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AN INVESTIGATION OF SOME METAMORPHOSED DYKES OF THE NAIN AREA, LABRADOR: PART 2–GEOCHEMISTRY OF THE AKKUNEQ DYKES OF THE DOG ISLAND REGION

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ABSTRACT

Geochemical analysis of metamorphosed mafic dykes, termed the Akkuneq dykes, which intrude the Archean gneisses in the Nain region, Labrador, suggests the presence of at least four distinct chemical groups, subdivided according to Zr/Nb and Ba/Rb ratios. The variable recrystallization of the dykes does not seem to have affected their chemical signature, and hence metamorphism was mainly isochemical. Chemical comparisons of the Akkuneq dykes with other Labrador dyke swarms show two of the four groups to be similar to the mid-Proterozoic Harp dykes, although on the basis of field evidence they are demonstrably not contemporaneous swarms. Chemical evolution trends deduced from the Akkuneq dyke data suggest a dominant role for crystal fractionation processes. Furthermore, integration of dyke chemical type with field characteristics shows some evidence of a link between magma evolution, dyke orientation and width. Many of the dykes may represent leaks from a subcrustal magma chamber, although whether this episode is of Archean or Proterozoic age is unknown. The presence of distinct chemical groups in the Akkuneq dyke assemblage is not in itself indicative of several episodes of dyke magmatism. Chemical signature may be controlled by mantle evolution processes but further geochronological constraints are required to test this hypothesis.

INTRODUCTION

In recent years, much progress has been made in the understanding of dyke swarms and their relative importance to the geological record. Episodes of dyke emplacement have been linked, spatially, temporally and chemically, to magmatism of continental flood basalt (CFB) type (e.g., LeCheminant and Heaman, 1989). Large continental dyke swarms are interpreted as forming the root zones to CFB provinces, and consequently are best exposed in exhumed terranes of mainly Proterozoic age. However, fundamental challenges still exist in understanding the relative influence that different petrogenetic processes have in the generation of continental basaltic magmas. One reason for the continuing controversy is that the precise chronological and petrological relationships between the large plutons, dyke swarms and flood basalts that make up these igneous suites are still, in many cases, relatively poorly understood. The degree to which secular evolution of the mantle may have affected magma chemistry is also in need of resolution.

The Nain region of Labrador (Figure 1) is an excellent area to study these two problems. The region is host to voluminous, mid-Proterozoic plutonic rocks, consisting predominantly of massive anorthosites, norites, troctolites and granitoids collectively termed the Nain Plutonic Suite (NPS). Recent studies in the Nain area (Ryan, 1991, 1992; Ryan *et al.*, 1991; Connelly and Ryan, 1992; Cadman *et al.*, 1993a) have also shown that the region has been injected by at least six generations of mafic dykes, ranging in age from ca. 2.5 to 1.29 Ga. Four generations of these dykes predate the intrusion of the NPS, and have been given the name Akkuneq dykes*. These intrusions, the subject of this paper, have textures and a mineralogy that indicate metamorphic recystallization up to granulite facies; some are demonstrably intruded into ductile country rocks and were subjected to shear deformation. Examination of the Akkuneq dyke assemblage was undertaken in 1992 in an attempt to define their chemical, structural and geochronological relationship with other rocks and tectonic events in the Nain area, especially to ascertain whether there is a connection between the dykes and the development of the NPS.

Many dyke samples were collected from the region around Dog Island, northeast of Nain village (Figure 2) during July and August of 1992. These have been chemically

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[1] Labrador Mapping Section

* The name Akkuneq dykes has been proposed by A.B. Ryan in a manuscript recently submitted to 'Precambrian Research'. Akkuneq is an Inuit term meaning 'that which lies between'.

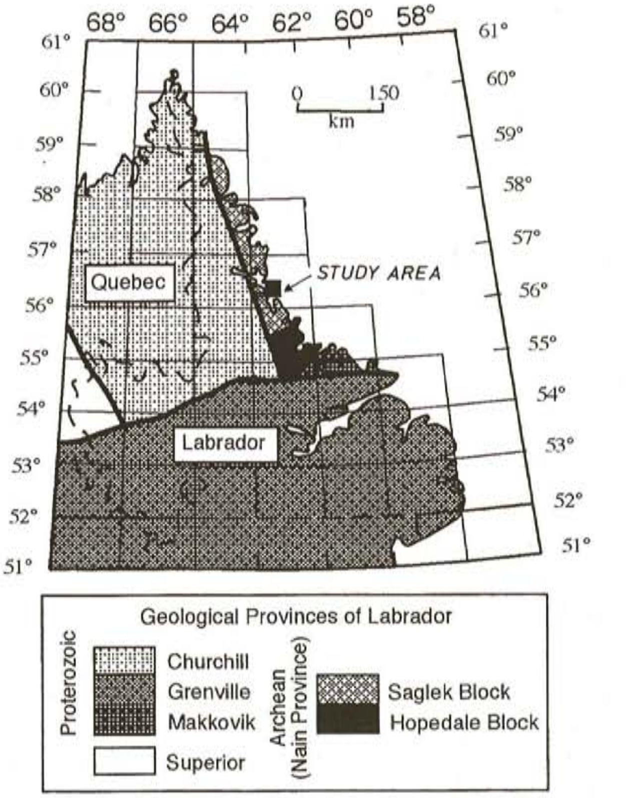

Figure 1. *Location of the study area in relation to the regional tectonic framework of Labrador.*

analyzed for major and trace elements. The purpose of this paper is, therefore, to (1) present a preliminary chemical classification of the Akkuneq dyke assemblage; (2) compare the chemistry of the Akkuneq dykes with other Labrador dyke swarms; (3) discuss the possible relationship between the Akkuneq dykes and the NPS; and (4) discuss how basic dyke magmatism in Labrador has evolved throughout geological time.

PREVIOUS WORK

Much of the pioneering work on the rocks of the Nain area was carried out by E.P. Wheeler in an extensive research program starting in 1926 and lasting until 1974 (Wheeler, 1942, 1960). Subsequently, a number of studies have focussed on more specific topics and problems, for instance the anorthosites and associated rocks of the NPS, which were studied during the ten-year (1971-1981) Nain Anorthosite Project under the co-ordination of S.A. Morse (cf. Morse, 1983). Studies of the gneissic country rocks were carried out by de Waard (1971), Taylor (1979) and more recently by Bridgwater *et al.* (1990) and Ryan (1991, 1992).

Compared to the gneissic host rocks, the dykes of the Nain region, although noted by earlier workers such as Upton (1971, 1974), have until recently been comparatively neglected. Consequently, their characteristics and potential significance to understanding crust and mantle evolution remained largely unknown until re-examination by Ryan (1991, 1992) during remapping of the Nain area between 1990 and 1992.

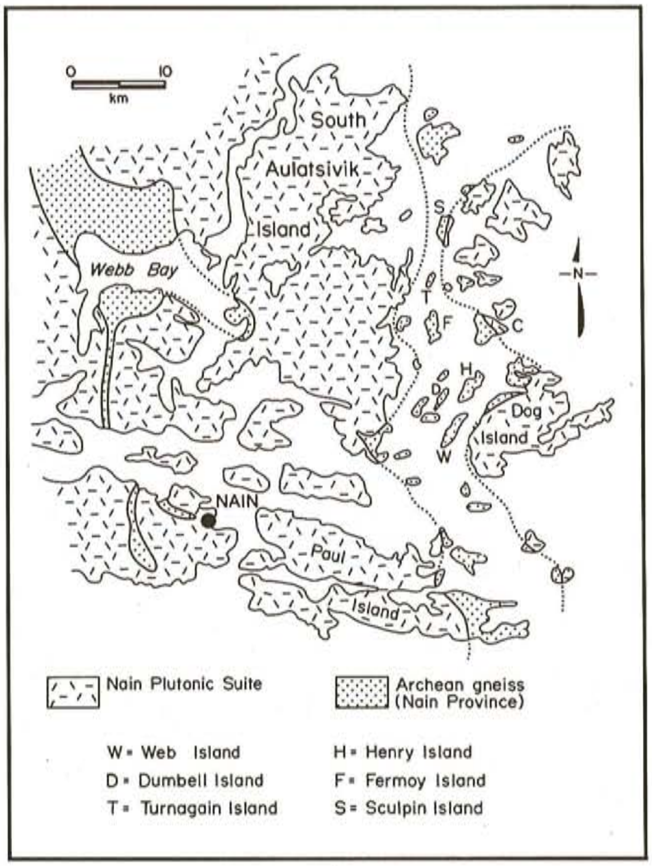

Figure 2. *General geology of the archipelago east of Nain (after Ryan, 1991).*

GEOLOGICAL SETTING

The Archean Nain Province comprises a superbly exposed sequence of metamorphic and igneous rocks along the northern and central segments of the Labrador coast (Figure 1). The Nain Province is subdivided into two distinct crustal blocks. The older Saglek block occupies the northern half of the Province; its major rock units range in age between 3900 Ma–2500 Ma (Bridgwater and Schiøtte, 1991). Rocks of Early- and Mid- Archean age are dominant, including migmatized layered tonalitic and granodioritic gneisses, minor quartz monzonites, Fe-rich granodiorites and metagabbros, and basic supracrustal and intrusive units. Bridgwater and Schiøtte (1991) suggest that tectonic intercalation of Early and Mid-Archean gneisses occurred around 2700 Ma and that this event correlates with a terrane amalgamation episode postulated for the Archean rocks of West Greenland (Friend *et al.*, 1987, 1988; Nutman *et al.*, 1989). Recent age-dating in the Nain area further suggests a Late Archean terrane amalgamation of the Saglek and Hopedale blocks (Connelly and Ryan, 1992). At least three generations of mafic dykes intrude the Saglek block; the Mid-Archean porphyritic Saglek dykes, a Late Archean swarm, perhaps correlative with the Hopedale dykes in the Hopedale block (Bridgwater and Schiøtte, 1991), and the Early Proterozoic Domes–Napatok swarms (Ryan 1990; Ermanovics and Van Kranendonk, 1990). The Hopedale block comprises polydeformed gneisses of predominantly granodioritic to tonalitic composition, ranging in age between 3200 and 2800 Ma. The gneisses have a predominantly northeast–southwest trend interpreted by Ermanovics *et al.* (1982) to be Late Archean. This foliation overprints an earlier northwest–southeast-oriented foliation termed the Hopedalian trend dated at 3100 Ma (Grant *et al.*, 1983). Earlier events, around 3300–3250 Ma (from U–Pb zircon techniques; Loveridge *et al.*, 1987), were mainly erased by the Hopedalian event (Ermanovics *et al.*, 1982). The Hopedale block is intruded by three generations of mafic dykes: the Late Archean Hopedale dykes, the Early Proterozoic Kikkertavak dykes and the Mid-Proterozoic Harp dykes. U–Pb geochronological studies yield emplacement ages of 2235 ± 2 Ma and 1273 ± 1 Ma for some members of the Kikkertavak and Harp dyke swarms respectively (Cadman *et al.*, 1993b). The Nain Province is bounded to the west and south by the Early Proterozoic Churchill and Makkovik provinces, respectively. Metamorphism associated with the accretion of these terranes dated at ca. 1.8 Ga (Wardle *et al.*, 1990; Ermanovics and Ryan, 1990) variably overprints Archean rocks of the Nain Province.

The gneisses of the Nain region that host the dykes that are the focus of this study, occupy a narrow north-trending septum between NPS intrusions in an area that lies approximately half-way between the Hopedale and Saglek blocks. The Archean gneissic rocks in this region have not been examined in detail until recently: Bridgwater *et al.* (1990) attempted to correlate them with units present within the Saglek and Hopedale blocks; Ryan (1991) subdivided them into four main lithological groups, which are in turn divisible into a number of distinct units:

1) *quartzofelspathic gneisses and foliated granitic rocks,* including migmatized tonalites and granodiorites, wispy migmatitic granitoids, foliated granitoids and aplite sheets;
2) *granulite-facies quartzofelspathic gneisses;* in some cases higher grade equivalents of (1);
3) *metasedimentary gneisses;* and
4) *mafic gneisses,* including two types of well-layered, mafic granulites, one of which lies adjacent to some anorthositic plutons and may be related to NPS magmatism.

The Akkuneq dykes intrude all the above rock-types, with the possible exception of some of the enigmatic mafic granulites that occur marginal to the NPS plutons (Ryan, 1992).

MINERALOGY AND PETROGRAPHY

The Akkuneq dykes of the Nain region show a complex and diverse mineralogy, often varying substantially between different intrusions at a single locality. Only a brief summary of the mineralogical features is given here. A more detailed account is in preparation (B. Ryan, unpublished data, 1994).

The primary minerals of the Akkuneq dykes have been, in most dykes, modified by granulite- or amphibolite-facies metamorphism. Where igneous textures are preserved, plagioclase and clinopyroxene and accessory oxide are the dominant crystal phases. Olivine is rare, being observed in only two cases by the authors. Phyric plagioclase is visible both at outcrop and at thin section scale. In some dykes, the feldspars are black or grey, similar to the plagioclase crystals observed in 'dark facies' members of the NPS described by Wheeler (1942). In other cases, white laths of plagioclase, a few millimetres in length, form radial aggregates, which superficially resemble 'snowflake' textures within some troctolitic NPS rocks described by Berg (1980).

The primary groundmass of Akkuneq dykes, as noted above, is dominated by plagioclase and clinopyroxene. However, in the majority of intrusions the groundmass assemblage has been recrystallized as polygonal crystals of plagioclase and secondary brown or green amphibole (replacing pyroxene), although original plagioclase phenocrysts are recognizably preserved. Biotite and granular orthopyroxene are also widespread secondary minerals. Biotite crystals define a foliation in many recrystallized dykes with otherwise granoblastic texture. The proportions of secondary minerals, both to primary phases and to each other, vary substantially between individual intrusions.

GEOCHEMICAL CLASSIFICATION

The Akkuneq dyke assemblage sampled in the Dog Island region in 1992 shows a surprising degree of chemical homogeneity, in spite of the considerable evidence (e.g., crosscutting relationships) for multiple dyke generations and subsequent metamorphic overprinting. On most chemical criteria, the Akkuneq dykes do not show marked compositional differences that allow confident subdivision into different groups. Concentration in most elements varies smoothly, and ratios between high field strength elements (e.g., Ti/Zr), which are least likely to be affected by metamorphism, are relatively constrained. The Akkuneq dykes are most easily subdivided using variation in the ratios Zr/Nb and Ba/Rb. On this basis, dykes have been subdivided into four groups (Table 1). The incompatible element spidergrams of each group are shown in Figure 3, with representative chemical analyses given in Table 2. However, it should be noted that without firm chronological information these groups cannot be inferred to represent separate dyke swarms.

Table 1. Provisional classification criteria of the Akkuneq dyke assemblage

	Zr/Nb	Ba/Rb
Akkuneq A	4.8-7.4	13.1-31.3
Akkuneq B	9.4-23.5	10.5-41.2
Akkuneq C	9.7-21.2	78.8-107.4
Akkuneq D	5.8-19.2	1.2-8.7

The use of Ba/Rb ratios in classification needs justification. Such LIL-elements are generally considered

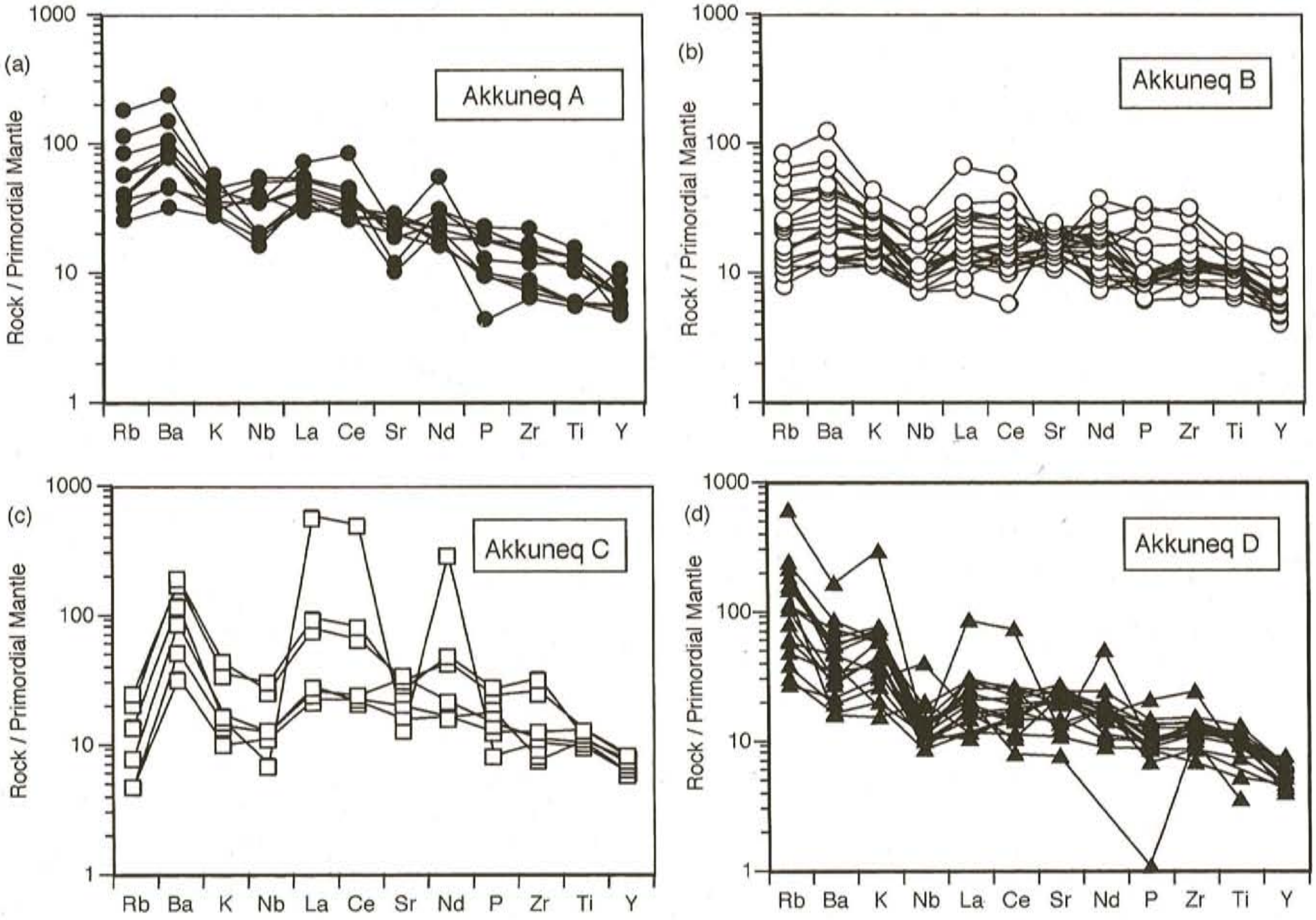

Figure 3. *Incompatible element spidergram patterns showing the signatures of the four chemical groups identified to date in the Akkuneq dyke assemblage.*

poor discriminants of primary magma chemistry, because their aqueous mobility leaves them susceptible to chemical interchange during metamorphism involving H_2O flux. Thus, metamorphism would be expected to result in a smooth variation in Ba/Rb values, rather than the distinct groups of values evident in Figure 4. Akkuneq dykes also contain relatively low amounts of water (H_2O = 0-3.9 percent; measured by loss of volatiles during sample ignition) compared to retrogressed, LIL-element-depleted Kikkertavak dykes (H_2O percent = 0.74-5.37 percent; Cadman *et al.*, 1992b) situated in the southeast of the Hopedale block. Most importantly, the Akkuneq B, C and D groups each plot on chemical evolution trends consistent with igneous fractionation (see below).

If LIL-element ratios in the Akkuneq dykes are indeed primary, then the growth of hornblende and biotite during recrystallization was an isochemical process and could not have involved the flux of aqueous fluids through the dyke. It is suggested that fluids were added to the dykes by magma scavenging of components liberated from hydrated country rocks below the present level of exposure. The igneous fractionation of anhydrous phases (such as plagioclase and clinopyroxene) would also increase H_2O contents in the remaining magma. Recrystallization in the presence of this fluid phase would then result in the growth of hydrous minerals.

The Akkuneq dykes chemically resemble continental flood basalts (CFB) in possessing negative Nb anomalies (i.e., $Nb/La < 1.06$) in their spidergram pattern (Figure 3). This signature has been widely recognized in CFB suites and within other Proterozoic dyke swarms (e.g., Weaver and Tarney, 1981; Thompson *et al.*, 1983). Comparisons can also be made between the Akkuneq dykes and other Labrador dyke swarms using major- and trace-element ratios. The Akkuneq data are superimposed on the datafields from the Kikkertavak and Harp dykes in Figure 4. The Zr/Nb plot (Figure 4a) shows that the Akkuneq A group is clearly chemically different from the other Akkuneq groups, Kikkertavak and Harp swarms. On all the plots, the C group stands out as a distinct cluster, epecially on Figure 4c where their higher Ba/Rb values put them well above the range of the other groups and the other dyke fields.

Table 2. Representative chemical analyses for the Akkuneq A, B, C and D dyke groups

Group sample	A N91-92	A N103-92	B N15-92	B N50-92	C N76-92	C N122-92	D N10-92	D N66-92
SiO_2	50.07	47.27	46.70	45.11	58.56	44.25	43.69	46.78
TiO_2	3.40	1.23	1.62	2.48	2.39	2.31	2.30	1.55
Al_2O_3	14.23	16.42	18.15	16.47	13.02	15.27	15.83	14.26
Fe_2O_3	14.35	14.66	12.30	15.88	11.91	17.42	15.45	12.93
MnO	0.14	0.20	0.17	0.21	0.15	0.24	0.20	0.18
MgO	4.39	6.75	7.25	6.71	2.33	6.79	9.38	10.67
CaO	9.12	8.92	9.17	8.77	5.74	10.56	9.70	9.50
Na_2O	3.23	3.46	3.71	3.28	4.17	2.23	2.74	2.89
K_2O	0.57	0.89	0.76	0.72	1.13	0.55	0.49	1.09
P_2O_5	0.488	0.202	0.180	0.369	0.597	0.379	0.202	0.149
LOI%	0.15	0.71	0.63	0.16	0.17	-0.24	-0.21	1.48
Mg#	41.6	51.8	57.9	49.6	31.3	47.6	58.6	65.8
Nb	27	13	5	9	21	9	14	7
Zr	196	88	89	150	362	83	153	95
Y	26	24	21	36	32	34	23	21
Sr	693	541	451	330	565	332	518	249
Rb	11	25	23	11	16	5	92	37
Th	0	1	0	1	0	0	0	0
Ga	29	20	21	24	25	25	27	20
Zn	171	110	100	127	130	135	137	122
Ni	70	81	95	91	12	94	86	297
Sc	17	26	28	31	16	34	31	28
V	136	186	213	162	195	285	272	224
Cr	78	130	68	83	7	94	94	1121
Co	42	55	53	61	34	59	65	56
Cu	41	39	42	57	69	64	63	52
Ba	357	562	243	419	1230	580	111	317
La	26	22	8	20	65	19	8	21
Ce	66	48	25	43	147	38	25	44
Nd	41	23	23	33	65	22	22	24

CORRELATION OF FIELD RELATIONSHIPS AND CHEMICAL GROUPS

The multigeneration aspect and the diverse morphological and structural characteristics of the Akkuneq dyke assemblage are its most intriguing aspects (Ryan, 1991, 1992; Cadman *et al.*, 1993a). Ryan, (1991, 1992) previously noted the diffculty in correlating dyke mineralogy or relative age with trend, and thus the problem encountered when attempting to correlate dykes from isolated outcrops. This problem has not been resolved by the present study where data indicate, for instance, that dykes with similar orientation fall in all four chemical groups. Similarly, there is no apparent correlation between chemical groups and the structural character of the dykes.

There is some indication from intersecting dykes in single outcrops that it may be possible to locally establish a link betwen chemistry and relative age. For example, a set of crosscutting dykes on Dumbell Island shows subtle variations in specific chemical signatures. At this locality are two green granulite dykes, crosscut by shear zones, which have Akkuneq group A signatures. These dykes are dated at 2560 ± 10 Ma, postulated to indicate the timing of emplacement (Connelly and Ryan, 1992). These Archean intrusions are crosscut by a set of black-weathering dykes that likewise show a group A signature. However, a close inspection of the spidergram patterns shows some differences in pattern between the two sets of intrusions, notably in Nb/La and Ti/Y ratio (Figure 5). These two dykes are also crosscut by another set of black dykes that have group D chemical attributes.

In the Dog Island region, Akkuneq group B dykes attain the greatest thicknesses (up to 9 m). Their widths appear to be correlative with their orientation. The thickest dykes have 090° orientations, but dykes deviating from this trend by 10° have widths less than 3 m (Figure 6a). Group B orientation and width also show some evidence of correlation with chemical evolution. An index commonly used in the study of basaltic fractionation processes is Mg# ([MgO/40.304] / {[MgO/40.304] / [Fe203/93.936]}), which should decline in value as fractionation progresses. Plots of strike vs Mg# (Figure 6b) show some evidence of a clockwise rotation in orientation of Group B Akkuneq dykes from 060° to 120° with Mg# 70 to 45. Mean dyke widths range between 0.1 to

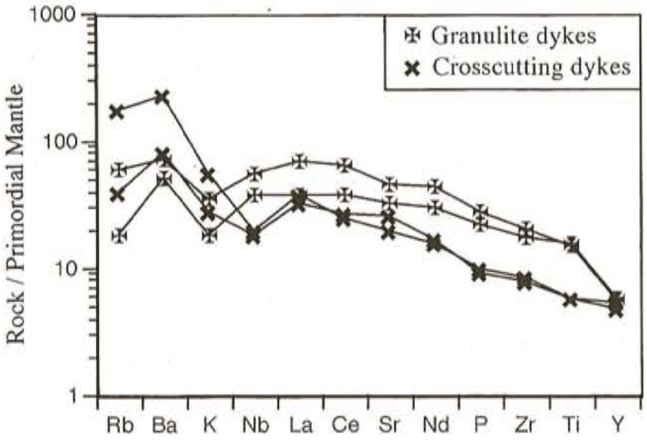

Figure 5. *Incompatible element spidergram patterns for Archean green granulite dykes and crosscutting north-trending black dykes, Dumbell Island.*

2.5 m from Mg# 70-60, 1-9 m between Mg# 50-60, and 0.1 to 5.5 m between Mg# 30-50 (Figure 6c). No strong link between dyke chemistry and width or orientation is apparent for Akkuneq A, C or D group intrusions, although this may reflect the current smaller dataset for these groups.

PETROGENESIS

The Akkuneq dykes of groups B, C and D all define trends that indicate each has undergone a separate fractionation history that is comparable to that of continental flood basalt magmas. Figures 7a and b indicate that relatively primitive samples in these groups (Mg#>60) have a slight increase in CaO with decrease in Mg#. However, more evolved samples have a strong positive correlation between CaO and Mg#. Similar chemical variation in the Karoo dykes and Deccan flood basalts led Cox (1980) to suggest that this trend was formed by the initial fractionation of olivine, followed by the low-pressure fractionation of clinopyroxene and plagioclase. Oxides or elements incompatible with these phases, such as TiO_2, P_2O_5 and Zr, increase in concentration with time, but plot on a line of constant ratio (Figure 7c-f). Akkuneq A group dykes clearly plot on ratios distinct from the other dyke groups.

Incompatible mobile elements such as Rb, Ba and K_2O should also show a systematic increase with progressive fractionation, if unaffected by crustal contamination or later

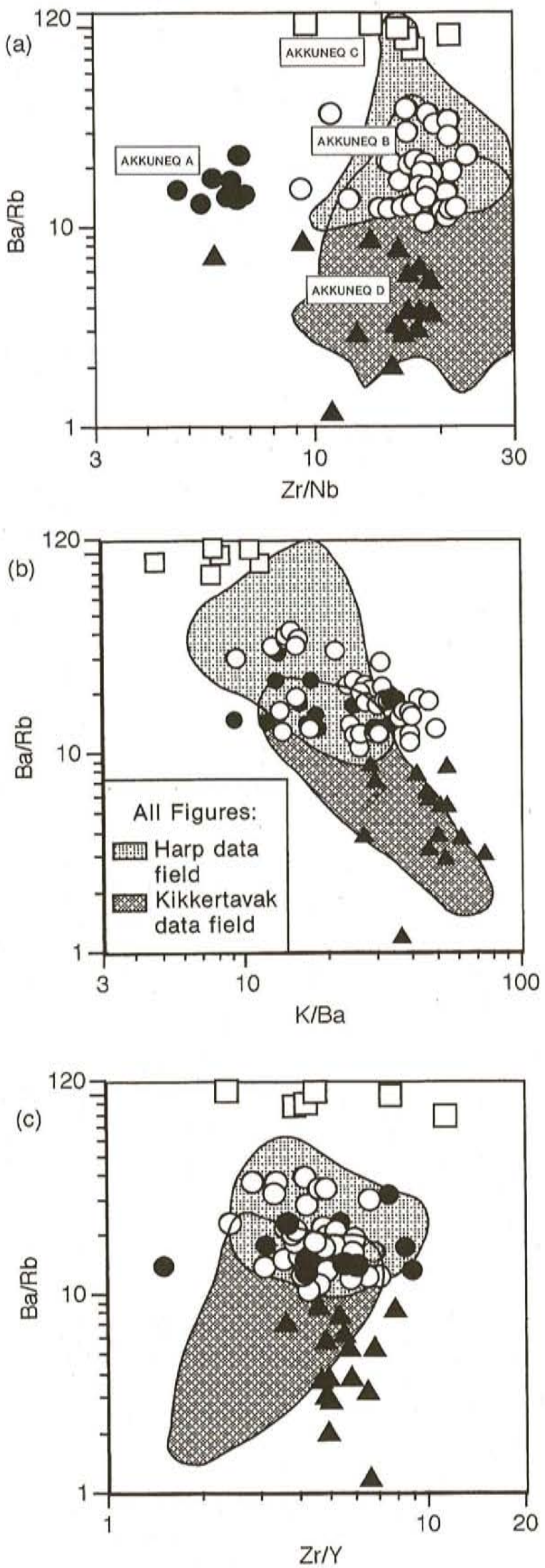

Figure 4. *Incompatible trace-element ratios comparing the Akkuneq dyke chemical groups with each other and the datafields of the Early Proterozoic Kikkertavak and Mid-Proterozoic Harp dyke swarms intruding the Hopedale block. (The degree of overlap between the Kikkertavak and Harp fields is overstated, as Early Proterozoic alteration has increased the Ba/Rb ratio in some Kikkertavak dykes.)*

remobilization. However, LIL-elements do show a degree of scatter when plotted against Mg# for the Akkuneq A dykes (Figure 8a), suggesting that other processes may also have been important. In contrast, the B, C and D groups show a coherent increase of potassium (and Rb and Ba) with decreasing Mg# (Figures 8a and b), suggesting that neither crustal contamination during fractionation or later remobilization have affected LIL-element abundances. Elements compatible with olivine or clinopyroxene, such as Ni and Cr, show clear hyperbolic trends with decreasing Mg# (Figure 8c-f), typical of fractionation involving ferromagnesian minerals. In all three of these plots, more than one fractionation trend is apparently present.

Further evidence of the importance of fractional crystallization is the chemistry of xenolithic material in a 2.4-m-wide, northeast-trending dyke located on the north coast of Dog Island. The dyke is situated near the margin of the Jonathon intrusion and is exceptionally rich in coarse, plagioclase-rich xenolith material. The xenoliths are tentatively interpreted to be of cognate origin (Cadman *et al.*, 1993a). The incompatible element spidergram (Figure 9) of a carefully sampled xenolith shows it to have a similar chemical signature to B or C groups. However, the exceptionally pronounced Ba anomaly (Ba/Rb =140) means that the xenolith cannot be strictly placed in either of these chemical groups.

DISCUSSION

CLASSIFICATION

As deduced in the section above, the classification of the Akkuneq dykes according to Ba/Rb ratio appears to be a valid indicator of primary chemical differences in magma chemistry for the B, C and D groups. However, the internal differences in Ti/Y or Nb/La ratios, and the lack of definite fractionation trends, suggest that not all intrusions within the A group are comagmatic. Given that this group contains the only dyke in the Dog Island region for which an absolute age has been determined, the future refining of the characteristics of the group will be important in fully understanding the evolution of the dyke suite. Although Ryan (1991) postulated that several distinct swarms may be present in the Nain area, it should also be stated here that the chemical subgroups defined by this study cannot be used to corroborate the existence of several dyke swarms: it is quite possible that many or even all the subgroups belong to the same igneous event, or that each group was intruded as several magma batches over a protracted period of time. The relatively constricted sampling area of this study compared to earlier field surveys of the Nain region (Ryan, 1990, 1991, 1992),

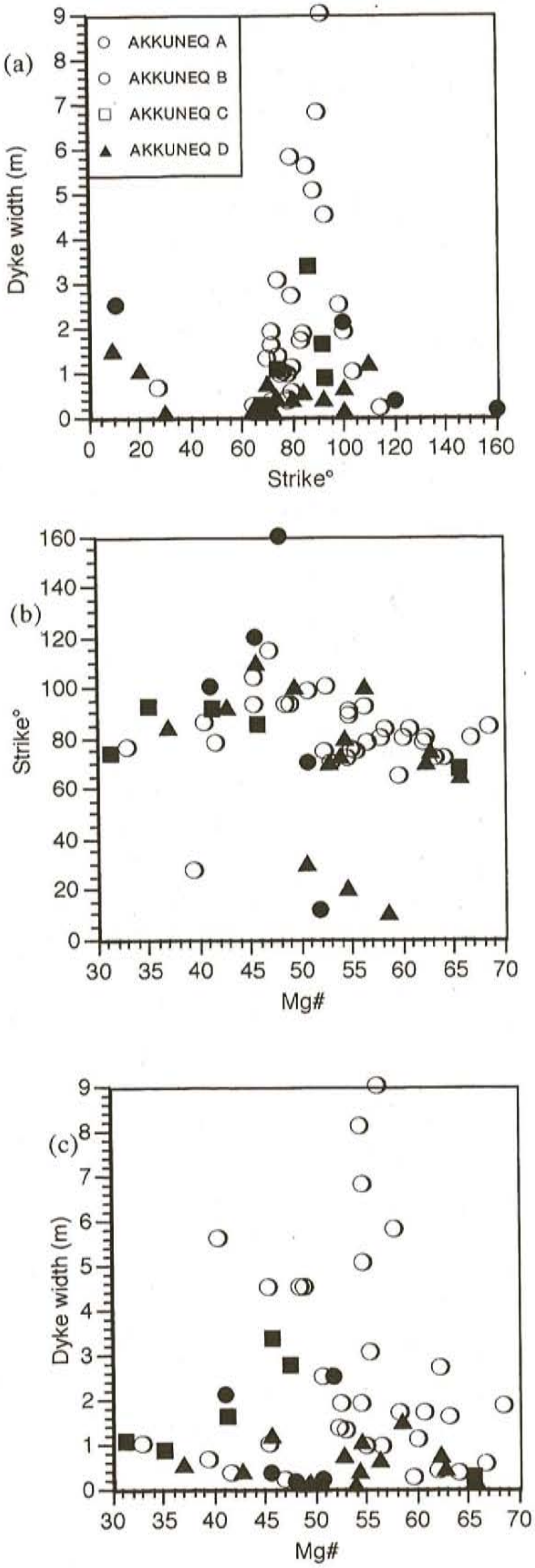

Figure 6. *Diagrams showing the relationship between dyke orientation, width and magma chemistry for the four Akkuneq chemical groups.*

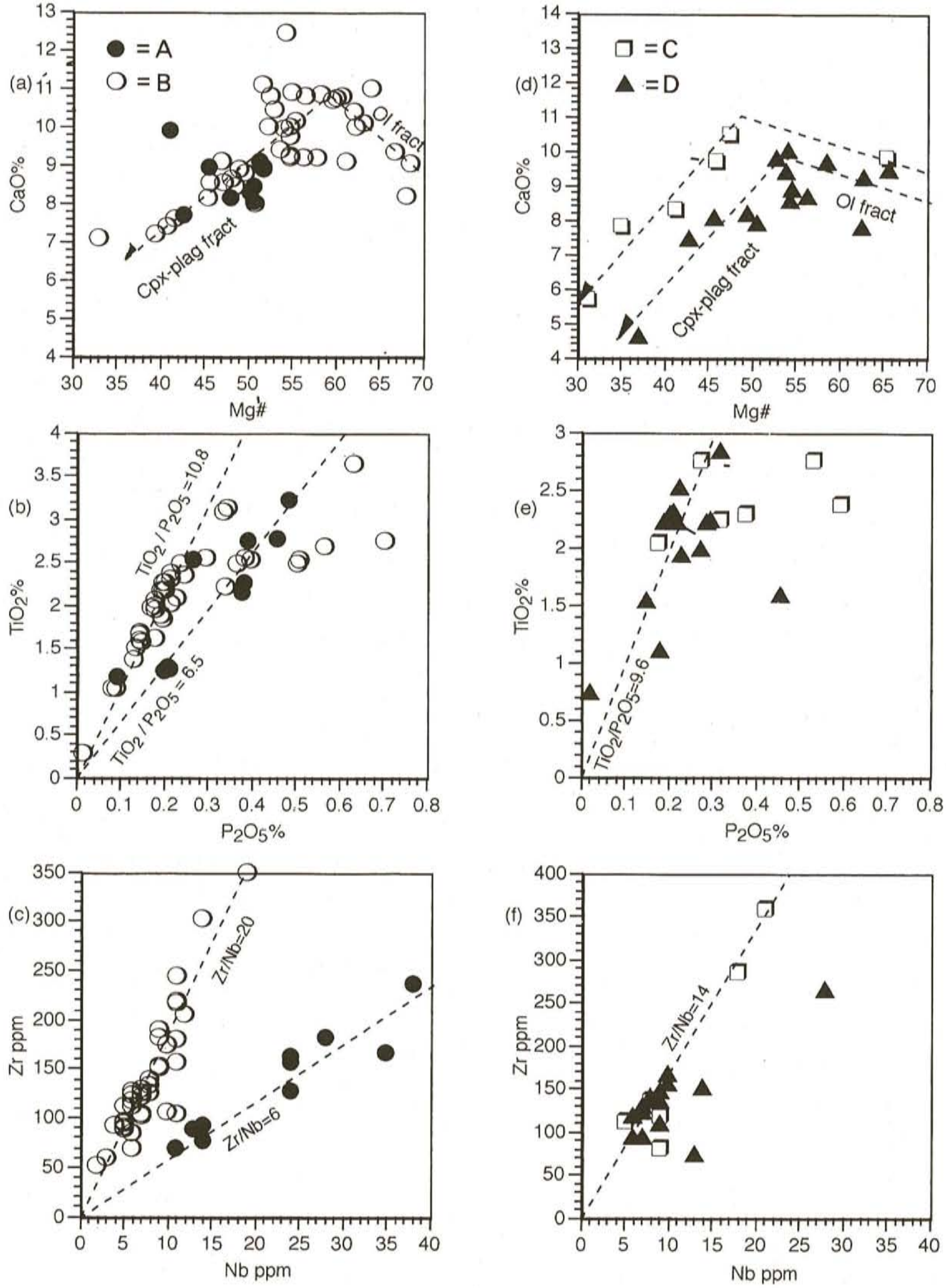

Figure 7. *Biaxial plot showing element variation in the Akkuneq dykes A-D groups. Dashed lines represent postulated fractionation trends.*

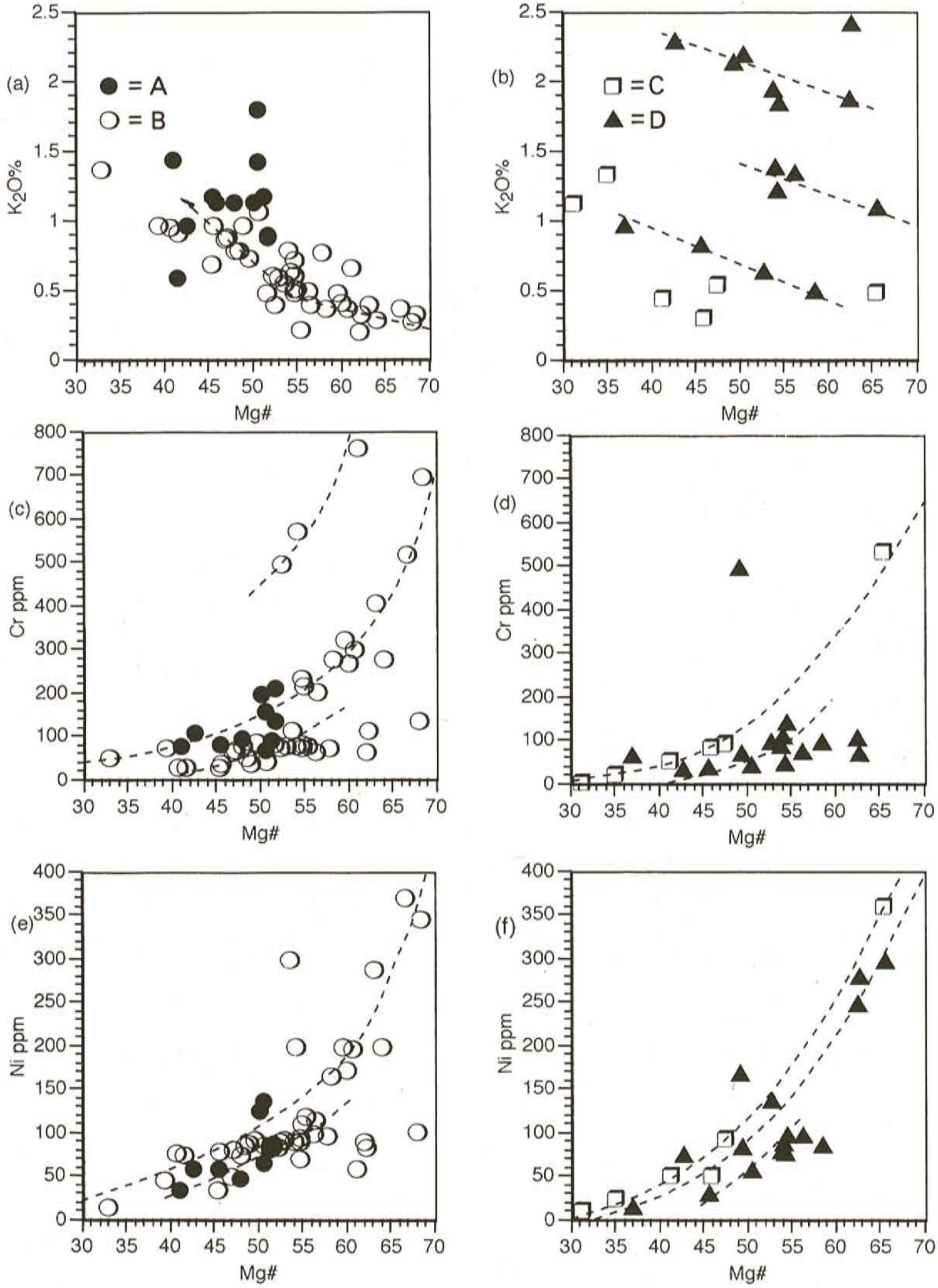

Figure 8. *Biaxial plot showing element variation in the Akkuneq dykes A-D groups. Dashed lines represent postulated fractionation trends.*

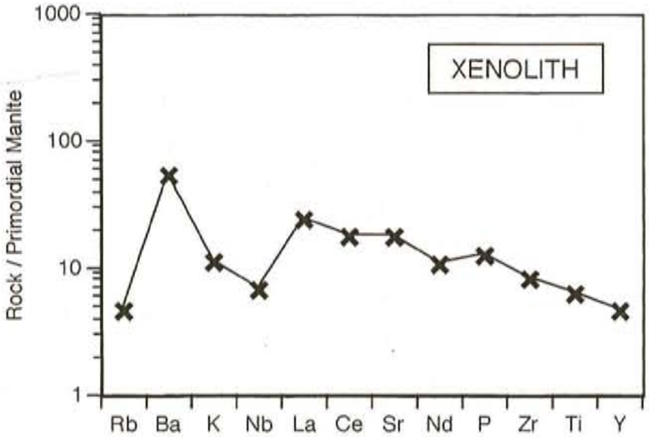

Figure 9. *Incompatible element spidergram of cognate(?) xenolith situated within 053° trending dyke, north coast of Dog Island.*

however, may make it statistically unrepresentative of the regional variation.

CORRELATION

Ryan (1991) suggested that some of the dykes intruded within the Nain area may be equivalent to Early Proterozoic swarms situated in the Saglek and Hopedale blocks. However, it is clear from trace-element ratios that none of the defined Akkuneq groups are likely to be comparable with the Kikkertavak tholeiites from the Hopedale area. This does not rule out the possibility that some of the Nain area dykes do indeed correlate with the Kikkertavak dykes or Domes–Napatok swarms, which intrude the Saglek block.

The chemical signature of Akkuneq B group appears superficially similar to that of the Harp dykes (cf. Figure 4). Field setting alone, however, shows clearly that there are no chronological correlations between the B dykes and the Harp dyke swarm. The Akkuneq B dykes are thin, mostly east–west-trending intrusions that predate at least the period of metamorphism associated with NPS emplacement. By contrast, the Harp dykes are unaltered, commonly very thick (>100 m) northeast-trending intrusions that crosscut the Mid-Proterozoic Harp Lake complex (Meyers and Emslie, 1977) and yield a U–Pb age (Cadman *et al.*, 1993b) younger than any of the NPS plutons.

RELATIONSHIP TO THE NPS AND MAGMATIC EVOLUTION

Given the evidence that crystal fractionation dominates intragroup variation, the idea that the Akkuneq dykes are precursors to NPS magmatism, constituting leaks from sub or lower crustal magma chambers (Ryan, 1991), appears attractive. However, the dykes are petrographically disimilar to basic (noritic) members of the NPS, and the sole Archean age for the Dumbell Island Akkuneq dyke shows that at least some of the suite analyzed for this study substantially predates the NPS. The lack of age constraints dictates that caution is required in interpreting chemical variation in the Akkuneq dykes, as each intragroup 'trend' may be formed by the emplacement of near-identical batches of magma over a protracted time period. Alternatively, if all the dykes prove to belong to a Late Archean event, and are therefore unrelated to the NPS, this does not disprove the 'leaking magma chamber' theory. Two lines of circumstantial evidence can be considered: 1) The Nain region dykes are quite unlike the wide, linear and laterally continuous dyke swarms such as the Harp and Kikkertavak dykes. The variable trends and narrow widths of the Akkuneq dykes are perhaps more suited to derivation from a nearby, larger chamber(s) rather than direct intrusion from the mantle. In the B group, the dykes with the largest widths correspond to the postulated change in fractionating minerals, i.e., from olivine to clinopyroxene–plagioclase (i.e., Mg# 60-50). As further clinopyroxene–plagioclase fractionation results in iron enrichment and thus an increase in density, this stage of fractionation may correspond to a magma density minimum. Hence, the thickest dykes may represent the ease in which magmas could escape the chamber and intrude the host rocks above them; 2) Foliated granites cut by Akkuneq dykes on Misfit and Dumbell islands give U–Pb dates of 2578 ± 3 Ma, interpreted as an emplacement age (Connelly and Ryan, 1992). This age predates the emplacement of the dated granulite dyke on Dumbell Island by ca. 20 Ma. Several authors (e.g., Bellieni *et al.*, 1986; Marsh, 1989) have suggested that the generation of acidic magmas at depth is connected with the emplacement of large basic bodies. Hence, the basic dyke may have been derived from a large magma chamber that had also instigated crustal melting and granite formation.

If the magma chamber hypothesis is correct, then the relative constancy of LIL-element ratios along each fractionation trend implies apparent lack of crustal assimilation during fractionation (assimilation and fractional crystallization; DePaolo, 1981). The lack of contamination may be considered odd when the U–Pb dates and intrusion morphology suggest that many of the dykes were emplaced into hot country rock, which should greatly increase the likelihood of wall-rock meltback (Bruce and Huppert, 1989). However, modern magma chamber models strongly suggest that crystallization is confined mostly to the boundary zone at the wall-rock interface (e.g., Marsh, 1989). A consequence of boundary layer crystallization is that the potential thermal erosion of the country rock is quickly limited by its onset. Hence, once a rigid crust of solidified material at the wall-rock interface is established, further fractionation should take place without the addition of crustal contaminants.

This conclusion leads to the question of what process leads to the heterogeneity of LIL-element ratios that define the Akkuneq chemical groups. One possibility is that prior to fractionation, the magmas may be variably contaminated by sialic material (e.g., Arndt *et al.*, 1993). However, Foley (1992) has argued that the trace-element signature of many ultrapotassic melts was derived by the melting of incompatible element-rich veins situated within the lithosphere. He further argued that basaltic magmas could be produced by mixing such melts with more depleted components. Therefore, basaltic magmas formed in this way could be expected to have similar trace-element signatures (though lower abundances) to potassic alkaline magmas. Figure 10 shows the spidergram pattern for average Archean felsic crust (Taylor and McLennan, 1985) and the Early Proterozoic Mount Bundy lamprophyres, Australia (Sheppard and Taylor, 1992). Clearly the LIL-element ratios of the Akkuenq dyke assemblage could not be produced by bulk mixing of MORB-type magmas with the Archean crustal composition shown, although other types of crustal contaminants may be available. In contrast, the Mount Bundy lamprophyres have similar LIL-element ratios to the Akkuneq A, B and C groups. One possibility, therefore, is that the high Ba signature of the A, B and C groups is derived from partial melting and mixing of melts derived from enriched and depleted mantle components.

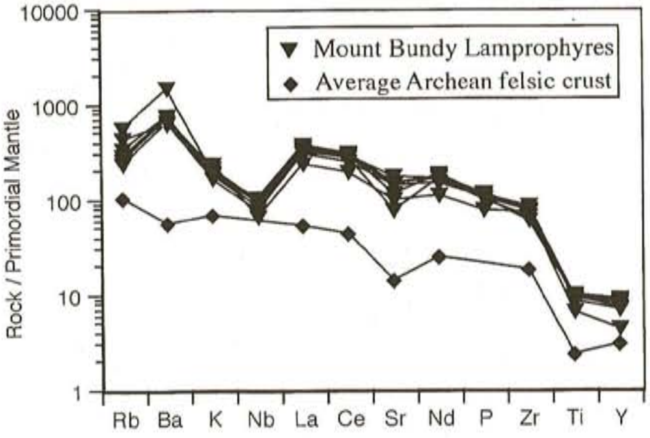

Figure 10. *Incompatible element spidergrams of average Archean felsic crust (Taylor and McLennan, 1985) and samples of Mt. Bundy lamprophyres (Sheppard and Taylor, 1992).*

SECULAR EVOLUTION OF THE MANTLE

The chemical signatures of the Akkuneq B and C groups are similar to those of the Mid-Proterozoic Harp dykes, but are possibly of Archean age. This raises important questions concerning mantle evolution. If the dykes are of Archean age, then a long-lived component has controlled the chemical signature of basaltic magmas in the Nain region from Archean to Mid-Proterozoic time. Such a component could be either of crustal or mantle origin, as discussed in the section above. It could be argued that this component was not regionally extensive, as the Early Proterozoic Kikkertavak dykes intruding the Hopedale block have clearly different signatures. However, caution is needed in interpretation, as a study of the Kikkertavak dykes shows them to preserve dominantly lateral flow directions (Cadman *et al.*, 1992a). Hence, their chemical signature may not reflect the nature of the mantle or crust in the Hopedale block.

Alternatively, if dykes in the Akkuneq B and C groups prove to be related to the NPS, their similar chemical signature to the Harp dykes would increase the evidence for secular evolution of the Earth's mantle, with more enriched sources becoming more important with time (e.g., Condie 1985). Mid-Proterozoic dykes having similar chemical signatures to the Harp dykes and the B and C groups have been reported from Antarctica (Sheraton *et al.*, 1990). Condie *et al.* (1987) suggest that secular enrichment of the mantle was necessary to explain chemical differences in dykes of differing ages within the Archean Superior Province of Canada. However, further age constraints are needed on the Akkuneq dyke assemblage before the nature of mantle evolution (if any) can be understood in more detail.

FUTURE WORK

The summer of 1993 was spent sampling dykes in the region southeast of Nain village (Figure 2). Approximately 100 samples will be analyzed for bulk geochemistry. In addition, seven samples were collected for U–Pb baddeleyite dating at the NERC Isotope Geoscience Laboratory (NIGL) at Keyworth, England. A comprehensive isotope study is also planned including Sm–Nd, Rb–Sr, Pb–Pb and O–O systems at this facility. A small number of oriented samples for paleomagnetic work were also collected. Microprobe analyses of minerals and computer modelling of petrogenesis processes will also be undertaken. It is hoped that this integrated approach will greatly enhance the available database on the Akkuneq dyke suite, so that some of the outstanding problems regarding the age and origin of the dykes can be answered.

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