	42.62	67.11
AL2O3	2.45	13.87
FE2O3	1.00	2.53
FEO	9.86	4.19
MGO	35.94	1.55
CAO	5.07	2.08
NA2O	0.36	6.06
K2O	0.91	0.96
TIO2	0.41	0.90
MNO	0.17	0.11
P2O5	0.01	0.19
TOTAL	98.91	99.52
PPM		
BA	44	2691
NB	2	19
ZR	18	540
Y	7	59
SR	47	344
RB	3	12
ZN	73	86
CU	42	85
NI	2326	1
CR	3566	42
APPROXIMATE GRID REFERENCE		
NG	435189	438191

TABLE 6. INTERFLOW HORIZONS

Analyses	Division
1-2	Bole and associated amygdaloid derived from olivine + spinel porphyritic basalt
3	'Pisolitic' bole
4	Weathered basalt
5-8	Ben Scaalan boles and ironstones
9	Bole derived from olivine + spinel porphyritic basalt

TERTIARY INTERFLOW HORIZONS FROM WEST-CENTRAL SKYE Table 6

	1	2	3	4	5	6	7	8	9
	750302	750303	750305	750306	750307	750308	750309	750310	750310
WEIGHT PERCENT									
SIO2	34.27	43.67	35.62	40.39	51.54	26.40	46.57	7.01	41.13
AL2O3	26.53	18.53	28.15	20.99	27.77	20.85	24.66	20.63	24.20
FE2O3	27.60	1.75	13.23	1.25	1.75	1.50	2.50	1.00	19.85
FEO	0.00	11.47	0.00	14.91	6.28	36.05	11.93	60.68	0.00
MGO	1.61	8.83	1.31	6.11	2.49	2.23	1.48	1.75	2.29
CAO	0.64	4.94	6.29	9.94	2.18	1.32	1.06	0.85	0.50
NA2O	6.10	4.07	5.43	2.02	3.78	3.62	6.94	0.00	5.57
K2O	0.48	0.60	0.07	0.25	0.24	0.10	0.31	0.46	0.76
TIO2	5.74	1.94	4.51	1.91	3.30	3.54	3.04	0.01	6.34
MNO	0.08	0.16	0.03	0.19	0.06	0.20	0.06	0.20	0.03
P2O5	0.08	0.11	0.03	0.10	0.10	0.12	0.08	0.28	0.03
TOTAL	102.73	96.07	99.77	98.05	99.49	95.93	98.63	92.67	100.71
PPM									
BA	65	41	52	117	36	138	242	1	168
NB	21	6	78	2	28	20	88	1	111
ZR	176	128	783	154	887	311	1190	31	862
Y	27	23	12	17	67	28	53	19	43
SR	57	136	333	642	145	115	165	26	170
RB	3	3	3	0	2	4	4	9	6
ZN	105	87	54	95	152	171	108	101	64
CU	180	66	120	52	30	152	496	103	38
NI	132	269	42	178	81	122	37	40	119
CR	2008	285	963	442	32	727	226	106	2532
APPROXIMATE GRID REFERENCE									
NG	309308	309308	312299	379190	335260	335260	335260	335260	338360

TABLE 7. CENTRAL COMPLEX AUREOLE

Analyses	Division	Description
1-3,37-39	3c	Inner zone, high-grade basaltic hornfels
9-10,42-44	3b	Inner zone, extensively altered and incipient hornfels
8,11-16,40-41	3a	Inner zone, extensively altered, olivine coronas
17-23	2	Middle zone, amphibole-rich alteration. Green rocks
4-7,24-36	1b	Outer zone, considerably altered olivine as mica/talc pseudomorphs
Normal successions e.g. Sk751501-6 Sk751301-07 Sk760401-10	1a	Outer zone, olivine may be fresh but usually as iddingsitic or serpentinous pseudomorphs. Some zeolites present in amygdales

TERTIARY LAVAS FROM WEST-CENTRAL SKYE CENTRAL COMPLEX AUREOLE **Table 7**

	1	2	3	4	5	6	7	8	9	10
	751004	751006	751007	751101	751101	751103	751104	751604	751608	751611
WEIGHT PERCENT										
SIO2	47.24	44.79	44.60	46.71	46.69	46.83	46.73	50.25	45.88	46.98
AL2O3	15.24	14.55	16.57	15.41	15.26	15.67	15.59	14.75	14.65	14.83
FE2O3	1.50	1.50	1.50	1.50	1.50	1.50	1.50	2.00	1.50	1.50
FEO	9.30	11.25	11.76	10.22	9.50	11.03	10.11	10.42	11.25	10.03
MGO	9.33	14.59	11.97	10.85	11.70	9.58	10.90	5.13	10.04	8.33
CAO	12.20	9.60	10.10	10.37	11.06	9.97	9.57	10.18	11.83	12.91
NA2O	2.30	1.27	1.80	2.19	2.05	2.43	2.66	3.23	1.60	2.24
K2O	0.21	0.41	0.25	0.50	0.33	0.51	0.55	1.07	0.16	0.24
TIO2	1.39	0.82	1.61	1.16	1.10	1.29	1.29	1.47	1.56	1.51
MNO	0.16	0.19	0.14	0.15	0.16	0.17	0.17	0.18	0.17	0.18
P2O5	0.06	0.11	0.10	0.13	0.09	0.14	0.14	0.13	0.07	0.06
TOTAL	98.93	99.08	100.40	99.20	99.24	99.12	99.21	98.81	98.71	98.86
PPM										
BA	30	171	136	224	84	233	266	465	34	68
NB	0	1	0	3	4	3	1	5	1	2
ZR	47	47	67	79	73	93	90	190	73	125
Y	11	14	8	18	16	21	20	34	21	12
SR	265	234	350	361	256	334	393	432	236	278
RB	0	4	2	4	4	6	5	21	1	3
ZN	48	88	70	73	68	86	76	108	82	83
CU	56	62	20	81	118	96	99	131	132	85
NI	109	613	387	109	224	106	217	38	129	158
CR	430	1168	839	273	27	98	332	157	412	252
APPROXIMATE GRID REFERENCE										
NG	412225	412225	412225	406204	406204	403201	401200	422204	422204	414214

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   CENTRAL COMPLEX AUREOLE

	11	12	13	14	15	16	17	18	19	20
	751901	751902	751903	751904	751905	751906	760201	760202	760203	760204
WEIGHT PERCENT										
SIO2	48.35	48.70	47.07	44.24	45.97	46.77	46.37	46.17	47.11	47.42
AL2O3	14.14	17.18	17.76	13.90	14.26	14.86	11.55	14.55	9.93	11.81
FE2O3	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
FEO	9.79	8.32	7.93	11.06	11.45	10.42	11.77	11.06	11.50	11.62
MGO	8.74	6.67	6.35	13.75	9.68	9.14	13.75	12.56	14.34	13.55
CAO	11.94	12.51	14.85	10.41	12.45	11.80	9.73	8.84	10.50	7.91
NA2O	1.93	2.66	2.22	1.58	1.30	2.41	2.37	2.12	2.15	2.69
K2O	0.97	0.17	0.17	0.44	0.10	0.18	0.20	0.51	0.15	0.60
TIO2	1.24	1.12	1.05	1.50	1.75	1.47	1.23	1.20	1.32	1.36
MNO	0.20	0.16	0.14	0.19	0.17	0.17	0.19	0.18	0.19	0.19
P2O5	0.06	0.07	0.03	0.09	0.06	0.07	0.02	0.08	0.02	0.07
TOTAL	98.87	99.06	99.07	98.75	98.69	98.79	98.68	98.77	98.72	98.72
PPM										
BA	135	38	48	185	58	95	203	294	173	299
NB	8	3	2	5	3	4	2	2	3	1
ZR	232	77	69	136	92	98	77	87	78	78
Y	33	24	21	29	24	23	18	20	21	20
SR	186	265	257	218	207	251	288	351	420	402
RB	2	1	3	8	0	2	4	7	2	11
ZN	82	63	53	92	84	72	73	71	72	81
CU	117	113	87	98	150	155	72	86	96	99
NI	399	251	540	834	491	383	232	163	262	293
CR	106	67	54	358	133	159	692	321	693	722
APPROXIMATE GRID REFERENCE										
NG	409225	409225	410225	410225	410225	410225	413202	413202	413199	413199

TERTIARY LAVAS FROM WEST-CENTRAL SKYE CENTRAL COMPLEX AUREOLE

	21	22	23	24	25	26	27	28	29	30
	760205	760207	760208	760501	760502	760503	760504	760505	760509	760510
WEIGHT PERCENT										
SIO2	48.43	45.62	46.24	46.26	45.23	45.83	47.83	47.48	46.85	45.71
AL2O3	12.22	10.43	10.24	12.96	13.26	11.50	11.22	11.20	12.32	12.50
FE2O3	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
FEO	12.70	12.66	12.12	11.50	12.80	14.07	12.29	11.43	12.68	13.46
MGO	10.22	13.99	14.59	13.04	12.00	10.68	10.32	12.37	10.79	11.26
CAO	7.99	10.32	11.13	10.16	8.44	9.19	9.72	10.35	9.30	8.32
NA2O	2.27	1.98	1.57	1.73	2.88	2.97	3.36	2.91	2.49	2.34
K2O	1.22	0.28	0.04	0.21	0.34	0.38	0.27	0.06	0.51	1.10
TIO2	1.62	1.56	1.03	1.15	1.84	2.01	1.85	1.24	1.88	1.96
MNO	0.21	0.21	0.19	0.19	0.22	0.22	0.21	0.20	0.19	0.17
P2O5	0.21	0.04	0.00	0.01	0.09	0.09	0.06	0.00	0.06	0.19
TOTAL	98.59	98.59	98.65	98.71	98.60	98.44	98.63	98.74	98.57	98.51
PPM										
BA	862	282	14	120	260	443	287	61	298	655
NB	6	2	2	3	3	4	3	0	5	7
ZR	126	94	53	68	107	127	106	69	145	167
Y	25	18	22	18	23	26	21	17	25	26
SR	447	373	167	314	423	461	505	334	471	533
RB	12	5	3	5	8	5	5	3	8	15
ZN	86	83	82	77	109	109	91	76	78	106
CU	64	37	133	69	276	76	189	103	5	12
NI	81	228	577	195	163	125	83	196	15	13
CR	120	379	1392	471	371	282	489	282	17	42
APPROXIMATE GRID REFERENCE										
NG	413197	413195	413195	428182	431181	431181	431181	433180	434168	438169

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   CENTRAL COMPLEX AUREOLE

	31	32	33	34	35	36	37	38	39	40
	760511	760512	760513	760514	760516	760517	760804	760805	760807	760811
WEIGHT PERCENT										
SIO2	52.30	51.09	46.36	46.79	47.40	47.15	46.23	44.42	47.18	47.36
AL2O3	13.43	12.17	12.49	10.95	12.44	12.99	12.29	12.69	13.86	8.62
FE2O3	2.00	2.00	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
FEO	10.83	11.77	15.01	12.29	11.14	10.67	10.68	13.90	9.22	11.96
MGO	4.96	5.54	8.38	13.39	12.12	11.99	14.11	13.68	12.15	15.72
CAO	5.61	6.99	7.30	10.12	9.87	10.86	10.23	8.46	11.61	10.24
NA2O	3.78	3.88	3.30	1.60	2.40	2.11	2.18	2.20	2.38	1.67
K2O	2.72	2.06	0.71	0.15	0.34	0.12	0.14	0.20	0.03	0.24
TIO2	2.44	2.47	2.65	1.41	1.31	1.22	1.24	1.20	0.88	1.16
MNO	0.16	0.20	0.21	0.19	0.19	0.18	0.19	0.21	0.18	0.20
P2O5	0.58	0.52	0.42	0.03	0.04	0.01	0.02	0.06	0.00	0.00
TOTAL	98.81	98.69	98.33	98.62	98.75	98.80	98.81	98.46	98.99	98.67
PPM										
BA	1174	929	676	123	266	109	88	151	108	204
NB	16	14	12	2	3	4	3	0	2	1
ZR	[illegible]33	305	298	97	103	80	42	31	15	70
Y	34	38	49	18	19	18	15	12	11	16
SR	728	633	459	210	437	258	215	292	374	264
RB	44	31	8	3	6	0	4	4	1	5
ZN	119	118	107	91	76	81	77	100	67	124
CU	0	0	21	65	106	130	10	85	41	141
NI	0	0	30	161	275	216	573	479	304	376
CR	0	0	233	341	315	348	856	788	855	758
APPROXIMATE GRID REFERENCE										
NG	440170	440170	441170	442171	442172	442173	432195	432195	431193	436190

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   CENTRAL COMPLEX AUREOLE

	41	42	43	44
	760812	760814	760815	760818
WEIGHT PERCENT				
SIO2	48.30	50.93	47.91	47.83
AL2O3	8.50	10.69	12.78	13.56
FE2O3	1.50	1.50	1.50	1.50
FEO	11.39	8.51	11.32	11.17
MGO	14.36	11.86	11.21	10.95
CAO	10.96	11.16	9.29	9.87
NA2O	2.02	3.01	2.57	2.46
K2O	0.24	0.18	0.50	0.11
TIO2	1.19	1.34	1.41	1.10
MNO	0.20	0.19	0.18	0.17
P2O5	0.09	0.00	0.00	0.25
TOTAL	98.75	99.07	98.67	98.76
PPM				
BA	143	113	225	220
NB	2	2	3	1
ZR	66	64	103	87
Y	17	17	21	21
SR	310	333	314	337
RB	5	3	13	1
ZN	99	89	82	69
CU	117	123	81	159
NI	370	149	185	143
CR	856	552	283	159
APPROXIMATE GRID REFERENCE				
NG	436190	438188	438191	438177

APPENDIX 2

C.I.P.W. Normative data

Table 1. Basalt lavas

2. Hawaiite lavas
3. Mugearite lavas
4. Benmoreite and Trachyte lavas
5. Intrusions

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

Table 1

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740106	740607	750301	750602	750604	751211	751212	751501	7706	7616	7717	740305
ORTHOCLASE	5.2	3.6	3.0	1.3	2.2	1.0	1.0	2.2	1.1	2.3	1.0	1.9
ALBITE	21.6	16.3	17.7	19.9	22.0	14.0	14.4	17.8	16.2	16.3	16.6	22.0
ANORTHITE	25.6	32.0	30.0	28.9	28.2	21.4	21.7	28.8	29.3	31.0	28.3	30.1
NEPHELINE	4.7	1.1	0.3	0.2	0.0	1.4	1.2	1.6	1.1	2.4	0.1	0.0
DIOPSIDE	10.5	11.4	9.2	17.1	15.0	20.3	20.0	16.2	14.0	13.3	13.7	12.5
HYPERSTHENE	0.0	0.0	2.8	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	4.7
OLIVINE	25.9	30.6	32.3	27.9	23.3	37.0	36.8	28.3	33.4	30.0	35.6	21.5
MAGNETITE	2.9	1.9	1.9	1.8	1.8	1.9	1.9	2.2	1.9	1.8	1.8	1.5
ILMENITE	2.5	2.7	2.7	2.5	2.7	2.5	2.6	2.6	2.6	2.4	2.4	4.6
APATITE	1.0	0.5	0.5	0.4	0.5	0.4	0.4	0.3	0.5	0.5	0.4	0.8
DIFF. INDEX	31.5	21.0	20.6	21.4	24.2	16.4	16.6	21.6	18.4	21.0	17.7	23.9
NA/(NA+K)	0.86	0.84	0.86	0.94	0.91	0.94	0.95	0.91	0.95	0.91	0.95	0.92
(NA+K)/AL	0.42	0.26	0.27	0.28	0.31	0.30	0.30	0.30	0.26	0.28	0.25	0.30
F3/(F2+F3)	0.17	0.10	0.09	0.10	0.12	0.10	0.10	0.12	0.10	0.09	0.10	0.08

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740306	740402	741001	741002	741103	750118	750203	750501	751206	751207	751208	751209
ORTHOCLASE	2.1	2.2	3.2	2.4	3.4	2.2	3.3	2.6	2.6	2.9	2.2	2.1
ALBITE	21.4	21.8	21.4	22.6	25.5	19.7	22.0	25.4	22.4	21.4	19.7	24.6
ANORTHITE	32.1	29.4	31.3	31.9	27.4	31.0	24.7	31.3	27.5	25.5	27.9	28.9
NEPHELINE	0.0	0.0	0.7	0.0	0.0	1.7	6.8	0.4	0.1	6.1	1.2	2.1
DIOPSIDE	11.0	12.6	9.8	10.1	14.0	13.0	15.4	10.9	12.9	14.6	12.2	11.0
HYPERSTHENE	4.7	2.7	0.0	6.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OLIVINE	21.1	25.7	27.1	19.1	21.3	25.7	20.2	21.8	27.0	22.1	29.5	22.7
MAGNETITE	1.9	2.2	2.2	2.2	2.2	2.2	2.5	2.2	2.3	2.6	1.8	2.2
ILMENITE	4.8	2.8	3.6	4.0	4.6	4.0	4.5	4.7	4.6	4.2	4.8	5.6
APATITE	0.9	0.6	0.8	0.7	0.8	0.5	0.7	0.7	0.7	0.5	0.6	0.8
DIFF. INDEX	23.6	24.0	25.3	25.0	28.9	23.7	32.0	28.3	25.1	30.4	23.0	28.8
NA/(NA+K)	0.91	0.91	0.86	0.91	0.89	0.92	0.92	0.91	0.90	0.92	0.92	0.94
(NA+K)/AL	0.28	0.30	0.34	0.29	0.36	0.30	0.45	0.33	0.33	0.42	0.31	0.36
F3/(F2+F3)	0.06	0.11	0.11	0.11	0.11	0.10	0.13	0.10	0.10	0.12	0.07	0.09

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	751210	751214	751702	751703	760306	760307	760308	740101	740104	740201	740502	740507
ORTHOCLASE	1.9	1.5	1.3	1.3	2.3	2.8	1.3	4.2	1.4	2.7	2.1	2.9
ALBITE	23.7	22.2	26.1	20.7	20.6	18.1	22.8	29.0	17.8	24.4	23.2	21.5
ANORTHITE	25.3	25.8	26.5	27.3	22.6	22.3	33.8	20.1	32.7	27.2	32.1	28.0
NEPHELINE	5.6	5.7	3.6	9.0	7.8	5.3	0.0	1.5	1.8	3.4	2.9	6.6
DIOPSIDE	12.7	15.2	13.3	14.2	16.2	17.6	11.4	17.5	15.8	14.1	13.7	13.5
OLIVINE	22.4	22.1	20.9	20.6	23.9	26.7	23.6	19.1	24.4	20.3	19.4	20.2
MAGNETITE	2.6	2.6	2.6	2.6	2.6	2.2	1.9	2.6	2.2	2.3	2.2	2.6
ILMENITE	5.1	4.4	5.1	3.9	3.9	4.7	4.5	5.1	3.3	4.7	3.8	4.2
APATITE	0.8	0.5	0.7	0.4	0.3	0.3	0.6	0.8	0.6	0.7	0.6	0.6
DIFF. INDEX	31.2	29.4	31.0	31.0	30.6	26.2	24.2	34.6	21.0	30.6	28.2	31.0
NA/(NA+K)	0.95	0.96	0.96	0.97	0.94	0.91	0.95	0.89	0.94	0.92	0.94	0.92
(NA+K)/AL	0.43	0.41	0.40	0.43	0.47	0.42	0.27	0.49	0.27	0.39	0.33	0.41
F3/(F2+F3)	0.11	0.11	0.11	0.12	0.11	0.08	0.09	0.14	0.10	0.11	0.10	0.12

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740508	740801	740901	740904	741104	750614	750707	751001	751502	751502	751704	760304
ORTHOCLASE	3.4	1.8	2.0	2.0	2.2	1.1	3.3	3.7	1.7	1.7	3.0	1.8
ALBITE	21.8	23.8	15.8	15.5	21.1	27.1	22.3	20.2	22.3	22.5	23.4	24.0
ANORTHITE	30.9	32.9	31.9	31.9	33.6	29.5	28.8	28.3	26.0	26.0	27.0	30.8
NEPHELINE	3.6	0.1	6.5	6.7	4.2	0.2	0.0	1.3	6.8	6.7	4.3	0.0
DIOPSIDE	12.4	10.6	15.4	15.7	9.3	12.2	13.9	19.0	16.3	16.3	17.1	14.5
HYPERSTHENE	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	3.2
OLIVINE	21.2	23.2	22.2	22.1	22.7	22.8	24.0	21.7	19.1	18.7	17.3	18.2
MAGNETITE	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.6	2.9	2.6	2.2
ILMENITE	3.8	4.7	3.4	3.4	3.8	4.1	3.5	3.1	4.6	4.5	4.7	4.7
APATITE	0.7	0.6	0.6	0.5	0.9	0.6	0.6	0.5	0.5	0.5	0.6	0.6
DIFF. INDEX	28.8	25.7	24.3	24.2	27.5	28.5	25.7	25.2	30.8	31.0	30.6	25.8
NA/(NA+K)	0.90	0.93	0.94	0.94	0.93	0.96	0.88	0.87	0.96	0.96	0.92	0.93
(NA+K)/AL	0.35	0.29	0.33	0.33	0.33	0.34	0.32	0.33	0.43	0.43	0.40	0.31
F3/(F2+F3)	0.11	0.09	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.14	0.13	0.10

TERTIARY LAVAS FROM WEST-CENTRAL SKYE BASALTS

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740209	751407	760401	751201	751201	751202	751203	751215	751216	751218	740103	740105
ORTHOCLASE	6.3	0.9	2.7	1.6	2.3	3.8	1.8	1.3	1.3	1.0	1.4	1.4
ALBITE	32.7	16.6	21.5	16.3	17.2	23.0	17.3	19.6	19.8	25.0	24.8	22.0
ANORTHITE	26.2	39.8	22.1	31.6	31.0	25.5	32.1	29.2	28.4	25.9	30.9	33.8
NEPHELINE	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.7	0.0	2.6	0.0
DIOPSIDE	8.2	27.4	22.5	22.6	19.3	21.2	18.9	26.2	26.5	23.2	12.1	5.7
HYPERSTHENE	0.0	0.4	7.8	4.7	6.9	1.9	8.8	0.0	0.0	13.8	0.0	0.0
OLIVINE	15.4	10.8	19.0	17.7	16.2	18.1	15.8	17.9	16.9	4.6	21.0	30.2
MAGNETITE	2.9	1.8	1.8	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
ILMENITE	4.7	2.2	2.5	2.9	2.7	4.0	2.7	2.9	3.0	4.0	4.4	3.7
APATITE	1.4	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.4	0.7	0.6
DIFF. INDEX	41.2	17.5	24.2	17.9	19.6	26.8	19.2	21.4	22.8	26.0	28.7	24.0
NA/(NA+K)	0.86	0.95	0.89	0.92	0.89	0.87	0.91	0.94	0.95	0.97	0.96	0.94
(NA+K)/AL	0.46	0.19	0.37	0.23	0.25	0.36	0.24	0.28	0.31	0.35	0.35	0.28
F3/(F2+F3)	0.15	0.13	0.10	0.11	0.11	0.10	0.11	0.12	0.11	0.11	0.10	0.10

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	760404	740606	740608	750105	750111	751302	750807	750808	750809	750810	750811	750812
ORTHOCLASE	2.2	4.4	5.5	1.4	6.1	2.7	0.5	0.6	0.7	0.5	0.6	0.5
ALBITE	25.1	24.1	17.6	22.2	25.1	21.2	14.8	17.6	12.5	16.7	14.9	15.0
ANORTHITE	21.6	29.6	35.0	34.0	29.1	29.1	36.2	33.3	34.9	36.2	35.9	35.5
NEPHELINE	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
DIOPSIDE	23.0	12.7	10.3	5.8	6.0	11.7	21.1	24.8	22.5	21.8	21.6	22.5
HYPERSTHENE	4.5	3.8	22.3	0.0	9.6	0.0	8.6	3.3	9.3	4.9	7.2	6.1
OLIVINE	18.9	19.0	3.2	30.0	15.8	28.2	15.2	16.3	16.5	16.2	16.3	17.0
MAGNETITE	2.2	2.2	1.8	1.8	2.2	2.2	1.5	1.9	1.5	1.8	1.5	1.5
ILMENITE	2.4	3.5	3.6	3.7	4.5	4.4	1.7	1.9	1.7	1.6	1.7	1.8
APATITE	0.1	0.6	0.8	0.6	0.6	0.5	0.3	0.3	0.3	0.2	0.3	0.3
DIFF. INDEX	27.3	28.5	23.1	24.1	31.1	24.0	15.3	18.2	13.2	17.2	15.5	15.5
NA/(NA+K)	0.92	0.85	0.77	0.94	0.81	0.89	0.97	0.97	0.95	0.97	0.96	0.97
(NA+K)/AL	0.40	0.34	0.26	0.28	0.36	0.30	0.18	0.22	0.17	0.20	0.19	0.19
F3/(F2+F3)	0.11	0.12	0.10	0.09	0.10	0.10	0.09	0.10	0.08	0.10	0.09	0.08

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BASALTS

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	750813	750814	750906	750907	750908	750909	750910	750911	750912	750915
ORTHOCLASE	0.5	0.4	0.6	0.5	0.5	0.8	0.6	1.2	0.8	0.9
ALBITE	14.8	15.6	15.8	17.3	14.1	17.0	15.4	16.4	17.3	17.0
ANORTHITE	36.7	37.8	33.4	34.0	34.5	33.9	35.3	33.9	33.3	32.9
DIOPSIDE	22.2	20.4	26.2	25.1	22.6	23.3	20.3	23.5	23.3	23.7
HYPERSTHENE	7.8	8.3	7.2	3.8	11.8	5.9	9.5	9.0	7.2	9.6
OLIVINE	14.6	14.0	12.9	15.4	12.7	14.8	15.0	11.6	13.7	11.7
MAGNETITE	1.5	1.5	1.5	1.8	1.5	1.8	1.5	1.8	1.8	1.8
ILMENITE	1.7	1.7	2.1	1.8	2.1	2.1	2.1	2.0	2.3	2.0
APATITE	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.3	0.3
DIFF. INDEX	15.2	16.1	15.4	17.8	14.5	17.8	16.0	17.6	18.1	17.9
NA/(NA+K)	0.97	0.98	0.97	0.97	0.97	0.96	0.96	0.94	0.96	0.95
(NA+K)/AL	0.15	0.18	0.21	0.22	0.18	0.22	0.19	0.22	0.22	0.22
F3/(F2+F3)	0.09	0.09	0.08	0.10	0.08	0.10	0.08	0.10	0.10	0.10

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

Table 2

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740108	740202	740203	740206	740207	740301	740304	740308	740406	740512	740802	741107
ORTHOCLASE	4.3	3.8	6.0	8.5	8.1	5.7	6.7	6.3	4.0	6.5	3.8	3.8
ALBITE	39.5	31.9	33.0	35.1	33.5	34.7	33.9	32.5	30.1	32.4	34.2	26.6
ANORTHITE	20.9	26.3	22.1	23.6	23.5	22.5	22.0	24.8	25.8	23.9	26.4	31.5
NEPHELINE	0.0	0.0	4.3	0.0	0.0	0.0	2.1	0.8	0.0	4.0	0.0	0.0
DIOPSIDE	6.0	8.4	8.9	5.5	6.0	4.8	6.7	8.0	9.6	8.8	6.3	3.3
HYPERSTHENE	4.8	4.2	0.0	4.4	10.3	8.2	0.0	0.0	8.4	0.0	1.8	15.6
OLIVINE	14.4	15.4	15.5	12.9	8.9	14.5	16.4	17.3	12.3	14.1	17.4	10.6
MAGNETITE	2.9	2.5	3.0	2.9	2.9	2.6	2.9	2.6	2.6	2.9	2.5	2.2
ILMENITE	5.8	6.3	6.1	5.8	5.6	5.4	6.0	6.5	6.2	6.1	6.4	5.3
APATITE	1.3	1.1	1.1	1.2	1.2	1.5	1.3	1.2	1.0	1.0	1.2	1.0
DIFF. INDEX	43.8	35.7	43.3	43.6	41.6	40.5	42.8	39.6	34.1	43.2	38.0	30.4
NA/(NA+K)	0.91	0.90	0.88	0.81	0.81	0.87	0.86	0.85	0.89	0.86	0.90	0.88
(NA+K)/AL	0.52	0.42	0.53	0.49	0.48	0.49	0.52	0.46	0.41	0.51	0.43	0.34
F3/(F2+F3)	0.13	0.11	0.14	0.15	0.15	0.11	0.13	0.11	0.11	0.14	0.11	0.09

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	741108	741112	750104	750105	750408	750506	750801	750815	750816	750817	750819	750918
ORTHOCLASE	5.5	6.7	6.5	6.1	3.8	5.8	5.3	4.4	4.6	4.5	5.0	6.6
ALBITE	26.2	37.2	34.9	32.5	33.0	32.3	28.3	29.1	30.0	29.7	31.4	33.2
ANORTHITE	30.5	25.0	19.7	25.5	26.7	25.7	25.0	23.2	25.0	23.7	25.4	24.0
NEPHELINE	0.0	0.4	3.1	0.0	0.3	0.0	2.6	2.8	0.6	2.0	0.3	0.0
DIOPSIDE	1.5	5.9	9.9	8.2	8.1	5.9	12.2	14.2	12.2	13.1	10.8	7.9
HYPERSTHENE	19.7	0.0	0.0	4.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	2.1
OLIVINE	7.3	15.2	16.2	14.1	18.0	16.8	18.0	17.8	19.0	16.8	18.9	16.1
MAGNETITE	2.6	2.9	2.9	2.6	2.9	2.6	2.6	2.6	2.6	2.6	2.6	2.9
ILMENITE	5.7	5.6	5.4	6.1	6.1-	6.5	5.3	5.2	5.1	4.8	4.9	6.0
APATITE	1.0	1.2	1.4	1.6	1.0	1.2	0.7	0.7	0.7	0.8	0.7	1.0
DIFF. INDEX	31.7	44.2	44.5	38.6	37.1	38.1	36.2	36.3	35.3	36.1	36.7	40.0
NA/(NA+K)	0.83	0.86	0.87	0.85	0.90	0.85	0.87	0.89	0.88	0.89	0.87	0.84
(NA+K)/AL	0.35	0.48	0.55	0.44	0.42	0.44	0.45	0.47	0.43	0.46	0.43	0.47
F3/(F2+F3)	0.11	0.15	0.13	0.12	0.13	0.11	0.11	0.11	0.11	0.11	0.11	0.14

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	750919	750920	750921	750922	751213	7634	740405	750116	750117	750512	750606	750618
ORTHOCLASE	6.7	5.4	4.9	4.8	5.5	3.6	4.0	5.7	3.8	6.2	3.9	4.7
ALBITE	34.1	36.5	40.1	37.2	32.5	33.3	30.4	34.2	37.4	31.4	31.7	31.0
ANORTHITE	23.1	21.0	20.3	21.5	24.1	22.3	25.8	21.3	22.0	23.8	21.7	22.8
NEPHELINE	0.0	0.0	0.0	0.0	1.6	2.6	0.0	2.6	3.4	2.8	6.4	2.5
DIOPSIDE	9.4	8.2	10.4	9.5	7.9	12.1	6.5	8.3	8.3	8.1	10.8	13.4
HYPERSTHENE	2.5	5.5	0.0	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.0
OLIVINE	13.9	12.8	14.1	15.8	18.4	16.3	12.3	17.7	15.7	17.5	15.8	16.9
MAGNETITE	3.0	2.9	3.0	3.0	2.9	2.9	2.5	2.9	2.9	2.9	2.9	2.6
ILMENITE	6.4	6.2	5.9	5.8	6.0	5.9	5.6	6.0	5.5	6.2	5.8	5.4
APATITE	1.0	1.4	1.2	1.3	1.1	0.9	0.9	1.2	1.0	1.0	1.0	0.7
DIFF. INDEX	40.9	42.0	45.0	42.0	39.6	39.5	34.4	42.6	44.6	40.5	42.0	38.2
NA/(NA+K)	0.84	0.88	0.93	0.89	0.87	0.92	0.89	0.88	0.92	0.86	0.92	0.89
(NA+K)/AL	0.48	0.51	0.54	0.51	0.47	0.50	0.41	0.53	0.53	0.49	0.54	0.48
F3/(F2+F3)	0.15	0.12	0.14	0.13	0.14	0.13	0.12	0.13	0.14	0.14	0.13	0.11

TERTIARY LAVAS FROM WEST-CENTRAL SKYE HAWAIITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740311	740409	740511	740705	740706	740902	740903	750101	750103	750106	750503	750605
ORTHOCLASE	9.7	5.5	5.9	3.1	5.5	4.9	5.0	6.5	3.8	6.7	3.8	3.2
ALBITE	35.2	34.5	34.2	34.0	30.7	33.0	32.7	36.0	34.4	35.8	33.6	34.3
ANORTHITE	21.6	22.9	23.6	28.2	25.7	24.1	24.7	24.0	22.6	25.1	26.0	26.4
NEPHELINE	0.0	3.2	2.8	0.4	1.8	4.9	3.4	1.2	6.0	0.3	0.7	0.0
DIOPSIDE	5.8	7.8	6.3	5.8	6.5	6.6	7.1	5.4	10.4	6.4	8.1	7.4
HYPERSTHENE	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
OLIVINE	15.7	16.4	17.0	19.1	18.5	14.3	16.5	17.8	14.7	16.7	19.3	18.9
MAGNETITE	2.9	2.9	3.0	2.6	2.5	2.9	2.9	2.9	2.9	2.9	2.6	2.6
ILMENITE	3.4	6.7	6.1	5.8	5.4	5.9	5.6	5.0	4.7	5.2	5.2	5.0
APATITE	2.0	0.9	1.2	1.1	1.2	1.3	1.1	1.0	0.5	0.8	0.7	0.7
DIFF. INDEX	44.9	43.2	42.9	37.4	38.1	42.8	41.1	43.8	44.1	42.8	38.1	37.5
NA/(NA+K)	0.79	0.89	0.88	0.92	0.87	0.90	0.89	0.86	0.93	0.85	0.91	0.92
(NA+K)/AL	0.52	0.51	0.50	0.41	0.44	0.51	0.48	0.50	0.53	0.47	0.44	0.43
F3/(F2+F3)	0.14	0.13	0.13	0.12	0.12	0.14	0.14	0.14	0.15	0.14	0.11	0.12

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   HAWAIITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	750610	741004	760702	760703	740404	740501	740504	740605	750205	750206	750207	750401
ORTHOCLASE	5.2	3.0	2.9	2.5	3.9	4.9	6.1	2.6	3.4	4.4	3.9	4.1
ALBITE	34.2	39.7	35.5	39.0	32.5	30.9	35.1	18.5	26.9	26.8	29.6	28.6
ANORTHITE	24.1	29.0	22.8	26.0	28.4	23.9	24.6	23.7	28.1	28.0	24.7	25.9
NEPHELINE	0.0	1.0	2.6	2.4	0.0	0.7	0.0	9.7	0.0	0.7	1.4	0.0
DIOPSIDE	9.3	7.5	13.2	10.3	1.2	16.0	6.2	16.1	17.7	17.7	15.8	8.1
HYPERSTHENE	1.1	0.0	0.0	0.0	9.5	0.0	2.7	0.0	1.6	0.0	0.0	6.7
OLIVINE	16.3	11.9	13.8	11.9	14.8	14.9	15.0	22.4	17.1	16.2	17.8	16.9
MAGNETITE	2.6	2.9	2.9	2.9	2.6	2.6	3.0	2.9	2.2	2.9	2.6	2.3
ILMENITE	6.2	4.1	5.3	4.2	5.9-	5.3	6.1	3.5	2.7	3.0	3.3	6.3
APATITE	1.0	0.9	0.8	0.8	1.2	0.8	1.2	0.6	0.4	0.4	0.8	1.2
DIFF. INDEX	39.3	43.7	41.0	43.9	36.4	36.4	41.2	30.8	30.3	31.9	35.0	32.7
NA/(NA+K)	0.88	0.94	0.94	0.95	0.90	0.87	0.86	0.94	0.89	0.87	0.90	0.88
(NA+K)/AL	0.46	0.45	0.50	0.48	0.40	0.45	0.47	0.46	0.36	0.38	0.44	0.40
F3/(F2+F3)	0.12	0.18	0.15	0.18	0.13	0.14	0.14	0.14	0.13	0.17	0.15	0.09

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   HAWAIITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	750802	750803	750901	750902	750904	750905	750913	750916	751204	751205	740208	740303
ORTHOCLASE	4.9	4.7	4.7	7.2	4.9	5.0	5.1	4.5	4.0	3.0	6.0	5.9
ALBITE	30.3	29.3	34.6	33.3	30.2	29.5	31.0	27.0	28.2	23.2	29.8	38.2
ANORTHITE	26.3	25.4	25.1	23.6	23.7	25.8	23.5	27.0	27.5	21.5	25.9	18.8
NEPHELINE	0.0	0.0	0.4	0.0	0.0	0.0	0.9	0.0	1.0	8.6	1.1	0.6
DIOPSIDE	8.7	10.7	6.3	6.6	10.8	11.1	11.9	9.0	9.1	15.5	10.0	8.2
HYPERSTHENE	2.1	2.3	0.0	6.1	3.0	3.9	0.0	7.2	0.0	0.0	0.0	0.0
OLIVINE	19.0	19.2	18.9	13.5	18.9	16.2	19.2	17.0	21.0	20.2	15.3	18.0
MAGNETITE	2.6	2.6	2.6	3.0	2.6	2.6	2.5	2.2	3.0	2.9	2.6	3.0
ILMENITE	5.3	5.1	6.3	5.6	5.1	5.1	5.1	5.2	5.3	4.4	5.4	5.6
APATITE	0.8	0.8	1.1	1.2	0.8	0.8	0.8	0.8	1.0	0.6	0.8	1.4
DIFF. INDEX	35.2	34.0	39.7	40.5	35.1	34.5	37.0	31.5	33.2	34.8	36.9	44.9
NA/(NA+K)	0.87	0.87	0.89	0.83	0.87	0.86	0.87	0.86	0.89	0.93	0.85	0.88
(NA+K)/AL	0.41	0.41	0.46	0.47	0.44	0.41	0.46	0.38	0.40	0.51	0.43	0.56
F3/(F2+F3)	0.11	0.11	0.12	0.14	0.11	0.11	0.11	0.09	0.14	0.14	0.12	0.13

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   HAWAIITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740703	750606	750708	750924
ORTHOCLASE	4.2	3.9	4.4	3.8
ALBITE	37.3	34.0	30.1	33.2
ANORTHITE	21.9	21.9	21.6	23.8
NEPHELINE	0.0	5.5	0.0	0.0
DIOPSIDE	7.0	11.0	7.3	8.6
HYPERSTHENE	4.8	0.0	1.4	1.6
OLIVINE	14.1	15.1	16.7	18.3
MAGNETITE	2.9	2.9	2.9	2.6
ILMENITE	6.4	5.1	5.8	6.7
APATITE	1.3	0.7	1.5	1.4
DIFF. INDEX	41.5	43.4	43.5	37.0
NA/(NA+K)	0.90	0.92	0.90	0.90
(NA+K)/AL	0.50	0.54	0.51	0.45
F3/(F2+F3)	0.13	0.13	0.14	0.11

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   MUGEARITES

Table 3

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740401	740302	740510	740513	740701	741101	750914	750208	750405	760301	7602	7624
ORTHOCLASE	4.8	5.8	6.9	6.4	4.4	10.3	7.0	5.0	6.6	13.0	7.9	6.0
ALBITE	43.3	42.6	38.1	33.2	43.4	41.1	39.6	42.8	38.9	36.7	37.9	39.2
ANORTHITE	12.9	15.6	17.1	19.5	20.7	12.7	20.0	19.1	21.4	12.0	16.3	18.0
NEPHELINE	5.3	1.0	4.6	6.5	0.0	5.3	0.9	2.2	5.6	2.4	3.3	2.0
DIOPSIDE	11.0	8.7	9.4	10.7	5.4	9.7	9.7	6.8	9.5	12.7	9.8	10.5
HYPERSTHENE	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2
OLIVINE	12.9	16.6	14.2	13.6	15.5	12.3	13.4	15.1	15.6	13.8	14.1	12.9
MAGNETITE	3.6	3.3	3.3	3.3	2.9	3.6	2.9	3.3	2.9	3.6	3.3	3.3
ILMENITE	4.7	4.9	5.0	5.8	5.2	3.2	5.4	4.3	6.4	3.9	5.9	6.1
APATITE	1.6	1.5	1.4	1.0	1.7	1.8	1.0	1.4	1.1	1.9	1.6	1.7
DIFF. INDEX	53.3	49.4	49.6	46.1	47.6	56.7	47.5	50.1	43.0	52.1	49.1	47.2
NA/(NA+K)	0.92	0.89	0.88	0.88	0.91	0.84	0.86	0.91	0.87	0.77	0.86	0.88
(NA+K)/AL	0.70	0.63	0.62	0.58	0.55	0.72	0.56	0.59	0.54	0.70	0.63	0.59
F3/(F2+F3)	0.18	0.14	0.15	0.15	0.14	0.16	0.15	0.16	0.13	0.16	0.16	0.17

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   MUGEARITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	740509	740905	750201	750202	750204	750703	750703	751801	740204	740205	740310	740407
ORTHOCLASE	6.3	7.6	6.0	11.6	9.4	2.8	4.2	13.3	7.8	9.1	8.4	5.6
ALBITE	35.3	36.9	44.0	37.3	42.8	36.5	35.6	40.4	35.7	35.2	34.5	33.1
ANORTHITE	17.4	20.6	16.8	8.2	9.9	16.7	17.9	8.2	20.1	19.5	21.3	22.1
NEPHELINE	5.7	5.0	3.1	10.2	7.0	8.5	7.0	7.3	4.2	4.1	3.0	7.4
DIOPSIDE	9.7	7.1	4.7	11.2	9.6	13.2	12.7	10.7	8.4	7.6	10.1	7.0
OLIVINE	14.9	12.8	16.7	12.1	11.1	12.7	13.3	10.3	13.9	14.4	12.7	14.1
MAGNETITE	3.3	3.3	3.3	3.6	4.0	3.3	3.3	4.0	3.3	3.3	3.3	3.3
ILMENITE	5.0	5.2	3.8	4.2	3.9	5.3	5.2	3.6	5.4	5.6	5.4	6.2
APATITE	1.3	1.4	1.6	1.7	2.2	0.8	0.7	2.2	1.2	1.1	1.2	1.3
DIFF. INDEX	48.3	49.5	53.1	59.0	59.2	47.8	45.8	61.0	47.7	48.4	45.9	46.1
NA/(NA+K)	0.89	0.87	0.90	0.84	0.86	0.95	0.92	0.81	0.86	0.83	0.83	0.90
(NA+K)/AL	0.62	0.58	0.64	0.81	0.78	0.64	0.61	0.81	0.57	0.58	0.54	0.55
F3/(F2+F3)	0.14	0.18	0.16	0.18	0.20	0.16	0.16	0.22	0.17	0.15	0.17	0.16

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   MUGEARITES

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	750607	750608	750609	750923	750903	750917
ORTHOCLASE	5.9	7.4	7.0	12.4	13.6	16.3
ALBITE	35.6	35.0	36.2	35.6	39.3	34.7
ANORTHITE	19.5	20.3	19.3	13.9	16.7	13.1
NEPHELINE	4.3	3.9	5.1	3.7	0.2	5.2
DIOPSIDE	8.3	8.2	7.8	11.7	9.1	12.3
OLIVINE	17.2	16.1	15.3	12.0	11.2	8.9
MAGNETITE	3.3	3.3	3.3	3.6	3.3	3.7
ILMENITE	5.0	4.7	4.9	5.0	5.2	4.2
APATITE	0.9	1.0	1.1	1.2	1.4	1.6
DIFF. INDEX	45.8	46.3	48.4	51.7	53.0	56.2
NA/(NA+K)	0.89	0.86	0.87	0.78	0.76	0.74
(NA+K)/AL	0.57	0.56	0.59	0.57	0.63	0.71
F3/(F2+F3)	0.15	0.14	0.16	0.18	0.19	0.22

TERTIARY LAVAS FROM WEST-CENTRAL SKYE   BENMOREITES AND TRACHYTES

Table 4

NORMCAL .. P.C.G.GILL

SUMMARY NORM TABLE

	77010	77011	750804	750805	750806	7625	7603	7604	7605
QUARTZ	0.0	0.0	11.2	11.1	11.3	11.8	3.9	4.8	3.9
CORUNDUM	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
ORTHOCLASE	15.0	15.5	25.9	23.0	22.6	24.3	27.6	26.9	26.3
ALBITE	49.4	47.1	43.3	42.1	42.3	41.0	51.7	51.1	53.5
ANORTHITE	9.3	9.4	6.7	7.5	7.8	7.2	2.3	2.6	2.2
NEPHELINE	2.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIOPSIDE	3.7	4.7	0.4	2.7	2.5	0.0	2.9	1.9	3.1
HYPERSTHENE	0.0	0.0	3.7	5.1	4.8	6.9	5.0	6.1	4.5
OLIVINE	12.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAGNETITE	4.1	4.0	3.4	4.0	4.0	4.0	4.4	4.4	4.4
HEMATITE	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
ILMENITE	2.4	2.6	3.2	3.1	3.2	3.1	1.1	1.1	1.1
APATITE	1.9	2.0	1.6	1.4	1.5	1.4	1.1	1.2	1.1
DIFF. INDEX	66.7	66.1	80.4	76.2	76.2	77.1	83.2	82.7	83.7
NA/(NA+K)	0.79	0.78	0.64	0.66	0.66	0.64	0.67	0.67	0.68
(NA+K)/AL	0.79	0.79	0.84	0.82	0.81	0.81	0.95	0.94	0.95
F3/(F2+F3)	0.23	0.22	0.54	0.43	0.44	0.45	0.42	0.40	0.43

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

Table 5

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	DY001	DY002	DY003	DY004	DY005	DY006	DY007	DY008	DY009	DY010	DY011	DY012
QUARTZ	0.0	0.0	0.0	2.6	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
ORTHOCLASE	15.2	3.2	3.1	9.2	5.9	0.1	23.3	0.5	1.8	0.0	3.5	2.7
ALBITE	35.9	26.2	30.7	31.6	33.1	20.0	39.6	19.5	18.1	3.7	26.4	20.2
ANORTHITE	3.6	11.0	4.6	5.4	3.1	18.6	11.0	17.3	20.0	9.1	28.5	29.8
NEPHELINE	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIOPSIDE	19.5	34.0	29.9	29.0	29.7	34.8	9.8	36.9	23.0	14.6	15.1	15.4
WOLLASTONITE	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0
HYPERSTHENE	0.0	14.2	18.1	17.0	15.7	1.4	0.0	7.5	1.7	6.5	1.5	23.0
OLIVINE	16.5	6.8	5.4	0.0	4.8	20.5	0.0	13.6	29.8	63.7	19.9	4.3
MAGNETITE	3.7	2.2	3.0	2.9	2.9	2.2	3.6	2.2	2.2	1.5	2.2	1.8
ILMENITE	3.2	2.4	4.7	2.2	4.0	2.4	2.2	2.5	3.2	0.9	2.4	1.9
APATITE	0.9	0.0	0.5	0.1	0.6	0.0	0.5	0.0	0.2	0.0	0.5	0.9
DIFF. INDEX	52.5	29.5	33.8	43.5	39.1	20.1	68.0	20.0	19.9	3.7	29.9	22.9
NA/(NA+K)	0.73	0.90	0.91	0.79	0.86	0.99	0.64	0.98	0.91	1.00	0.89	0.89
(NA+K)/AL	0.89	0.59	0.80	0.80	0.67	0.37	0.75	0.38	0.34	0.18	0.36	0.29
F3/(F2+F3)	0.18	0.10	0.09	0.16	0.12	0.10	0.45	0.10	0.10	0.07	0.11	0.09

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	DY013	DY014	DY015	DY016	DY017	7638	7620	DY020	7408-I	741105	750502	750507
QUARTZ	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ORTHOCLASE	0.2	1.5	3.6	0.9	0.7	2.6	0.1	11.5	0.5	0.3	1.2	0.3
ALBITE	12.2	18.0	23.0	19.6	20.1	29.5	6.6	36.0	20.5	17.6	19.4	20.2
ANORTHITE	28.7	31.1	25.7	27.9	33.2	27.6	26.6	11.2	32.7	34.5	29.4	30.2
NEPHELINE	0.0	0.7	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0
DIOPSIDE	12.4	29.6	19.4	26.6	21.7	9.7	0.9	21.8	20.1	23.4	20.8	22.0
HYPERSTHENE	13.9	0.0	22.0	0.6	5.0	14.3	9.0	0.0	8.3	0.9	18.2	13.1
OLIVINE	28.6	15.3	0.0	19.8	15.4	9.8	52.6	7.9	13.5	19.2	6.1	9.6
MAGNETITE	1.5	1.9	2.3	1.8	1.9	2.2	1.5	3.4	1.9	1.8	1.9	1.9
ILMENITE	2.0	2.0	2.0	2.3	1.7	3.1	0.8	3.3	2.1	1.8	2.7	2.4
APATITE	0.5	0.1	0.7	0.4	0.2	1.0	1.6	0.8	0.4	0.5	0.4	0.4
DIFF. INDEX	12.5	20.1	27.8	20.5	20.8	32.1	6.7	51.7	21.0	17.9	20.6	20.5
NA/(NA+K)	0.08	0.93	0.87	0.96	0.97	0.92	0.99	0.80	0.98	0.98	0.94	0.99
(NA+K)/AL	0.19	0.26	0.35	0.28	0.25	0.38	0.12	0.72	0.25	0.22	0.27	0.26
F3/(F2+F3)	0.07	0.10	0.13	0.09	0.10	0.11	0.09	0.18	0.09	0.10	0.09	0.09

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	750511	750603	750701	751701	760305	7615	7626	7629	751005	760802	760813	751105
QUARTZ	0.0	0.0	0.0	0.0	0.0	0.0	4.2	4.7	0.0	0.0	0.0	0.0
ORTHOCLASE	0.3	0.2	0.5	3.8	2.1	1.4	6.7	7.0	2.9	0.5	0.4	1.0
ALBITE	14.3	19.2	14.9	21.9	18.0	22.8	32.1	30.0	9.3	16.2	13.0	16.8
ANORTHITE	36.9	31.1	36.0	29.2	34.4	30.8	19.3	20.6	36.2	28.0	24.2	32.0
NEPHELINE	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
DIOPSIDE	16.6	22.5	18.2	19.9	16.8	24.3	13.7	14.0	20.6	26.1	31.0	22.7
HYPERSTHENE	15.4	16.4	20.5	18.5	17.8	0.0	15.7	16.6	5.0	5.1	8.2	15.6
OLIVINE	12.0	6.4	5.9	2.1	5.7	14.3	0.0	0.0	21.9	20.1	19.0	7.5
MAGNETITE	1.5	1.8	1.5	2.2	1.9	2.2	2.6	2.6	2.2	2.2	2.2	2.2
ILMENITE	1.8	2.0	2.0	2.1	3.0	2.3	3.2	3.1	1.7	1.8	1.9	2.1
APATITE	0.3	0.3	0.3	0.4	0.4	0.8	1.5	1.5	0.2	0.0	0.0	0.2
DIFF. INDEX	14.6	19.4	15.5	25.6	20.0	25.4	43.0	41.7	12.2	16.7	13.4	17.8
NA/(NA+K)	0.98	0.99	0.97	0.86	0.90	0.95	0.84	0.82	0.77	0.97	0.97	0.95
(NA+K)/AL	0.17	0.25	0.19	0.32	0.24	0.31	0.51	0.49	0.15	0.24	0.23	0.23
F3/(F2+F3)	0.08	0.11	0.08	0.14	0.11	0.14	0.16	0.16	0.10	0.12	0.11	0.13

TERTIARY INTRUSIVE IGNEOUS ROCKS FROM WEST-CENTRAL SKYE

NORMCAL .. R.C.O.GILL

SUMMARY NORM TABLE

	751105	760803	760808	760806	760809	760816
QUARTZ	1.2	0.0	0.0	0.0	0.0	20.3
ORTHOCLASE	3.9	3.2	0.5	0.0	0.1	5.7
ALBITE	21.6	35.7	12.0	0.0	3.1	51.5
ANORTHITE	27.7	1.4	26.0	2.6	5.1	7.8
NEPHELINE	0.0	2.6	0.0	3.3	0.0	0.0
DIOPSIDE	26.9	34.6	25.5	9.5	16.0	1.1
HYPERSTHENE	13.9	0.0	8.6	0.0	1.5	7.7
OLIVINE	0.0	13.1	23.8	85.1	71.9	0.0
CAL ORTHOSIL	0.0	0.0	0.0	0.4	0.0	0.0
MAGNETITE	2.2	2.9	2.2	1.5	1.5	3.6
ILMENITE	2.3	5.7	1.2	0.7	0.8	1.7
APATITE	0.2	0.6	0.0	0.0	0.0	0.5
DIFF. INDEX	26.8	41.7	12.6	0.3	3.1	77.6
NA/(NA+K)	0.85	0.93	0.96	1.00	0.98	0.91
(NA+K)/AL	0.33	0.94	0.20	0.11	0.25	0.79
F3/(F2+F3)	0.13	0.11	0.13	0.08	0.08	0.35

APPENDIX 3

Mineral analyses by microprobe

Table 1. Olivines

2. Pyroxenes

3. Feldspars

4. Amphiboles

5. Spinels (spinel and magnetite series)

6. Ilmenites

TABLE 1. OLIVINES

Analyses	Location	Host rock
1-3,4-5	Core to rim	Olivine + spinel porphyritic basalt
6,7-8	"	" " " "
9-10	"	" " " "
11-12	"	" " " "
13,14-15	"	" " " "
16-17	"	Olivine porphyritic basalt
18,19,20-21	"	Olivine + plagioclase porphyritic basalt
22	Groundmass	" " " "
23,24-27	Core to rim traverse	" " " "
28	Groundmass	Low-alkali,high-calcium olivine tholeiite
29-30,31	Core to rim	" " " "
32-35	Micropheno-cryst	Hawaiite
36,37-38	Core to rim micropheno-cryst	"
39-40	"	"
41,42	Micropheno-cryst	Mugearite
43-44	Core to rim micropheno-cryst	"
45	Micropheno-cryst	"
46	"	Composite Hawaiite of Dun Ard an t-Sabhail
47,48	Groundmass?	Benmoreite
49,50	"	Alkali trachyte of Cnoc Scarall
51	"	High-grade basaltic hornfels

TERTIARY LAVAS, WEST-CENTRAL SKYE   TABLE 1   OLIVINES

	1	2	3	4	5	6	7	8	9	10
	751212	751212	751212	751212	751212	7616	7616	7616	740607	740607
WEIGHT PERCENT OXIDE										
SIO2	39.54	39.62	40.33	39.94	40.57	40.93	39.97	38.62	40.06	39.88
TIO2	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02
AL2O3	0.07	0.07	0.13	0.08	0.10	0.08	0.01	0.02	0.08	0.05
CR2O3	0.03	0.03	0.06	0.04	0.02	0.02	0.02	0.01	0.00	0.00
FEO	10.17	10.46	10.53	10.80	10.81	11.17	11.12	16.57	10.53	13.47
MNO	0.05	0.06	0.13	0.13	0.05	0.05	0.17	0.21	0.19	0.22
MGO	48.92	48.69	48.74	48.50	48.37	48.36	48.20	47.73	47.54	46.43
CAO	0.20	0.28	0.32	0.31	0.24	0.22	0.24	0.27	0.32	0.29
NA2O	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.00	0.01
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIO	0.35	0.34	0.45	0.33	0.32	0.25	0.35	0.24	0.43	0.37
TOTAL	99.36	99.54	100.69	100.12	100.48	101.08	100.11	99.84	99.18	100.73
STRUCTURAL FORMULA ON THE BASIS OF 4 OXYGENS										
SI	0.9816	0.9824	0.9884	0.9857	0.9954	0.9982	0.9873	0.9779	0.9964	0.9900
TI	0.0006	0.0000	0.0000	0.0001	0.0000	0.0000	0.0006	0.0006	0.0004	0.0005
AL	0.0020	0.0020	0.0038	0.0022	0.0029	0.0022	0.0004	0.0007	0.0025	0.0015
CR	0.0008	0.0006	0.0012	0.0008	0.0004	0.0004	0.0004	0.0001	0.0000	0.0000
FE	0.2116	0.2168	0.2158	0.2229	0.2219	0.2319	0.2318	0.3517	0.2191	0.2797
MN	0.0011	0.0013	0.0026	0.0027	0.0010	0.0010	0.0036	0.0045	0.0040	0.0047
MG	1.8055	1.7991	1.7800	1.7838	1.7687	1.7679	1.7744	1.6549	1.7623	1.7176
CA	0.0071	0.0074	0.0084	0.0081	0.0064	0.0060	0.0066	0.0104	0.0085	0.0074
NA	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0018	0.0093	0.0000	0.0001
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NI	0.0071	0.0068	0.0089	0.0065	0.0062	0.0041	0.0075	0.0050	0.0087	0.0073
END MEMBER COMPOSITIONS										
FE	10.48	10.75	10.81	11.11	11.15	11.50	11.56	17.07	11.06	14.00
MG	89.52	89.25	89.12	88.89	88.85	88.50	88.44	82.93	88.94	86.00

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 1 OLIVINES

	11	12	13	14	15	16	17	18	19	20
	740607	740607	750602	750602	750602	751002	751002	740801	740801	740801
WEIGHT PERCENT OXIDE										
SIO2	39.22	39.16	39.77	39.15	37.02	40.22	38.77	37.59	38.04	37.81
TIO2	0.01	0.00	0.01	0.01	0.04	0.02	0.01	0.05	0.05	0.07
AL2O3	0.05	0.05	0.07	0.07	0.07	0.00	0.06	0.13	0.13	0.21
CR2O3	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.02	0.02	0.04
FEO	14.25	15.42	11.67	12.00	18.65	17.50	17.78	27.53	27.96	28.60
MNO	0.12	0.07	0.12	0.07	0.09	0.24	0.24	0.37	0.38	0.44
MGO	46.02	45.34	48.08	47.89	44.15	42.31	41.66	34.33	32.93	32.41
CAO	0.27	0.20	0.26	0.15	0.27	0.19	0.24	0.30	0.30	0.44
NA2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIO	0.34	0.22	0.36	0.29	0.23	0.28	0.27	0.09	0.09	0.11
TOTAL	100.28	100.47	100.35	99.65	100.54	100.76	99.03	100.41	99.89	100.23
STRUCTURAL FORMULA ON THE BASIS OF 4 OXYGENS										
SI	0.9870	0.9856	0.9989	0.9853	0.9804	1.0132	0.9987	1.0000	1.0173	1.0123
TI	0.0002	0.0000	0.0002	0.0002	0.0009	0.0004	0.0001	0.0009	0.0010	0.0014
AL	0.0016	0.0018	0.0021	0.0020	0.0021	0.0000	0.0017	0.0040	0.0040	0.0068
CR	0.0001	0.0001	0.0002	0.0005	0.0004	0.0000	0.0000	0.0004	0.0004	0.0008
FE	0.2799	0.3023	0.2410	0.2468	0.3889	0.3687	0.3829	0.6123	0.6253	0.6435
MN	0.0025	0.0014	0.0024	0.0014	0.0018	0.0051	0.0053	0.0083	0.0085	0.0100
MG	1.7276	1.7222	1.7656	1.7641	1.7340	1.5882	1.5993	1.3605	1.3124	1.2932
CA	0.0072	0.0057	0.0067	0.0048	0.0071	0.0050	0.0065	0.0085	0.0087	0.0125
NA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0055
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NI	0.0070	0.0032	0.0080	0.0053	0.0047	0.0057	0.0056	0.0018	0.0019	0.0023
END MEMBER COMPOSITIONS										
FE	14.78	16.07	12.02	12.36	19.21	18.84	19.32	31.04	32.27	33.12
MG	85.22	83.93	87.98	87.64	80.79	81.16	80.68	68.96	67.73	66.88

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 1 OLIVINES

	21	22	23	24	25	26	27	28	29	30
	740801	740801	751001	751001	751001	751001	751001	750808	750907	750907
WEIGHT PERCENT OXIDE										
SIO2	36.98	36.82	39.72	40.89	40.21	39.27	40.22	37.15	38.48	36.73
TIO2	0.06	0.09	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.11
AL2O3	0.37	0.04	0.00	0.29	0.00	0.00	0.19	0.00	0.03	0.03
CR2O3	0.04	0.04	0.03	0.04	0.07	0.02	0.07	0.06	0.01	0.06
FEO	29.02	33.39	14.18	14.21	15.69	20.69	27.02	30.29	17.51	28.83
MNO	0.47	0.65	0.23	0.13	0.22	0.38	0.42	0.59	0.25	0.34
MGO	31.57	28.36	45.43	43.65	43.23	40.08	31.06	31.13	43.77	33.75
CAO	0.39	0.25	0.26	0.30	0.33	0.34	0.42	0.43	0.41	0.42
NA2O	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIO	0.11	0.08	0.26	0.14	0.21	0.09	0.12	0.18	0.10	0.05
TOTAL	99.43	99.85	100.12	99.66	99.97	100.88	99.55	99.91	100.56	100.21
STRUCTURAL FORMULA ON THE BASIS OF 4 OXYGENS										
SI	1.0023	1.0150	0.9947	1.0233	1.0131	1.0046	1.0675	1.0089	0.9765	0.9876
TI	0.0013	0.0018	0.0000	0.0000	0.0000	-0.0000	0.0007	0.0004	0.0000	0.0003
AL	0.0117	0.0012	0.0000	0.0086	0.0000	0.0001	0.0060	0.0000	0.0009	0.0009
CR	0.0009	0.0008	0.0007	0.0008	0.0014	0.0005	0.0014	0.0013	0.0001	0.0012
FE	0.6578	0.7698	0.2971	0.2974	0.3306	0.4427	0.5999	0.6879	0.3717	0.6482
MN	0.0109	0.0152	0.0049	0.0028	0.0046	0.0081	0.0095	0.0136	0.0053	0.0077
MG	1.2915	1.1650	1.6954	1.6283	1.6232	1.5282	1.2287	1.2600	1.6552	1.3532
CA	0.0115	0.0164	0.0071	0.0080	0.0090	0.0092	0.0118	0.0124	0.0111	0.0121
NA	0.0000	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0027	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NI	0.0024	0.0019	0.0052	0.0029	0.0043	0.0019	0.0026	0.0040	0.0021	0.0010
END MEMBER COMPOSITIONS										
FE	33.75	39.79	14.91	15.44	16.92	22.46	32.81	35.32	18.34	32.40
MG	66.25	60.21	85.09	84.56	83.08	77.54	67.19	64.68	81.66	67.60

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 1 OLIVINES

	31	32	33	34	35	36	37	38	39	40
	750907	740301	740301	750817	750817	740701	740701	740701	740810	740810
WEIGHT PERCENT OXIDE										
SIO2	36.56	37.04	36.42	34.38	34.98	35.85	35.28	33.24	34.91	35.40
TIO2	0.00	0.11	0.11	0.05	0.07	0.04	0.09	0.06	0.10	0.07
AL2O3	0.05	0.31	0.86	0.12	0.13	0.09	0.36	1.06	0.08	0.19
CR2O3	0.00	0.02	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.02
FEO	29.77	28.95	29.69	35.22	36.87	37.31	38.44	40.41	34.65	35.98
MNO	0.48	0.74	0.69	0.73	0.73	0.73	0.77	0.69	0.93	0.75
MGO	33.31	31.95	31.05	26.30	26.95	25.51	23.87	20.85	27.74	27.34
CAO	0.44	0.43	0.40	0.29	0.38	0.42	0.55	2.87	0.44	0.42
NA2O	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.02
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
NIO	0.04	0.05	0.10	0.04	0.03	0.02	0.02	0.12	0.13	0.05
TOTAL	100.64	99.62	99.36	99.04	100.04	99.95	99.40	99.30	99.05	100.25
STRUCTURAL FORMULA ON THE BASIS OF 4 OXYGENS										
SI	0.9832	1.0025	0.9925	0.9720	0.9841	1.0082	1.0057	0.9699	0.9843	0.9885
TI	0.0000	0.0023	0.0023	0.0012	0.0015	0.0009	0.0020	0.0014	0.0021	0.0015
AL	0.0015	0.0098	0.0277	0.0008	0.0011	-0.0030	0.0122	0.0367	0.0026	0.0062
CR	0.0000	0.0005	0.0005	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0004
FE	0.6695	0.6553	0.6767	0.8328	0.8675	0.8777	0.9164	0.9862	0.8172	0.8401
MN	0.0109	0.0170	0.0160	0.0175	0.0175	0.0173	0.0185	0.0171	0.0221	0.0178
MG	1.3349	1.2886	1.2611	1.1926	1.1301	1.0695	1.0139	0.9067	1.1658	1.1378
CA	0.0126	0.0125	0.0117	0.0089	0.0115	0.0128	0.0169	0.0896	0.0134	0.0125
NA	0.0000	0.0007	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0033	0.0009
K	0.0001	0.0000	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0004
NI	0.0035	0.0011	0.0022	0.0008	0.0006	0.0004	0.0005	0.0029	0.0030	0.0012
END MEMBER COMPOSITIONS										
FE	33.40	33.71	34.92	41.12	43.43	45.08	47.47	52.10	41.21	42.48
MG	66.60	66.29	65.08	58.88	56.57	54.92	52.53	47.90	58.79	57.52

TERTIARY LAVAS, WEST-CENTRAL SKYE TAPLE 1 OLIVINES

	41	42	43	44	45	46	47	48	49	50
	740905	740905	741101	741101	751801	760703	77011	77011	7605	7605
WEIGHT PERCENT OXIDE										
SIO2	34.93	35.42	33.39	34.18	34.63	35.63	33.91	33.56	32.09	32.86
TIO2	0.05	0.21	0.14	0.15	0.12	0.23	0.12	0.12	0.10	0.11
AL2O3	0.08	0.20	0.55	1.08	0.63	0.12	0.65	0.50	0.19	0.76
CR2O3	0.02	0.02	0.05	0.03	0.03	0.00	0.07	0.06	0.10	0.07
FEO	36.10	36.29	41.07	43.83	47.07	34.35	48.78	48.92	54.73	54.19
MNO	0.92	0.89	1.22	1.39	1.51	0.70	1.70	1.62	2.67	2.55
MGO	26.94	26.74	21.50	18.03	14.56	28.20	12.03	12.56	9.07	8.38
CAO	0.47	0.43	0.82	0.90	0.79	0.51	0.75	0.74	0.41	0.51
NA2O	0.04	0.03	0.24	0.62	0.20	0.27	0.16	0.16	0.00	0.01
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
NIO	0.03	0.37	0.13	0.07	0.12	0.03	0.12	0.10	0.15	0.11
TOTAL	99.56	100.30	99.12	100.27	99.66	100.04	98.29	98.34	99.54	99.58
STRUCTURAL FORMULA ON THE BASIS OF 4 OXYGENS										
SI	0.9856	0.9995	0.9772	0.9989	1.0333	0.9960	1.0310	1.0296	1.0115	1.0274
TI	0.0010	0.0043	0.0032	0.0033	0.0030	0.0047	0.0031	0.0030	0.0023	0.0025
AL	0.0026	0.0065	0.0190	0.0373	0.0222	0.0038	0.0228	0.0153	0.0069	0.0280
CR	0.0004	0.0005	0.0012	0.0008	0.0007	0.0001	0.0017	0.0012	0.0025	0.0017
FE	0.8520	0.8489	1.0053	1.0713	1.1704	0.8010	1.2193	1.2001	1.4427	1.4168
MN	0.0219	0.0211	0.0301	0.0344	0.0371	0.0165	0.0499	0.0471	0.0712	0.0676
MG	1.1328	1.1144	0.9378	0.7852	0.6516	1.1719	0.5003	0.5111	0.4261	0.3904
CA	0.0142	0.0128	0.0257	0.0283	0.0252	0.0153	0.0219	0.0209	0.0140	0.0171
NA	0.0020	0.0018	0.0138	0.0352	0.0115	0.0147	0.0101	0.0100	0.0000	0.0008
K	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0013	0.0013
NI	0.0006	0.0016	0.0030	0.0015	0.0029	0.0007	0.0029	0.0022	0.0038	0.0027
END MEMBER COMPOSITIONS										
FE	42.93	43.24	51.74	57.71	64.24	40.60	67.29	69.90	77.20	78.40
MG	57.07	56.76	48.26	42.29	35.76	59.40	32.71	30.10	22.80	21.60

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 1 OLIVINES

51

760805

WEIGHT PERCENT OXIDE

SIO2	36.57
TIO2	0.07
AL2O3	0.11
CR2O3	0.03
FEO	29.68
MNO	0.70
MGO	31.45
CAO	0.28
NA2O	0.00
K2O	0.00
NIO	0.19
TOTAL	99.07

STRUCTURAL FORMULA ON THE BASIS OF 4 OXYGENS

SI	1.0004
TI	0.0015
AL	0.0035
CR	0.0007
FE	0.6790
MN	0.0161
MG	1.2822
CA	0.0083
NA	0.0000
K	0.0000
NI	0.0042

END MEMBER COMPOSITIONS

FE	34.62
MG	65.38

TABLE 2. PYROXENES

Analyses	Location	Host rock
1-3	Groundmass	Olivine + spinel porphyritic basalt
4-5	Groundmass core to rim	" " "
7-8	" " "	" " "
9,10	Groundmass	Olivine porphyritic basalt
11	"	Doleritic basalt
12	"	Olivine + plagioclase porphyritic basalt
13	"	Low-alkali, high-calcium olivine tholeiite
14	"	Hawaiite
15,16	"	Coarse-grained mugearite
17	"	Feldspar macroporphyritic hawaiite
18,19	Micropheno-cryst	Intermediate sub-alkalic trachyte of Sleadale
20,21	Groundmass	Alkali trachyte of Cnoc Scarall
22,23	Phenocryst	Olivine + plagioclase + clino-pyroxene porphyritic basalt of An Sguman
24-26	Microphenocryst?	Transitional Basalt
27-30	Xenocryst OPX	Composite Hawaiite of Dun Ard an t-Sabhail
31,32	Microphenocryst	Andesite sill
33	Groundmass	High-grade basaltic hornfels

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 2 PYROXENES

	1	2	3	4	5	6	7	8	9	10
	751212	751212	751212	740607	740607	740607	7706	7706	751002	751002
WEIGHT PERCENT OXIDE										
SIO2	47.75	47.64	48.22	48.98	49.21	50.60	49.13	48.01	46.59	46.47
TIO2	2.96	2.83	2.47	1.38	2.58	1.16	2.50	3.85	3.50	3.43
AL2O3	5.64	5.67	5.66	4.73	3.97	3.75	4.91	3.93	5.24	5.43
CR2O3	0.16	0.11	0.16	1.14	0.82	0.71	0.50	0.40	0.01	0.01
FEO	10.44	11.18	11.73	7.14	8.32	7.42	9.03	9.99	10.14	10.03
MNO	0.11	0.19	0.11	0.16	0.15	0.14	0.12	0.14	0.21	0.21
MGO	11.80	11.72	11.87	14.30	13.98	14.69	12.33	12.41	10.67	10.69
CAO	20.94	19.71	19.82	21.28	20.87	20.68	20.71	20.79	21.35	21.29
NA2O	0.38	0.41	0.38	0.31	0.35	0.31	0.58	0.66	1.16	1.04
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIO	0.00	0.02	0.00	0.02	0.12	0.01	0.01	0.00	0.05	0.10
TOTAL	100.15	99.48	100.43	99.52	100.37	99.48	99.82	100.18	98.90	98.69
STRUCTURAL FORMULA ON THE BASIS OF 6 OXYGENS										
SI	1.7985	1.8558	1.8132	1.8321	1.7963	1.8845	1.8385	1.8022	1.7833	1.7862
TI	0.0837	0.0819	0.0698	0.0387	0.1533	0.0324	0.0712	0.1092	0.1009	0.0993
AL	0.2516	0.1228	0.2511	0.2085	0.1578	0.1647	0.2166	0.1728	0.2371	0.2459
CR	0.0049	0.0034	0.0048	0.0336	0.0065	0.0210	0.0138	0.0109	0.0004	0.0002
FE	0.3276	0.6250	0.3690	0.2235	0.2549	0.2311	0.2747	0.2736	0.3254	0.3223
MN	0.0035	0.0064	0.0035	0.0049	0.0045	0.0044	0.0039	0.0034	0.0067	0.0068
MG	0.6621	0.5065	0.6550	0.8021	0.7607	0.8153	0.7115	0.7150	0.6104	0.6122
CA	0.8450	0.7811	0.7985	0.8528	0.8163	0.8254	0.8268	0.8305	0.8783	0.8769
NA	0.0279	0.0313	0.0281	0.0277	0.0251	0.0227	0.0389	0.0437	0.0860	0.0775
K	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NI	0.0000	0.0005	0.0000	0.0006	0.0062	0.0002	0.0002	0.0001	0.0016	0.0030
END MEMBER COMPOSITIONS										
CA	46.05	43.83	43.57	45.40	44.58	44.10	46.10	45.45	48.41	48.41
FE	17.86	19.83	20.14	11.90	13.88	12.34	15.68	16.97	17.94	17.79
MG	36.09	36.34	36.29	42.70	41.54	43.56	38.22	37.68	33.65	33.80

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 2 PYROXENES

	11	12	13	14	15	16	17	18	19	20
	751104	740801	750807	740905	740810	740810	740311	750806	750806	7605

WEIGHT PERCENT OXIDE

	11	12	13	14	15	16	17	18	19	20
SIO2	50.24	50.42	52.82	48.48	50.24	49.53	49.74	48.16	50.58	49.37
TIO2	1.50	2.19	0.47	2.47	1.91	1.70	1.51	0.91	0.71	0.90
AL2O3	3.99	3.94	2.72	3.60	3.00	2.60	3.67	2.66	2.23	2.30
CR2O3	0.37	0.00	0.39	0.01	0.11	0.00	0.03	0.02	0.01	0.05
FEO	8.99	8.73	5.78	9.62	9.18	9.12	11.70	10.02	9.40	15.16
MNO	0.19	0.15	0.16	0.17	0.22	0.18	0.23	0.59	0.55	0.61
MGO	14.54	12.64	16.31	13.19	12.65	12.92	12.31	16.72	16.68	9.61
CAO	19.03	20.38	21.45	21.07	21.07	21.69	20.23	19.82	19.14	12.56
NA2O	0.42	0.61	0.26	0.65	0.69	0.68	0.58	0.75	0.73	4.61
K2O	0.00	0.02	0.00	0.02	0.03	0.03	0.00	0.02	0.02	0.03
NIO	0.16	0.03	0.05	0.01	0.00	0.06	0.04	0.00	0.00	0.16
TOTAL	99.43	99.38	100.11	99.21	98.99	98.50	99.54	99.67	100.04	95.36

STRUCTURAL FORMULA ON THE BASIS OF 6 OXYGENS

	11	12	13	14	15	16	17	18	19	20
SI	1.8781	1.8930	1.9356	1.8389	1.9032	1.8904	1.8791	1.8267	1.8898	1.9689
TI	0.0423	0.0618	0.0128	0.0706	0.0542	0.0487	0.0437	0.0261	0.0199	0.0269
AL	0.1758	0.1746	0.1177	0.1612	0.1336	0.1170	0.1659	0.1159	0.0984	0.1081
CR	0.0107	0.0000	0.0113	0.0004	0.0004	0.0001	0.0008	0.0005	0.0000	0.0015
FE	0.2813	0.2743	0.1772	0.3053	0.2904	0.2912	0.3592	0.3178	0.2938	0.5057
MN	0.0062	0.0049	0.0050	0.0059	0.0070	0.0057	0.0075	0.0189	0.0173	0.0206
MG	0.8297	0.7072	0.8744	0.7459	0.7129	0.7347	0.7038	0.9452	0.9289	0.5711
CA	0.7623	0.8198	0.8424	0.8566	0.8540	0.8870	0.8312	0.8053	0.7663	0.5368
NA	0.0305	0.0442	0.0183	0.0479	0.0503	0.0507	0.0433	0.0553	0.0526	0.3568
K	0.0000	0.0009	0.0000	0.0010	0.0012	0.0013	0.0000	0.0011	0.0007	0.0014
NI	0.0049	0.0009	0.0015	0.0004	0.0031	0.0017	0.0012	0.0000	0.0000	0.0050

END MEMBER COMPOSITIONS

	11	12	13	14	15	16	17	18	19	20
CA	41.13	45.52	44.48	44.90	45.98	46.37	43.88	38.94	38.53	33.27
FE	15.18	15.22	9.35	[illegible]	15.64	15.23	18.96	15.36	14.77	31.34
MG	43.69	39.26	46.17	[illegible]	38.38	38.40	37.16	45.70	46.70	35.39

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 2 PYROXENES

	21	22	23	24	25	26	27	28	29	30
	7605	760814	760814	751218	751218	751218	760703	760703	760703	760703
WEIGHT PERCENT OXIDE										
SIO2	50.42	49.12	50.77	51.50	50.39	48.45	49.26	48.85	48.41	48.28
TIO2	0.48	0.57	0.57	1.05	1.48	1.44	0.59	0.54	0.53	0.54
AL2O3	8.74	5.14	4.13	3.27	4.58	5.14	7.82	7.07	7.66	7.76
CR2O3	0.07	0.42	0.43	0.16	0.32	0.52	0.09	0.03	0.00	0.00
FEO	21.22	6.56	6.50	9.18	9.05	8.98	16.72	16.70	16.75	16.35
MNO	1.25	0.12	0.17	0.28	0.20	0.19	0.27	0.22	0.19	0.19
MGO	6.33	14.52	14.10	15.00	13.94	14.90	23.87	23.17	23.97	23.76
CAO	17.53	20.43	20.63	18.72	19.69	19.26	1.55	1.58	1.61	1.58
NA2O	0.98	0.37	0.43	0.19	0.28	0.28	0.29	0.32	0.20	0.12
K2O	0.09	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
NIO	0.11	0.00	0.00	0.00	0.00	0.09	0.07	0.10	0.09	0.02
TOTAL	99.02	97.24	99.73	99.37	99.93	99.26	100.53	98.59	99.32	98.61
STRUCTURAL FORMULA ON THE BASIS OF 6 OXYGENS										
SI	2.0025	1.9635	1.9115	1.9184	1.8800	1.8210	1.7899	1.8111	1.7831	1.7862
TI	0.0143	0.0162	0.0161	0.0295	0.0410	0.0407	0.0162	0.0152	0.0146	0.0150
AL	0.0344	0.2298	0.1841	0.1436	0.1996	0.2275	0.3249	0.3093	0.3327	0.3388
CR	0.0023	0.0125	0.0129	0.0047	0.0094	0.0156	0.0025	0.0009	0.0000	0.0000
FE	0.7048	0.2081	0.2055	0.2858	0.2798	0.2824	0.5081	0.5179	0.5159	0.5060
MN	0.0421	0.0038	0.0054	0.0089	0.0062	0.0061	0.0082	0.0069	0.0059	0.0060
MG	0.3747	0.8210	0.9062	0.8326	0.7680	0.8347	1.2927	1.2803	1.3103	1.3101
CA	0.7466	0.8303	0.8351	0.7472	0.7801	0.7752	0.0604	0.0626	0.0636	0.0625
NA	0.0749	0.0274	0.0313	0.0139	0.0202	0.0205	0.0203	0.0229	0.0146	0.0083
K	0.0046	0.0002	0.0000	0.0004	0.0006	0.0006	0.0000	0.0000	0.0000	0.0000
NI	0.0037	0.0000	0.0000	0.0000	0.0000	0.0030	0.0022	0.0030	0.0027	0.0005
END MEMBER COMPOSITIONS										
CA	40.86	44.66	42.90	40.65	42.68	40.97	3.25	3.36	3.36	3.33
FE	38.61	11.19	10.56	15.32	15.31	14.92	27.30	27.83	27.30	26.93
MG	20.53	44.15	46.54	44.03	42.01	44.11	69.45	68.81	69.34	69.74

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 2 PYROXENES

	31	32	33
	7626	7626	769805
WEIGHT PERCENT OXIDE			
SIO2	49.72	50.47	49.71
TIO2	0.49	0.85	1.29
AL2O3	1.20	1.37	3.76
CR2O3	0.01	0.05	0.28
FEO	14.17	12.89	9.33
MNO	0.48	0.28	0.22
MGO	14.72	14.42	13.75
CAO	18.55	17.27	20.86
NA2O	0.27	0.65	0.26
K2O	0.02	0.05	0.00
NIO	0.08	0.03	0.06
TOTAL	99.71	98.34	99.22
STRUCTURAL FORMULA ON THE BASIS OF 6 OXYGENS			
SI	1.9134	1.9341	1.8704
TI	0.0142	0.0245	0.0374
AL	0.0542	0.0619	0.1703
CR	0.0004	0.0015	0.0083
FE	0.4537	0.4134	0.2897
MN	0.0155	0.0091	0.0072
MG	0.8398	0.8249	0.7856
CA	0.7606	0.7098	0.8576
NA	0.0202	0.0485	0.0193
K	0.0009	0.0027	0.0000
NI	0.0024	0.0008	0.0019
END MEMBER COMPOSITIONS			
CA	37.03	36.44	44.36
FE	22.09	21.22	14.99
MG	40.88	42.34	40.65

TABLE 3. FELDSPARS

Analyses	Location	Host rock
1,2	Groundmass	Olivine + spinel porphyritic basalt
3	"	Dolerite basalt
4,5,6	Groundmass, phenocryst & interstitial	Olivine + plagioclase porphyritic basalt
7	Phenocryst core	Low-alkali, high-calcium olivine tholeiite
8-9	Core to rim	" " "
10,11	Groundmass	" " "
12	Phenocryst rim	" " "
13,14	Microphenocryst & groundmass	Hawaiite
15,16	Microphenocryst	"
17	Groundmass	"
18,19	Interstitial	"
20	Microphenocryst	"
21-23	"	Mugearite
24-29	Groundmass	"
30	Microphenocryst	"
31-33	Groundmass to interstitial traverse	"
34-35,36	Core to rim microphenocryst	Coarse-grained mugearite
37	Groundmass	Mugearite
38-40	Core to rim traverse	Feldspar macroporphyritic hawaiite
41,42	Groundmass	" " "
43	"	Benmoreite
44	Interstitial	"
45-46,47	Core to rim phenocryst	Intermediate, sub-alkalic trachyte of Sleadale
48,49	Groundmass	" " "
50	Microphenocryst	Alkali trachyte of Cnoc Scarall
51	Macrophenocryst	" " " " "
52,53-54,55	Core to rim phenocrysts	" " " " "
56	Groundmass	" " " " "
57,58	Phenocryst	Olivine + plagioclase + clino-pyroxene porphyritic basalt
59-61	Groundmass	Transitional basalt
62,64	After amygdale	High-grade basaltic hornfels
63	Groundmass	" " "
65,66	Original + patchy re-placement of macrophenocryst	Andesitic Sill

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	1	2	3	4	5	6	7	8	9	10
	740607	740607	751104	740801	740801	740801	750807	750808	750808	750808
WEIGHT PERCENT OXIDE										
SIO2	50.12	50.56	56.17	53.11	50.64	55.27	45.21	46.92	47.02	50.03
TIO2	0.03	0.00	0.04	0.09	0.05	0.08	0.00	0.00	0.00	0.00
AL2O3	29.29	30.74	23.14	28.97	31.33	24.16	29.30	33.45	32.39	28.61
CR2O3	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEO	0.10	0.21	0.56	0.62	0.62	2.37	3.39	0.51	0.87	0.73
MNO	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
MGO	0.01	0.00	0.29	0.01	0.01	0.02	2.34	0.15	0.22	0.56
CAO	15.26	14.01	14.59	10.06	14.08	9.62	17.87	19.56	16.60	16.30
NA2O	3.04	3.14	3.28	4.45	3.28	6.29	1.20	1.18	1.35	2.70
K2O	0.13	0.10	0.83	0.26	0.10	0.74	0.06	0.01	0.11	0.06
NIO	0.00	0.00	0.00	0.02	0.03	0.03	0.01	0.00	0.00	0.00
TOTAL	97.99	98.75	98.91	97.60	100.19	98.59	99.42	100.67	98.56	98.99
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS										
SI	2.3386	2.3297	2.5868	2.4497	2.3053	2.5660	2.1405	2.1465	2.1927	2.3239
TI	0.0016	0.0000	0.0014	0.0032	0.0031	0.0029	0.0000	0.0000	0.0000	0.0000
AL	1.6121	1.6705	1.2591	1.5761	1.6821	1.3225	1.6360	1.8085	1.7809	1.5672
CR	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	0.0042	0.0080	0.0215	0.0241	0.0237	0.0919	0.1344	0.0197	0.0340	0.0282
MN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0016	0.0000	0.0000	0.0000
MG	0.0005	0.0000	0.0201	0.0010	0.0009	0.0020	0.1651	0.0102	0.0155	0.0387
CA	0.7632	0.6916	0.7212	0.4970	0.6857	0.4787	0.9066	0.9116	0.8295	0.8110
NA	0.2749	0.2810	0.2930	0.3982	0.2892	0.5662	0.1105	0.1048	0.1220	0.2435
K	0.0078	0.0056	0.0492	0.0155	0.0058	0.0440	0.0039	0.0006	0.0064	0.0037
NI	0.0000	0.0000	0.0000	0.0008	0.0012	0.0012	0.0002	0.0000	0.0000	0.0000
END MEMBER COMPOSITIONS										
CA	72.97	70.70	67.82	54.57	69.95	43.96	88.80	89.63	86.59	76.64
NA	26.28	28.72	27.55	43.73	29.46	[illegible]	10.82	10.30	12.74	23.01
K	0.75	0.58	.63	1.70	0.59	.04	0.38	0.07	0.67	0.35

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	11	12	13	14	15	16	17	18	19	20
	750828	750828	740201	740301	750817	750817	750817	750817	750817	740510
WEIGHT PERCENT OXIDE										
SIO2	53.05	49.47	52.35	54.47	52.81	51.30	52.43	52.23	54.09	55.27
TIO2	0.00	0.00	0.10	0.03	0.05	0.05	0.10	0.14	0.05	0.09
AL2O3	21.51	30.03	28.04	26.95	28.02	27.48	27.53	27.15	26.29	26.75
CR2O3	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00
FEO	0.87	1.03	0.70	1.01	1.22	1.04	1.01	1.82	1.89	0.42
MNO	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.03
MGO	0.23	0.14	0.01	0.01	0.48	0.68	0.16	0.70	0.74	0.01
CAO	17.70	14.70	11.78	10.45	11.74	10.98	10.58	7.96	8.27	10.35
NA2O	3.23	2.96	4.90	5.47	4.03	4.11	4.78	5.47	5.72	5.92
K2O	0.03	0.02	0.19	0.30	0.23	0.21	0.29	1.02	1.06	0.19
NIO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	96.61	98.36	98.08	98.69	98.59	95.86	96.90	96.49	98.12	99.03
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS										
SI	2.5362	2.3439	2.4269	2.5014	2.4325	2.4276	2.4541	2.4614	2.5078	2.5216
TI	0.0000	0.0000	0.0034	0.0011	0.0019	0.0019	0.0037	0.0051	0.0019	0.0033
AL	1.2130	1.6496	1.5331	1.4594	1.5225	1.5336	1.5198	1.5090	1.4375	1.4396
CR	0.0000	0.0000	0.0000	0.0000	0.0003	0.0003	0.0000	0.0010	0.0003	0.0000
FE	0.0349	0.0400	0.0273	0.0389	0.0473	0.0412	0.0391	0.0716	0.0733	0.0160
MN	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0014
MG	0.0162	0.0097	0.0011	0.0006	0.0331	0.0477	0.0114	0.0494	0.0508	0.0006
CA	0.9065	0.7326	0.5850	0.5140	0.5797	0.5566	0.5307	0.4017	0.4110	0.5059
NA	0.2997	0.2676	0.4403	0.4869	0.3606	0.3767	0.4287	0.5003	0.5146	0.5232
K	0.0016	0.0013	0.0115	0.0178	0.0133	0.0129	0.0170	0.0615	0.0629	0.0107
NI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
END MEMBER COMPOSITIONS										
CA	75.06	73.18	56.42	50.46	60.79	58.82	54.35	41.71	41.58	48.65
NA	24.81	26.69	42.47	47.80	37.82	39.81	43.90	51.91	52.06	50.32
K	0.13	0.13	1.11	1.74	1.39	1.37	1.75	6.38	6.36	1.03

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	21	22	23	24	25	26	27	28	29	30
	740701	740701	740701	740701	740701	740701	740701	740701	740701	741101
WEIGHT PERCENT OXIDE										
SIO2	53.55	55.18	54.27	56.92	60.47	55.25	60.12	59.66	61.28	59.96
TIO2	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00
AL2O3	26.96	27.03	26.76	24.46	25.56	24.62	24.12	25.48	24.37	21.79
CR2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EFO	0.52	0.42	0.43	0.31	0.46	0.00	0.40	0.00	0.60	2.50
MNO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MGO	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.10
CAO	9.69	9.39	9.05	7.69	6.58	7.04	6.09	6.13	6.32	6.79
NA2O	6.32	6.36	6.61	7.06	6.93	7.69	7.56	7.05	7.33	7.34
K2O	0.25	0.29	0.28	0.47	0.08	0.58	0.15	0.08	0.09	0.31
NIO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	97.30	98.68	97.39	96.92	100.10	95.18	98.44	98.40	100.02	98.79
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS										
SI	2.4984	2.5284	2.5218	2.6397	2.6880	2.6086	2.7204	2.6831	2.7293	2.7345
TI	0.0000	0.0000	0.0003	0.0004	0.0005	0.0000	0.0000	0.0000	0.0004	0.0000
AL	1.4837	1.4636	1.4665	1.3379	1.3401	1.3714	1.2857	1.3523	1.2804	1.1745
CR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	0.0209	0.0140	0.0130	0.0120	0.0180	0.0000	0.0140	0.0000	0.0230	0.0956
MN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MG	0.0000	0.0000	0.0005	0.0000	0.0007	0.0000	0.0000	0.0000	0.0014	0.0064
CA	0.4844	0.4612	0.4506	0.3822	0.3132	0.3561	0.2952	0.2959	0.3018	0.3324
NA	0.5715	0.5652	0.5958	0.6349	0.5970	0.7041	0.6624	0.6147	0.6329	0.6511
K	0.0151	0.0169	0.0166	0.0281	0.0044	0.0351	0.0084	0.0044	0.0053	0.0185
NI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
END MEMBEP COMPOSITIONS										
CA	45.23	44.21	42.39	36.57	34.24	32.51	30.56	32.34	32.11	33.17
NA	53.36	54.18	56.05	60.74	65.28	64.28	68.56	67.18	67.33	64.98
K	1.41	1.61	1.56	[illegible]	0.48	3.21	0.88	0.48	0.56	1.85

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	31	32	33	34	35	36	37	38	39	40
	741101	741101	741101	740810	740810	740810	751801	740311	740311	740311
WEIGHT PERCENT OXIDE										
SIO2	57.47	59.35	56.73	52.48	59.97	60.04	63.64	52.66	52.79	60.94
TIO2	0.01	0.00	0.11	0.07	0.00	0.00	0.01	0.00	0.00	0.03
AL2O3	23.96	22.44	22.76	26.17	21.28	21.32	23.91	31.23	30.19	24.42
CR2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
FEO	0.90	1.37	2.10	0.63	2.06	2.06	0.14	0.02	0.12	0.87
MNO	0.00	0.01	0.00	0.05	0.01	0.01	0.00	0.00	0.00	0.00
MGO	0.12	0.08	0.37	0.03	0.67	0.67	0.10	0.00	0.00	0.12
CAO	6.02	3.68	1.58	12.06	1.99	1.87	4.55	11.38	10.57	4.46
NA2O	7.17	8.24	10.01	5.10	10.69	11.63	7.62	4.50	4.74	6.99
K2O	0.47	1.05	2.10	0.22	1.89	2.04	0.92	0.06	0.07	0.32
NIO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	96.07	96.21	95.77	96.80	98.45	99.65	100.29	99.84	98.47	98.16
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS										
SI	2.6762	2.7565	2.6864	2.4699	2.7587	2.7428	2.9016	2.3779	2.4139	2.7569
TI	0.0002	0.0000	0.0038	0.0024	0.0001	0.0001	0.0002	0.0000	0.0000	0.0015
AL	1.3107	1.2290	1.2712	1.4526	1.1544	1.1486	1.2004	1.6634	1.6280	1.3028
CR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008
FE	0.0349	0.0531	0.0833	0.0247	0.0793	0.0787	0.0002	0.0006	0.0002	0.0346
MN	0.0000	0.0009	0.0000	0.0020	0.0005	0.0005	0.0000	0.0000	0.0000	0.0000
MG	0.0086	0.0054	0.0263	0.0022	0.0461	0.0459	0.0000	0.0000	0.0000	0.0098
CA	0.3003	0.1829	0.0801	0.6084	0.0930	0.0916	0.2173	0.5505	0.5180	0.2165
NA	0.6474	0.7417	0.9196	0.4656	0.9532	1.0396	0.6703	0.3937	0.4296	0.6134
K	0.0282	0.0625	0.1271	0.0129	0.1107	0.1186	0.0009	0.0035	0.0038	0.0180
NI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
END MEMBER COMPOSITIONS										
CA	30.77	18.53	7.11	55.98	9.04	7.38	26.31	58.09	54.96	25.53
NA	66.34	75.14	81.61	42.83	82.39	83.06	69.58	41.54	44.63	72.35
K	2.89	6.33	11.28	[illegible]	9.57	9.56	4.11	0.37	0.41	2.12

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	41	42	43	44	45	46	47	48	49	50
	740311	740311	77011	77011	750806	750806	750806	750806	750806	7605
WEIGHT PERCENT OXIDE										
SIO2	63.04	61.97	58.10	62.70	57.98	57.18	57.65	66.67	73.70	62.33
TIO2	0.00	0.00	0.01	0.00	0.05	0.06	0.19	0.20	0.19	0.00
AL2O3	22.30	25.76	26.44	21.83	25.94	25.46	25.55	15.92	15.03	20.98
CR2O3	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
FEO	0.89	0.10	0.03	0.18	0.55	0.59	0.52	0.55	0.53	0.77
MNO	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MGO	0.07	0.00	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00
CAO	6.61	3.09	7.86	2.75	7.03	6.94	7.07	2.06	0.97	3.62
NA2O	6.79	7.25	6.08	7.55	7.15	7.06	7.68	6.70	6.45	7.04
K2O	0.33	0.42	1.01	3.75	0.73	0.86	0.68	7.25	3.96	1.51
NIO	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.01	0.00
TOTAL	99.23	98.59	99.53	98.87	99.44	98.17	99.36	99.36	100.84	96.25
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS										
SI	2.8021	2.7524	2.5891	2.8458	2.6356	2.6162	2.6104	3.0367	3.1949	2.8643
TI	0.0000	0.0000	0.0003	0.0000	0.0017	0.0022	0.0064	0.0067	0.0061	0.0000
AL	1.1800	1.3495	1.4001	1.1495	1.3799	1.3742	1.3642	0.8560	0.7695	1.1371
CR	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000
FE	0.0302	0.0040	0.0011	0.0066	0.0207	0.0227	0.0199	0.0210	0.0191	0.0295
MN	0.0000	0.0000	0.0003	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MG	0.0050	0.0000	0.0062	0.0065	0.0002	0.0000	0.0001	0.0001	0.0001	0.0000
CA	0.3474	0.1469	0.3877	0.1315	0.3400	0.3402	0.3430	0.1006	0.0451	0.1782
NA	0.6319	0.6246	0.5272	0.6540	0.6255	0.6261	0.6744	0.5926	0.5421	0.6277
K	0.0209	0.0237	0.0507	0.2132	0.0418	0.0500	0.0395	0.4215	0.2191	0.0883
NI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0003	0.0003	0.0003	0.0000
END MEMBER COMPOSITIONS										
CA	35.40	19.47	37.70	14.05	33.75	33.47	32.46	9.03	5.59	19.92
NA	63.48	79.55	55.99	64.80	62.10	61.61	63.80	53.16	67.24	70.20
K	1.12	[illegible]	6.31	21.15	4.15	4.92	3.74	37.[illegible]	27.17	9.88

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	51	52	53	54	55	56	57	58	59	60
	7605	7605	7605	7605	7605	7605	760814	760814	751218	751218
WEIGHT PERCENT OXIDE										
SIO2	64.77	65.29	62.87	66.05	66.08	67.47	55.67	53.14	54.16	54.58
TIO2	0.00	0.00	0.04	0.00	0.00	0.00	0.05	0.03	0.00	0.00
AL2O3	22.12	21.67	21.18	17.89	18.59	18.36	22.76	24.83	26.86	27.55
CR2O3	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEO	0.18	0.30	0.24	0.68	0.57	1.19	0.62	0.63	0.35	1.16
MNO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MGO	0.00	0.00	0.00	0.00	0.03	0.31	0.15	0.17	0.00	0.00
CAO	3.54	2.82	3.24	1.77	0.43	0.41	16.93	15.97	12.38	12.02
NA2O	7.15	5.98	7.35	6.58	6.48	7.55	2.87	3.70	4.00	4.20
K2O	1.70	2.22	2.29	5.55	5.32	5.37	0.14	0.12	0.21	0.21
NIO	0.00	0.00	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00
TOTAL	99.46	98.28	97.36	98.52	98.30	100.66	99.20	98.56	97.97	99.72
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS										
SI	2.8634	2.9113	2.8628	3.0001	3.0177	2.9976	2.5698	2.4741	2.4985	2.4815
TI	0.0000	0.0000	0.0014	0.0000	0.0000	0.0000	0.0018	0.0011	0.0000	0.0000
AL	1.1556	1.1396	1.1375	0.9581	0.9899	0.9619	1.2366	1.3543	1.4611	1.4775
CR	0.0000	0.0000	0.0036	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	0.0067	0.0113	0.0091	0.0260	0.0215	0.0441	0.0240	0.0236	0.0141	0.0441
MN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MG	0.0000	0.0000	0.0000	0.0000	0.0023	0.0205	0.0102	0.0116	0.0000	0.0000
CA	0.1680	0.1349	0.1581	0.0861	0.0207	0.0197	0.8354	0.7972	0.6119	0.5854
NA	0.6141	0.5168	0.6490	0.5793	0.5672	0.6596	0.2561	0.3341	0.3581	0.3704
K	0.0961	0.1265	0.1330	0.3217	0.3060	0.3046	0.0080	0.0072	0.0123	0.0120
NI	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
END MEMBER COMPOSITIONS										
CA	19.13	17.34	16.82	8.72	2.32	2.02	75.98	70.02	62.29	60.49
NA	69.93	66.41	69.03	58.[illegible]9	63.45	66.73	23.29	29.34	36.45	38.27
K	10.94	[illegible].25	14.15	3[illegible]	34.23	3[illegible].[illegible]5	0.73	0.64	1.26	1.24

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 3 FELDSPARS

	61	62	63	64	65	66
	751218	760805	760805	760805	7626	7626
WEIGHT PERCENT OXIDE						
SIO2	53.86	52.23	49.91	50.27	59.20	57.40
TIO2	0.00	0.00	0.00	0.00	0.00	0.00
AL2O3	27.62	30.95	31.63	32.68	17.68	19.93
CR2O3	0.00	0.00	0.00	0.00	0.00	0.00
FEO	0.36	0.56	0.81	0.62	0.05	0.09
MNO	0.00	0.00	0.00	0.00	0.00	0.00
MGO	0.00	0.00	0.00	0.00	0.00	0.00
CAO	12.15	11.78	12.16	11.64	17.34	10.59
NA2O	4.55	3.78	4.14	4.78	4.28	9.92
K2O	0.22	0.34	0.34	0.39	0.10	0.50
NIO	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	98.78	99.65	99.00	100.39	98.73	98.44
STRUCTURAL FORMULA ON THE BASIS OF 8 OXYGENS						
SI	2.4696	2.3715	2.2982	2.2819	2.9412	2.6787
TI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AL	1.4958	1.6574	1.7176	1.7497	1.0246	1.0969
CR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	0.0140	0.0212	0.0311	0.0236	0.0018	0.0037
MN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MG	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CA	0.5971	0.5733	0.6111	0.5662	0.9222	0.5297
NA	0.4048	0.3331	0.3696	0.4210	0.4120	0.8975
K	0.0131	0.0197	0.0200	0.0226	0.0068	0.0301
NI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
END MEMBER COMPOSITIONS						
CA	58.83	61.90	60.68	56.07	68.77	36.35
NA	39.88	35.97	37.30	41.69	30.73	61.59
K	1.29	2.13	2.02	[illegible]	0.50	2.06

TABLE 4. AMPHIBOLES

Analyses	Location	Host rock
1,2	Groundmass	Feldspar macroporphyritic hawaiite
3,4	Phenocryst	Alkali trachyte of Cnoc Scarall

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 4 AMPHIBOLES

	1	2	3	4
	740311	740311	7605	7605
WEIGHT PERCENT OXIDE				
SIO2	46.49	47.52	50.36	45.68
TIO2	1.96	2.14	0.92	5.70
AL2O3	7.89	7.29	2.35	10.51
CR2O3	0.00	0.01	0.05	0.01
FEO	12.49	12.39	15.46	18.78
MNO	0.18	0.34	0.62	0.56
MGO	14.74	15.42	9.83	4.91
CAO	9.98	10.87	12.81	7.96
NA2O	3.13	1.35	4.70	2.07
K2O	1.06	1.06	1.05	0.58
NIO	0.06	0.04	0.16	0.00
TOTAL	97.99	98.72	98.28	96.76
STRUCTURAL FORMULA ON THE BASIS OF 23 OXYGENS				
SI	7.1137	7.2377	7.8757	6.7696
TI	0.2259	0.2457	0.1075	0.6448
AL	1.4236	1.3107	0.4322	1.8635
CR	0.0000	0.0007	0.0162	0.0014
FE	1.5982	1.5770	2.0229	2.3615
MN	0.0234	0.0185	0.0825	0.0729
MG	3.3594	3.4988	2.2845	1.1003
CA	1.6357	1.7733	2.1474	1.2830
NA	0.9269	0.3652	1.4273	0.6953
K	0.2075	0.2057	0.2099	0.1113
NI	0.0075	0.0044	0.0201	0.0000
END MEMBER COMPOSITIONS				
CA	24.81	25.89	33.94	27.34
FE	24.24	23.02	30.01	49.77
MG	50.95	51.09	36.05	23.[illegible]

TABLE 5. SPINELS
(spinel and magnetite series)

Analyses	Location	Host rock
1	Chrome-spinel within olivine phenocryst	Olivine + spinel porphyritic basalt
2	" " in embayment near olivine	" " " "
3	" " irregular in groundmass	" " " "
4-7	" " core to rim within groundmass	" " " "
8,9	Titaniferous magnetite Groundmass	Olivine + plagioclase porphyritic basalt
10	" " Microphenocryst	Hawaiite
11,12	" " "	Mugearite
13-15	" " core to rim traverse in phenocryst	Coarse-grained mugearite
16	" " microphenocryst	" " "
17	" " "	Intermediate, sub-alkalic trachyte of Sleadale
18	" " "	Alkali trachyte of Cnoc Scarall
19-21	Hercynite Xenocryst core	Composite Hawaiite of Dun Ard an t-Sabhail
22	" " rim	" " " "
23,24	Titaniferous Magnetite rim to xenocryst	" " " "
25	" " Microphenocryst	" " " "
26	" " Groundmass	High-grade basaltic hornfels

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 5 SPINELS

	1	2	3	4	5	6	7	8	9	10
	751212	751212	751212	7616	7616	7616	7616	740801	751001	740801
WEIGHT PERCENT OXIDE										
SIO2	1.87	0.23	0.27	0.27	0.40	0.43	1.36	1.10	1.18	2.35
TIO2	0.93	0.93	0.82	0.77	0.82	0.89	1.01	29.94	27.17	20.92
AL2O3	25.81	26.14	23.84	22.84	21.28	22.44	23.62	3.05	1.59	2.70
CR2O3	35.86	35.15	38.78	39.12	40.51	38.22	34.82	0.13	0.17	0.17
FE2O3	4.06	8.14	8.02	8.07	8.16	9.11	8.44	5.69	10.56	21.98
FEO	15.71	11.93	11.13	12.23	12.81	11.96	14.60	55.70	51.59	47.33
MNO	0.27	0.33	0.39	0.35	0.37	0.33	0.39	0.95	2.05	0.85
MGO	15.02	16.01	16.04	15.41	14.96	15.59	14.43	2.41	1.93	3.60
CAO	0.05	0.09	0.44	0.04	0.03	0.05	0.65	0.22	0.22	0.18
NA2O	0.00	0.04	0.45	0.09	0.03	0.07	0.15	0.43	0.04	0.35
K2O	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIO	0.33	0.33	0.20	0.40	0.39	0.52	0.46	0.03	0.25	0.26
TOTAL	99.94	99.38	100.40	99.67	99.76	99.62	99.94	99.64	96.75	100.70
STRUCTURAL FORMULA ON THE BASIS OF 32 OXYGENS										
SI	0.4470	0.0797	0.0647	0.0887	0.0974	0.1052	0.3293	0.3173	0.3952	0.6691
TI	0.1674	0.1662	0.1484	0.1404	0.1515	0.1633	0.1845	6.5001	6.1443	4.4796
AL	7.2592	7.3877	6.7343	6.5428	6.1482	6.4369	6.7472	1.0395	0.5635	0.9067
CR	6.7708	6.6552	7.3415	7.5142	7.8460	7.3494	6.6686	0.0291	0.0412	0.0378
FE	0.7291	1.4679	1.4457	1.4755	1.5045	1.6678	1.5391	1.2358	2.3891	4.7096
FE	3.1383	2.3877	2.2287	2.4857	2.6235	2.4327	2.9575	13.4462	12.9773	11.2734
MN	0.0538	0.0672	0.0796	0.0712	0.0763	0.0677	0.0801	0.2315	0.5220	0.2057
MG	5.3454	5.7128	5.7258	5.5794	5.4627	5.6501	5.2106	1.0348	0.8660	1.5297
CA	0.0129	0.0193	0.1139	0.0104	0.0079	0.0128	0.1679	0.0681	0.0705	0.0554
NA	0.0000	0.0164	0.2079	0.0373	0.0134	0.0352	0.0702	0.2428	0.0248	0.1945
K	0.0078	0.0009	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NI	0.0630	0.0565	0.0390	0.0778	0.0769	0.1007	0.0890	0.0064	0.0611	0.0601
END MEMBER COMPOSITIONS										
FE	36.99	29.48	28.02	[illegible]	32.44	30.10	36.21	92.85	93.74	88.05
MG	63.01	70.52	71.98	[illegible]	67.56	69.90	63.79	7.15	6.26	11.95

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 5 SPINELS

	11	12	13	14	15	16	17	18	19	20
	740905	741101	740810	740810	740810	740810	750806	7605	760703	760703
WEIGHT PERCENT OXIDE										
SIO2	2.93	0.95	0.34	0.34	2.19	0.66	0.39	0.54	0.21	0.18
TIO2	21.78	21.21	23.33	23.33	23.07	24.87	13.90	18.52	2.38	1.56
AL2O3	[illegible]	1.12	2.75	2.89	3.03	1.55	3.28	0.48	46.26	49.42
CR2O3	0.15	0.08	0.10	0.11	0.09	0.09	0.03	0.01	0.09	0.04
FE2O3	19.93	24.50	20.63	19.70	15.59	17.13	28.06	31.32	15.80	14.46
FEO	48.94	49.18	47.62	47.54	48.62	50.83	40.77	46.30	23.85	22.26
MNO	0.90	1.02	0.63	0.71	0.67	0.84	0.94	2.09	0.15	0.20
MGO	3.15	0.90	3.27	3.18	3.52	1.71	1.95	0.31	11.48	12.51
CAO	0.37	0.17	0.02	0.03	0.09	0.13	0.06	0.03	0.00	0.00
NA2O	0.26	0.42	0.14	0.10	0.25	0.17	0.00	0.01	0.01	0.00
K2O	0.00	0.00	0.05	0.04	0.05	0.03	0.00	0.00	0.00	0.00
NIO	0.24	0.24	0.25	0.27	0.24	0.28	0.09	0.00	0.08	0.04
TOTAL	99.65	99.79	98.96	97.74	97.41	98.27	99.47	99.60	100.32	100.77
STRUCTURAL FORMULA ON THE BASIS OF 32 OXYGENS										
SI	0.8443	0.2829	0.0989	0.1002	0.6420	0.1976	0.1142	0.1605	0.0477	0.0396
TI	4.7244	4.7415	5.1326	5.1839	5.0853	5.5817	3.0851	4.1984	0.4064	0.2780
AL	0.6813	0.3910	0.9495	1.0079	1.0476	0.5451	1.1399	0.1720	12.3775	12.9412
CR	0.0347	0.0190	0.0220	0.0251	0.0205	0.0219	0.0071	0.0026	0.0153	0.0076
FE	4.1199	5.4839	4.5413	4.3876	3.4373	3.8470	6.4541	7.1068	2.6978	2.4159
FE	11.8062	12.2260	11.6515	11.6245	11.9182	12.6868	10.0632	11.6738	4.5262	4.1330
MN	0.2195	0.2581	0.1684	0.1776	0.1662	0.2117	0.2348	0.5396	0.0300	0.0383
MG	1.3547	0.3981	1.3364	1.3581	1.5395	0.7600	0.8581	0.1438	3.8830	4.1398
CA	0.1135	0.0543	0.0049	0.0102	0.0273	0.0403	0.0198	0.0103	0.0000	0.0000
NA	0.1465	0.2409	0.0794	0.0553	0.1430	0.0971	0.0017	0.0032	0.0055	0.0000
K	0.0000	0.0000	0.0171	0.0169	0.0169	0.0124	0.0000	0.0000	0.0000	0.0000
NI	0.0566	0.0578	0.0583	0.0647	0.0561	0.0668	0.0232	0.0000	0.0142	0.0065
END MEMBER COMPOSITIONS										
FE	89.71	96.85	89.71	89.7[illegible]	88.56	94.35	92.1[illegible]	98.78	53.82	49.96
MG	10.29	3.15	10.29	1[illegible]	11.44	5.65	7.[illegible]	[illegible]	46.18	50.04

TERTIARY LAVAS, WEST-CENTRAL SKYE   TABLE 5   SPINELS

	21	22	23	24	25	26
	760703	760703	760703	760703	760703	760805
WEIGHT PERCENT OXIDE						
SIO2	0.16	0.17	1.12	0.36	0.74	0.89
TIO2	1.42	1.41	14.78	14.88	24.42	11.71
AL2O3	49.52	50.19	9.44	9.24	1.47	4.44
CR2O3	0.05	0.07	0.12	0.12	0.05	2.52
FE2O3	13.86	12.80	28.58	29.73	19.38	36.41
FEO	21.02	21.59	42.95	41.65	50.13	40.14
MNO	0.14	0.14	0.46	0.46	0.69	0.70
MGO	12.55	12.51	2.95	2.94	2.46	1.49
CAO	0.01	[illegible]	0.03	0.03	0.09	0.16
NA2O	0.00	0.00	0.06	0.06	0.06	0.00
K2O	0.00	0.00	0.00	0.00	0.00	0.00
NIO	0.11	0.10	0.11	0.17	0.15	0.18
TOTAL	99.47	98.98	100.61	99.65	99.64	98.64
STRUCTURAL FORMULA ON THE BASIS OF 32 OXYGENS						
SI	0.0397	0.0391	0.3129	0.1010	0.2177	0.2611
TI	0.2367	0.2365	3.1067	3.1699	5.3909	2.6095
AL	13.0984	13.2755	3.1131	3.0874	0.5091	1.5500
CR	0.0112	0.0122	0.0265	0.0269	0.0112	0.5914
FE	2.3334	2.1612	6.0129	6.2351	4.2742	8.1176
FE	4.0444	4.0503	10.0415	9.8641	12.2851	9.9457
MN	0.0265	0.0249	0.1084	0.1114	0.1717	0.1763
MG	4.1862	4.1824	1.2204	1.2428	1.0740	0.6522
CA	0.0012	[illegible]	0.0101	0.0102	0.0291	0.0485
NA	0.0000	0.0000	0.0335	0.0353	0.0329	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NI	0.0201	0.0200	0.0250	0.0380	0.0347	0.0418
END MEMBER COMPOSITIONS						
FE	49.14	49.20	89.08	88.81	91.96	93.79
MG	50.86	50.80	10.92	11.19	8.04	6.21

TABLE 6. ILMENITES

Analyses	Location	Host rock
1	Discrete crystal	High-grade basaltic hornfels
2	Irregular patch in groundmass	Intermediate, sub-alkalic trachyte of Sleadale

TERTIARY LAVAS, WEST-CENTRAL SKYE TABLE 6 ILMENITES

	1	2
	761345	759836
WEIGHT PERCENT OXIDE		
SIO2	0.33	0.25
TIO2	48.05	47.65
AL2O3	0.17	0.17
CR2O3	0.28	0.06
FE2O3	6.93	9.77
FEO	40.05	37.36
MNO	0.99	1.57
MGO	1.39	2.78
CAO	0.16	0.13
NA2O	0.07	0.05
K2O	0.00	0.03
NIO	0.00	0.14
TOTAL	98.27	99.27
STRUCTURAL FORMULA ON THE BASIS OF 6 OXYGENS		
SI	0.0169	0.0125
TI	1.8353	1.7959
AL	0.0103	0.0103
CR	0.0112	0.0024
FE	0.2653	0.3685
FE	1.7046	1.5453
MN	0.0427	0.0681
MG	0.1055	0.1777
CA	0.0055	0.0016
NA	0.0018	0.0049
K	0.0000	0.0019
NI	0.0000	0.0056
END MEMBER COMPOSITIONS		
FE	94.17	89.8[illegible]
MG	5.83	[illegible]

KEY TO MAPS [Symbols and divisions as in text figures 8 - 14]

LAVAS
- Basalt
- Hawaiite
- Mugearite
- Benmoreite
- Trachyte

PLUTONS
- Gabbro
- Peridotite

INTER-LAVA
- Tuff and Agglomerate
- Major 3° Sediments

MINOR SILLS
- 'Andesite Sill'
- Felsite

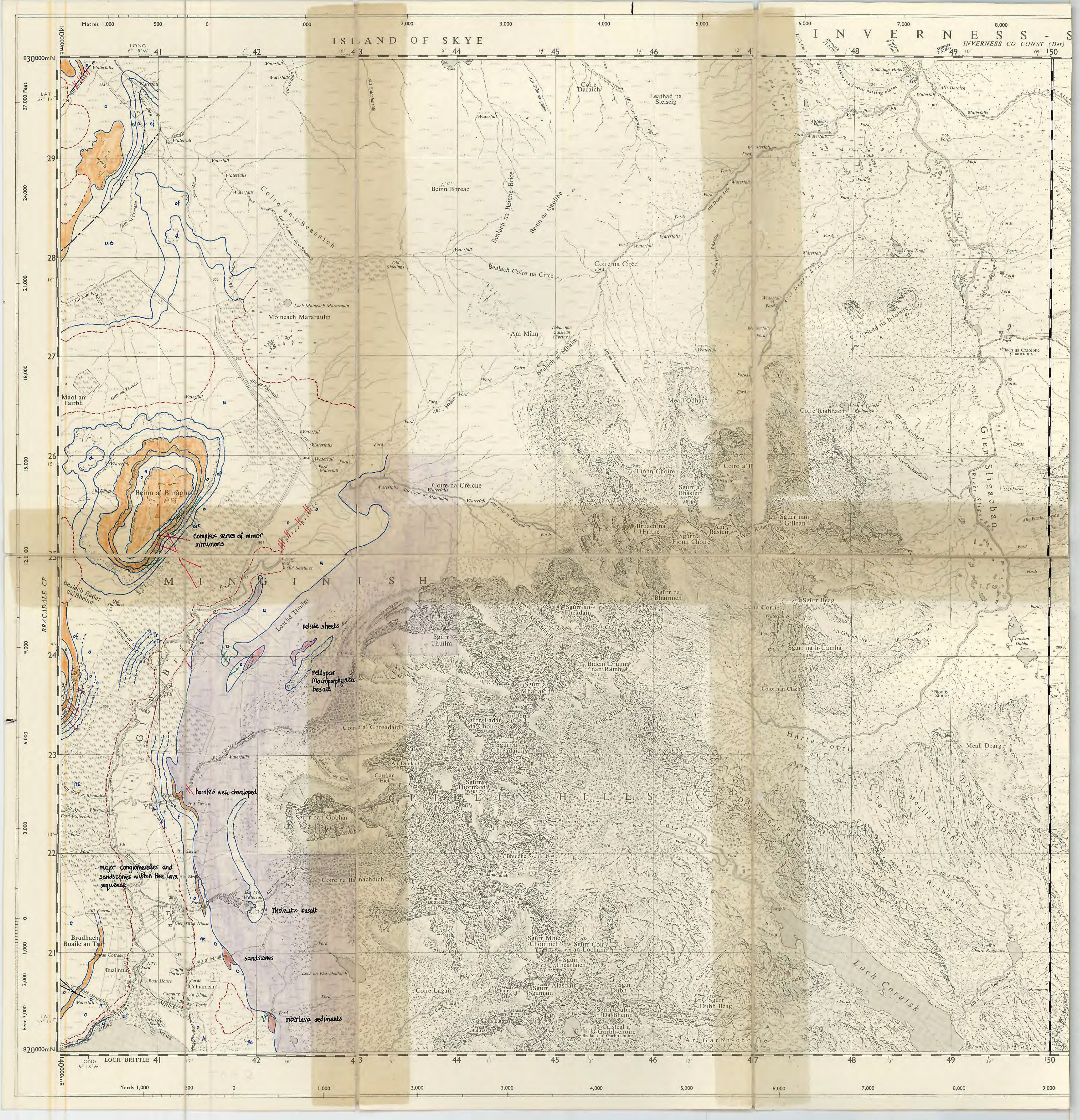
- Pre Tertiary and basal sill

- Dykes
- Inclined Sheets and Creagan Dubh Sill
- Fault
- Geological Boundary
- Drift Boundary

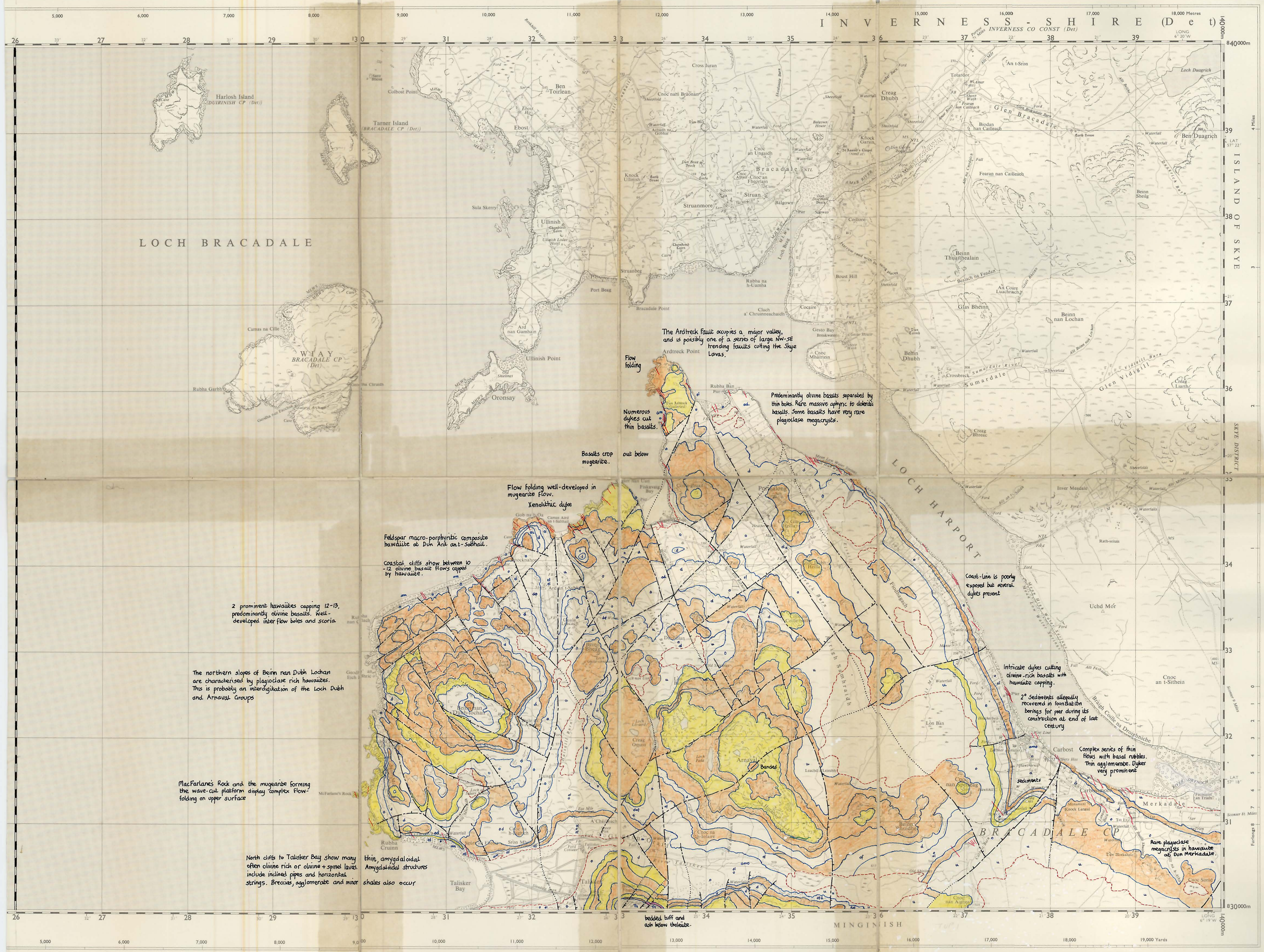
For subdivision symbols of lavas see Text fig. 8-14

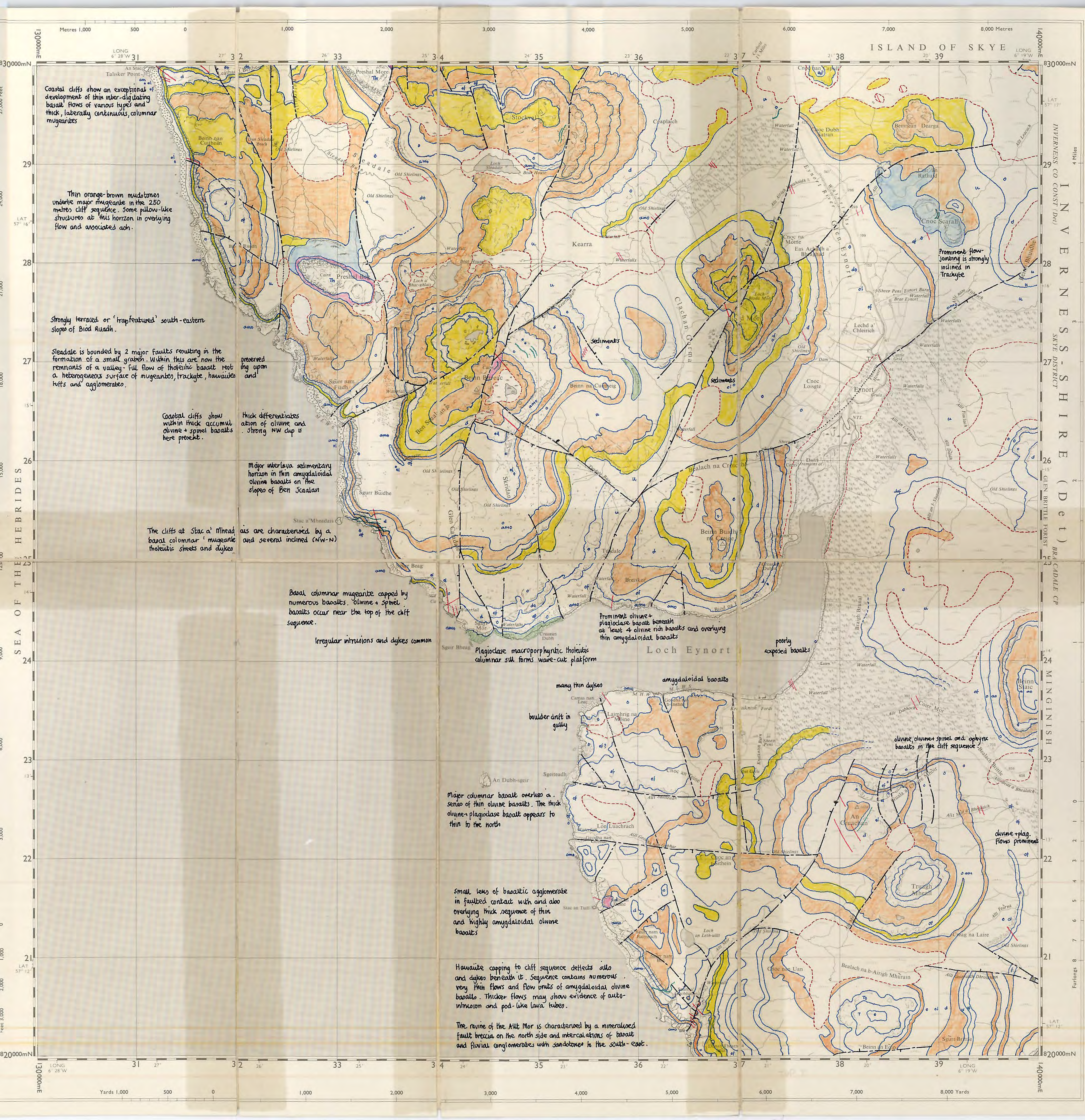
MAP SCALE 1 : 25,000
Lavas mapped as individual and associations of flows.


INVERNESS-SHIRE (Det)
MINGINISH
ISLAND OF SKYE
SKYE DISTRICT
INVERNESS CO CONST (Det)
BRACADALE CP
CUILLIN HILLS
SEA OF THE HEBRIDES
LOCH BRITTLE
SOAY SOUND
LOCH SCAVAIG
STRATH CP
SOAY
BRACADALE CP (Det)
Rubha Thearna Sgùrr
Geodha Daraich
Geodha na h-Airigh Mòire
Buaile Dhubh
Sron na Ciche
An Sguman
Coir' a' Ghobhainn
Ceann na Beinne
Loch Mhachdannach
Cnoc Leathan
An Leac
Càrn Mòr
Camas a' Mhùrain
Rubh' an Dùnain
Loch na h-Airde
Sgeir Mhòr
Sgurr nan Eag
Gars-bheinn
Rubha Buidhe
Rubh' a' Gheodha Bhuidhe
Ulfhart Point
Beinn Bhreac
Camas nan Gall
Cnoc na Moil Deirge
Rubha Dubh
Doire Chaol
Mol-chlach
Doire Mhòr
Major fluvial conglomerates and sandstones in cliffs. Also intruded by 'Andesitic Sill'. Some pillow-like structures above the sediments.
Cliff sequence is dominated by major hawaiites forming bold ridges and escarpments. Possibly cyclic occurrence. Mugearite is beautifully flow banded with small trough structures as above Allt Geodh'a'Ghamhna. Overlain by feldspar macroporphyritic basalts. Terracing very pronounced.
Small plug of gabbro in basalts. Banded.
2 small vents and masses of lava breccia
Radial coastal dyke on wave-cut platform.
olivine + plagioclase macroporphyritic flow in cliffs.
Major feldspathic peridotite dyke
Doleritic basalt overlies thin olivine basalts.
Sequence appears to be mainly of thin and often olivine rich basalts with rarer plagioclase microphenocrystic types and aphyric examples. The latter are generally more massive and melanocratic
Peridotite plug at the margins of the gabbros Hornfels lavas well-developed.
olivine rich and picritic (+ spinel) dykes
Small development of interlava sediments and tuff
Small vent overlain by the lavas sequence. Basal sill irregular
Banded tuff in lava sequence.
Coastline and coastal cliffs reveal the base to the 3° lavas. These are chacterised by the early appearance of differentiated types overlying a sequence of Torridonian Permo-Trias, Jurassic and Cretaceous strata with a slight angular unconformity. Sediments young to the west and are cut by numerous dykes. A thin tuff is present between the volcanics and sediments at some localities



ISLAND OF SKYE
INVERNESS-S
INVERNESS CO CONST (Det)
Metres 1,000
Yards 1,000
BRACADALE CP
LOCH BRITTLE
MINGINISH
CUILLIN HILLS
Glen Brittle
Glen Sligachan
Beinn Bhreac
Bealach na Bairnie Brice
Beinn na Gaoithe
Coire Daraich
Leathad na Steiseig
Bealach Coire na Circe
Coire na Circe
Coire an t-Seasaich
Moineach Mararaulin
Loch Moineach Mararaulin
Am Màm
Bealach a' Mhàim
Meall Odhar
Fionn Choire
Sgùrr a' Bhasteir
Am Basteir
Sgùrr nan Gillean
Bruach na Frìthe
Coire na Creiche
Coire Riabhach
Nead na h-Iolaire
Maol an Tairbh
Beinn a' Bhràghad
Bealach Eadar dà Bheinn
Sgùrr an Fheadain
Sgùrr na Bhairnich
Sgùrr Thuilm
Bidein Druim nan Ràmh
Sgùrr a' Mhadaidh
Sgùrr Beag
Sgùrr na h-Uamha
Coire a' Ghreadaidh
Sgùrr a' Ghreadaidh
Sgùrr Thormaid
Sgùrr nan Gobhar
Coire na Banachdich
Sgùrr Mhic Choinnich
Sgùrr Alasdair
Sgùrr Dubh Mòr
Sgùrr Dubh Beag
Coire Lagan
An Garbh-choire
Loch Coruisk
Harta Corrie
Meall Dearg
Druim nan Ràmh
Brudhach Buaile an Tuir
Glenbrittle House
Culnamean
complex series of minor intrusions
Felsite sheets
Feldspar Macroporphyritic basalt
hornfels well-developed
major conglomerates and sandstones within the lava sequence
Tholeiitic basalt
sandstones
interlava sediments


INVERNESS-SHIRE (Det)
INVERNESS CO CONST (Det)
ISLAND OF SKYE
SKYE DISTRICT
LOCH BRACADALE
LOCH HARPORT
MINGINISH
BRACADALE CP
WIAY
BRACADALE CP (Det)
Harlosh Island
DUIRINISH CP (Det)
Tarner Island
(BRACADALE CP (Det))
Oronsay
Ullinish Point
Ardtreck Point
Bracadale Point
Port Beag
Rubha Bàn
Talisker Bay
Rubha Cruinn
Carbost
Merkadale
Glen Bracadale
Glen Vidigill
Sumardale
Struanmore
Struan
Bracadale
Ebost
Ben Duagrich
Loch Duagrich
Beinn Dhubh
Beinn nan Lochan
Glas Bheinn
Beinn Thuaithealain
Uchd Mòr
Cnoc an t-Sìthein
Arnaval
Beinn nan Dubh-lochan
The Ardtreck Fault occupies a major valley, and is possibly one of a series of large NW-SE trending faults cutting the Skye Lavas.
Flow folding
Numerous dykes cut thin basalts.
Predominantly olivine basalts separated by thin boles. Rare massive aphyric to doleritic basalts. Some basalts have very rare plagioclase megacrysts.
Basalts crop out below mugearite.
Flow folding well-developed in mugearite flow.
Xenolithic dyke
Feldspar macro-porphyritic composite hawaiite at Dun Ard ant-Sabhail.
Coastal cliffs show between 10 -12 olivine basalt flows capped by hawaiite.
2 prominent hawaiites capping 12-13, predominantly olivine basalts. Well-developed inter flow boles and scoria
The northern slopes of Beinn nan Dubh Lochan are characterised by plagioclase rich hawaiites. This is probably an interdigitation of the Loch Dubh and Arnaval Groups
MacFarlane's Rock and the mugearite forming the wave-cut platform display complex flow-folding on upper surface
North cliffs to Talisker Bay show many thin, amygdaloidal often olivine rich or olivine + spinel lavas. Amygdaloidal structures include inclined pipes and horizontal strings. Breccias, agglomerate and minor shales also occur
Coast-line is poorly exposed but several dykes present
Intricate dykes cutting olivine-rich basalts with hawaiite capping.
2° Sediments allegedly recovered in foundation borings for pier during its construction at end of last century
Complex series of thin flows with basal rubbles. Thin agglomerate. Dykes very prominent
sediments
Banded
Rare plagioclase megacrysts in hawaiite at Dun Merkadale.
bedded tuff and ash below tholeiite.
18,000 Metres
19,000 Yards
4 Miles


ISLAND OF SKYE
INVERNESS-SHIRE (Det)
INVERNESS CO CONST (Det)
SKYE DISTRICT
GLEN BRITTLE FOREST
BRACADALE CP
MINGINISH
SEA OF THE HEBRIDES
Loch Eynort
Glen Eynort
Clachan Gorma
Kearra
Sleadale
Skridan
Talisker Point
Preshal More
Preshal Beg
Beinn nan Cuithean
Cnoc Scarall
Beinn Buidhe
Trutagh Mhead
An Cruachan
Sgurr Buidhe
Stac a' Mhadaidh
An Dubh-sgeir
Coastal cliffs show an exceptional development of thin inter-digitating basalt flows of various types and thick, laterally continuous, columnar mugearites
Thin orange-brown mudstones underlie major mugearite in the 250 metres cliff sequence. Some pillow-like structures at this horizon in overlying flow and associated ash.
Strongly terraced or 'trapfeatured' south-eastern slopes of Biod Ruadh.
Sleadale is bounded by 2 major faults resulting in the formation of a small graben. Within this are now the remnants of a valley-fill flow of tholeiitic basalt resting upon a heterogeneous surface of mugearites, trachyte, hawaiites and tuffs and agglomerates.
Coastal cliffs show within thick accumulation of olivine + spinel basalts here present.
thick differentiation of olivine and. Strong NW dip is
Major interlava sedimentary horizon in thin amygdaloidal olivine basalts on the slopes of Ben Scaalan
The cliffs at Stac a' Mheadais are characterised by a basal columnar 'mugearite' and several inclined (NW-N) tholeiitic sheets and dykes
Basal columnar mugearite capped by numerous basalts. Olivine + spinel basalts occur near the top of the cliff sequence.
Irregular intrusions and dykes common
Plagioclase macroporphyritic tholeiitic columnar sill forms wave-cut platform
Prominent olivine + plagioclase basalt beneath at least 4 olivine rich basalts and overlying thin amygdaloidal basalts
sediments
poorly exposed basalts
amygdaloidal basalts
many thin dykes
boulder drift in gully
Prominent flow-jointing is strongly inclined in Trachyte
olivine, olivine + spinel and ophyric basalts in the cliff sequence
olivine + plag. flows prominent
Major columnar basalt overlies a series of thin olivine basalts. The thick olivine + plagioclase basalt appears to thin to the north
Small lens of basaltic agglomerate in faulted contact with and also overlying thick sequence of thin and highly amygdaloidal olivine basalts
Hawaiite capping to cliff sequence deflects sills and dykes beneath it. Sequence contains numerous very thin flows and flow units of amygdaloidal olivine basalts. Thicker flows may show evidence of auto-intrusion and pod-like lava tubes.
The ravine of the Allt Mor is characterised by a mineralised fault breccia on the north side and intercalations of basalt and fluvial conglomerates with sandstones to the south-east.