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THE PETROGENESIS AND EMPLACEMENT OF PROTEROZOIC DYKE SWARMS, PART 2: GEOCHEMICAL PROCESSES AND PALEOSTRESS ANALYSIS

Andrew Cadman
Department of Geology, University of Leicester,
University Road, Leicester, England, LE1 7RH

ABSTRACT

The Early Proterozoic Kikkertavak dyke swarm of the Hopedale Block, Labrador, exhibits features that reflect the large-scale crust–mantle processes of magma genesis and emplacement common to many Proterozoic dyke swarms; this invites comparison both with other Proterozoic swarms and their smaller scale Phanerozoic equivalents. Good exposure of the Kikkertavak dyke swarm also allows the study of local magmatic and tectonic factors.

INTRODUCTION

Proterozoic dyke swarms, which have intruded into previously permobile Archean terranes, are found on every continent. Two such swarms are well preserved and exposed in the Hopedale Block of Labrador, allowing the study and comparison of primary petrological and structural aspects, both on a regional and on a local basis. The Kikkertavak dyke swarm, dated at 2200 Ma (Rb–Sr whole-rock date, B.J. Fryer, in Grant *et al.*, 1983), was chosen for an intensive and integrative study of existing geochemical, magmatic flow and swarm emplacement models. The younger Harp dyke swarm, dated at 1200 Ma (Rb–Sr whole-rock date, F.R. Voner, *in* Ermanovics *et al.*, 1982; Grant *et al.*, 1983), was also studied and sampled, although less intensively, for comparison purposes with the Kikkertavak swarm. The initial research results are presented in this paper.

PREVIOUS WORK

Little detailed research has been done on the Hopedale Block. The present evolutionary history of the area is based on regional 1:100,000-scale mapping by the Geological Survey of Canada (GSC) (Ermanovics, 1979, 1980, 1981a,b, 1984; Ermanovics and Raudsepp, 1979; Ermanovics and Korstgaard, 1981; Ermanovics *et al.*, 1982). The GSC focus has been to establish the petrological, geochronological and structural aspects of the Archean gneisses (e.g., Korstgaard and Ermanovics, 1984). Earlier work in the area has also concentrated on structural and metamorphic histories (e.g., Taylor, 1971) and correlation with similar terrains in West Greenland (e.g., Sutton *et al.*, 1972).

Apart from brief descriptions in the GSC reports, very little data are available on the Kikkertavak dykes. The Harp dykes, a series of younger intrusions within and adjacent to the Harp Lake anorthosite–gabbro plutonic complex situated approximately 100 km west of the present study area, have been investigated by Meyers and Emslie (1977).

Previous work as part of this project (1989) concentrated on intensive geochemical sampling of both swarms, in a limited area, in the centre of the Hopedale Block, and on the study of dyke–host-rock relationships and modes of dyke emplacement and dilation.

GEOLOGICAL SETTING OF THE DYKE SWARMS

The Hopedale Block lies in the southern part of the Nain Province, adjacent to the Churchill Province in the west and the Makkovik Province in the southeast (Figure 1). It consists of polydeformed, mainly granodioritic to tonalitic gneisses having a predominantly northeast–southwest (Fiordian)

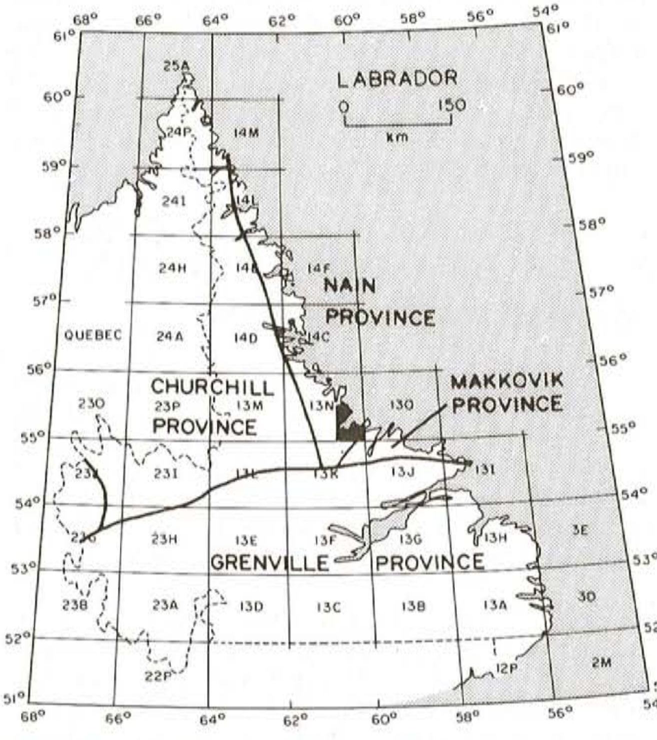

Figure 1. *Location of the Hopedale Block, Labrador. Study area shown in black.*

trend. The Fiordian-trending fabrics are interpreted by Ermanovics *et al.* (1982) to be late Archean and postdate the predominantly pretectonic Kanairiktok Intrusive Suite at about 2830 Ma (U–Pb zircon concordia, Loveridge *et al.*, 1987). The Fiordian trend overprints an earlier northwest–southeast (Hopedalian) trend that is preserved around and to the northwest of the village of Hopedale (Figure 2, Plate 1) and which gives U–Pb zircon and Rb–Sr whole-rock dates in the range between 3250 and 3000 Ma (Grant *et al.*, 1983; Loveridge *et al.*, 1987). Within both the Fiordian and Hopedalian domains, subvertical planar and linear fabrics show strong parallelism, suggesting block-wide, shear-zone deformation in both cases. The Fiordian-trending gneisses, which dominate the study area, are deformed agmatitic gneisses containing some amphibolite bands. The gneisses are at amphibolite facies, possibly retrogressed from a granulite-facies assemblage. Any earlier structural and metamorphic histories were largely erased by the Hopedalian event (Ermanovics *et al.*, 1982).

The post-Fiord-trend dykes are conspicuous as rectiplanar and irregular intrusive masses throughout the Hopedale Block and are superbly exposed along the ice-scoured coastline of the mainland and island archipelago, north of Kanairiktok Bay (Figure 2). Consequently, this area was chosen for detailed investigation, and fieldwork was undertaken mainly by boat.

Fieldwork done in 1989 concentrated on further geochemical sampling and the study of dyke–fissure dilation as a means to understanding the stress systems that acted on the Hopedale Block. Samples for rock magnetism studies (paleomagnetism and magnetic anisotropy) and U–Pb zircon dating were collected from both swarms. The macroscopic textures present within the Kikkertavak dykes were also examined. Work in 1989 also concentrated on enlarging the geographical spread of data. However, as a consequence of logistics, the study was confined to coastal areas and covered only a fraction of the total area of the Hopedale Block.

GEOCHEMISTRY AND PETROLOGY OF THE KIKKERTAVAK DYKES

MINERALOGY AND PETROLOGY

Four hundred and forty samples for geochemical analysis were collected in the Hopedale Block concentrating on the older (2.2 Ga) Kikkertavak dyke swarm but with some limited sampling of the Harp dykes (1.2 Ga). The study of geochemical variation on a regional and local basis was attempted, utilizing a geographic spread of localities and along-length or across-width sampling of individual dykes.

In thin section, the Kikkertavak dykes display a primary mineralogy of augite, plagioclase, ilmenite, magnetite and apatite. Plagioclase is the dominant phenocryst phase and may form megacrysts 5 to 15 cm long. These occur in extremely phyric, margin-parallel, laterally persistent layers in otherwise aphyric diabase (Plates 2 and 3). The texture is unique to the Kikkertavak swarm but is not present in most dykes of the suite and does not occupy a specific geographic area. Smaller phenocrysts (1 to 5 cm in length) are more common in Kikkertavak diabases than the megacrysts, and are similarly layered. The segregations into phyric and aphyric layers are regarded as a flow differentiation or differential accretion structure (see below). Glomeroporphyries of the smaller phenocrysts are common within the phyric layers (Plate 4). Other Kikkertavak diabases are aphyric, or plagioclase phyric with no flow differentiated structure or megacrysts. Coarser grained gabbroic dykes contain singular megacrysts but the differentiated phyric–aphyric structure is rare except in their diabase margins.

Augite forms a minor phenocryst phase in Kikkertavak dykes but is never visible as such in hand specimen; it is often best preserved as microphenocrysts along with plagioclase in glassy chilled margins or in fine-grained diabases.

The groundmass in the Kikkertavak dykes consists of ophitic plagioclase and augite with ilmenite and magnetite. The latter occurs as rims around ilmenite cores and as separate crystals, which may nucleate on pyroxene phenocrysts; apatite is a rare accessory phase. In contrast, the Harp dykes are rarely porphyritic and never megaphyric. In thin section, they show a simple mineralogy of olivine, augite, plagioclase and an opaque phase or phases.

ALTERATION

Locally, Kikkertavak dykes are altered to greenschist–lower-amphibolite-grade rocks in the mid-Proterozoic Kanairiktok shear zone (Ermanovics *et al.*, 1982), which forms the southern boundary of the Hopedale Block against the Makkovik Province (Figure 2). Within 5 km of the shear zone, augite develops actinolitic rims and plagioclase is heavily altered to sericite. Augite is unaltered at greater distances from the shear zone but variable sericitization of feldspar is seen throughout the area. Dyke margins are frequently sheared south of Kijuksuatalik Island (Figure 2). The low-grade metamorphism gives a characteristic greenish hue to many Kikkertavak dykes and distinguishes them from the non-metamorphosed Harp dyke swarm. Plagioclase in the Harp dykes shows only low degrees of seritization and augite is never severely altered. However, olivine is commonly partially or completely altered to serpentine even in dykes, where the remaining mineralogy shows little or no alteration.

MAJOR-ELEMENT GEOCHEMISTRY

Major-element plots of the Kikkertavak dykes are shown in Figures 3 to 5. Preliminary analysis of the geochemical trends indicates strong similarities to the trends of continental-flood basalt provinces, such as the Deccan Traps and Karoo lavas or the Tertiary Columbia River flood basalts. For example, the plot of calcium versus magnesium (Figure 3) shows two distinct geochemical groups; a large dataset of tholeiitic (low MgO) magmas with a positive correlation between calcium and magnesium and a small set of picritic

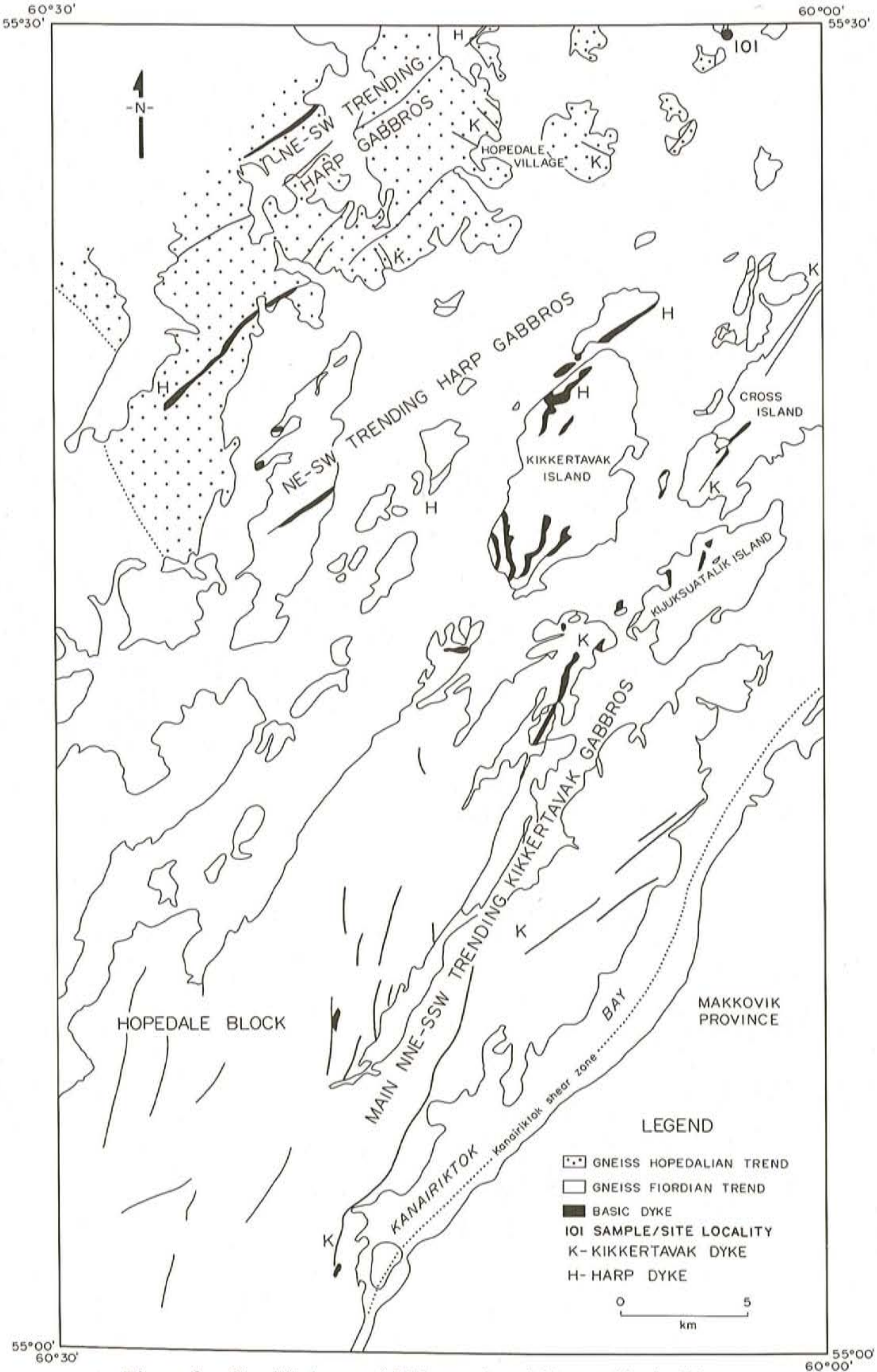

Figure 2. *Simplified map of Kikkertavak and Harp gabbroic dykes.*

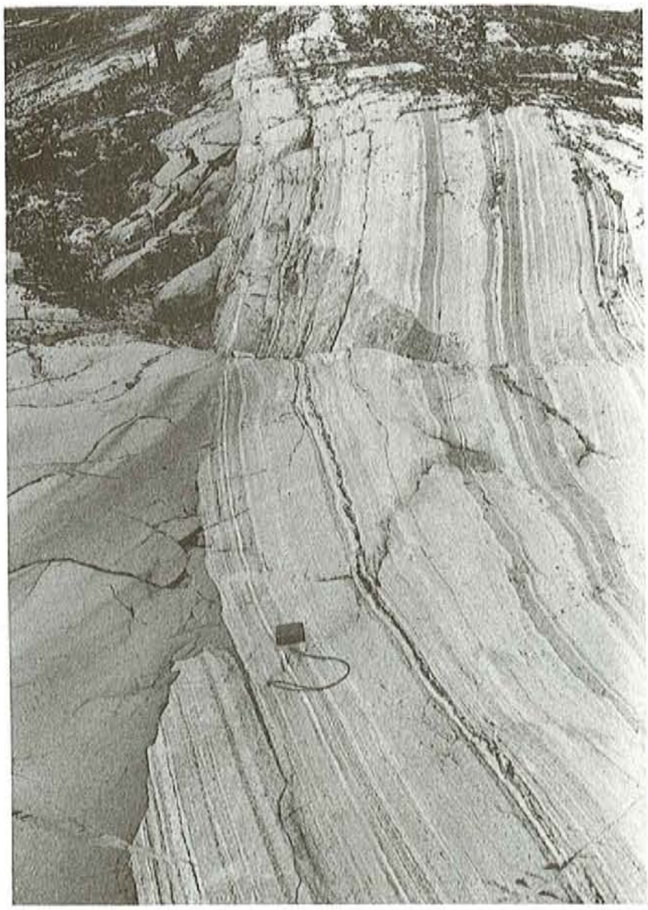

Plate 1. *Aphyric Kikkertavak dyke intruding conformably into Hopedalian-trending gneiss. Note planar Hopedalian foliation.*

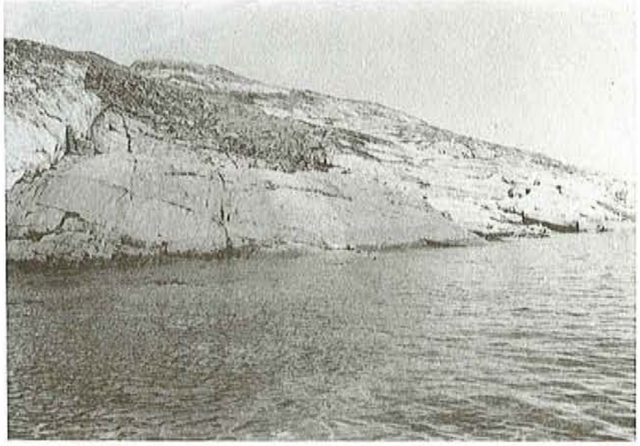

Plate 2. *Highly flow-differentiated Kikkertavak gabbro dyke. The central phyric band in the dyke contained plagioclase megacrysts up to 10 cm in length. Plagioclase phenocrysts made up to 80 percent of the rock in this 3-m-wide zone. The dyke is 23 m wide.*

(high MgO) magmas. If the lower magnesian samples have evolved from the picrites, olivine is the most likely phase to have been fractionated. The lack of olivine, in thin sections of the Kikkertavak dykes and the large gap between the two datasets, suggests that this process was complete at the presently exposed crustal level, probably because dense picritic liquids would have difficulty travelling upward through the crust and would therefore remain pooled at the moho until fractionated (Huppert and Sparks, 1985). However, in many petrological suites, picrites and non-picrites are genetically unrelated (J. Tarney, personal communication, 1989). Hence, if indeed the tholeiites were derived from the picritic dykes, a Ca-rich phase such as plagioclase or pyroxene must have fractionated with olivine. Alternatively, the picrites could represent olivine-rich cumulates resulting from the fractionation of these phases.

Plate 3. *Thin, laterally persistent phyric–aphyric bands resulting from differential accretion of plagioclase phenocrysts at locality 101 (Platten and Watterson, 1987).*

The broad calcium–magnesium correlation of the dataset suggests that after the fractionation of olivine was completed, clinopyroxene, and possibly plagioclase, became fractionating phases. This is a low-pressure process (Cox, 1980) and therefore suggests an upper crustal setting for the Kikkertavak dyke swarm exposed today. Superimposed on the dataset for the Kikkertavak dykes, on Figure 3, is the proposed fractionation path combined, from data from the Karoo and Deccan flood basalt provinces and associated dykes (Cox,

Plate 4. *Close-up of phyric–aphyric banding, locality 101. Note accompanying glomeroporphyritic texture.*

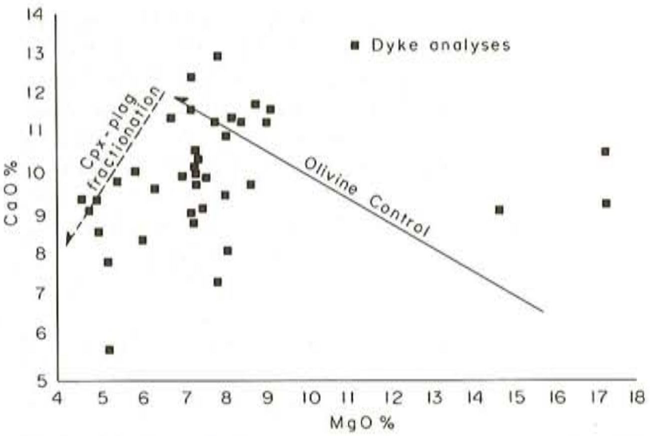

Figure 3. *Plot of CaO percent against MgO percent for dyke margins and centres of the Kikkertavak swarm. The cpx-plagioclase fractionation path is for the Karoo–Deccan flood basalts, after Cox (1980) and Cox and Hawksworth (1985).*

1980; Cox and Hawksworth, 1985), which show broadly similar trends. A clinopyroxene–plagioclase fractionation path drawn for the Kikkertavak dykes would run parallel to the trend of the Karoo magma, but the increase in calcium content from picrites to non-picrites, during olivine fractionation, is much less pronounced for the Kikkertavak dykes than for the Deccan flood basalts.

The plot of potash versus silica (Figure 4) shows a dominantly subalkalic composition. At present, there is little evidence for LILE-enriched heterogeneous sources for the Kikkertavak magmas, which tend to produce vertical plots of potash versus silica (Cox, 1980); the broadly positive correlation between potash and silica can be explained by fractional crystallization or by crustal contamination of the magma.

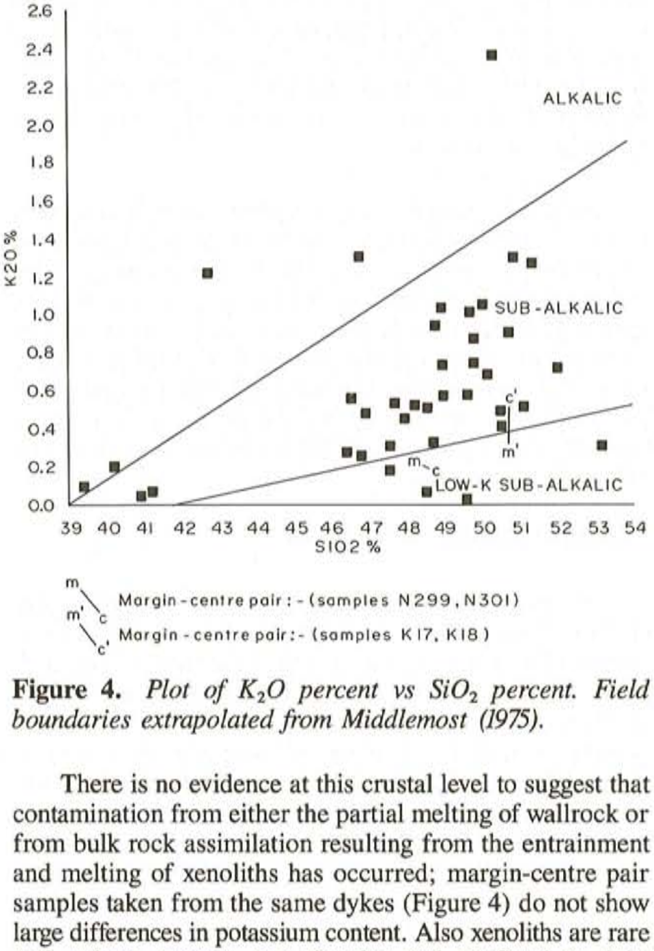

Figure 4. *Plot of K_2O percent vs SiO_2 percent. Field boundaries extrapolated from Middlemost (1975).*

There is no evidence at this crustal level to suggest that contamination from either the partial melting of wallrock or from bulk rock assimilation resulting from the entrainment and melting of xenoliths has occurred; margin-centre pair samples taken from the same dykes (Figure 4) do not show large differences in potassium content. Also xenoliths are rare and, where present, are singular and confined to dyke margins. These are certainly detached bridges formed by the linkage of *en echelon* crack arrays in the initial stages of dyke formation (Nicholson and Pollard, 1985). At only one place is an abundance of xenoliths observed, where 60 percent of a diabase dyke, which rapidly dies out upward, consists of tabular xenoliths, many of which are exotic and different from the granodioritic host rock. It has been argued previously that their presence and orientation are due to horizontal magma flow (Cadman, 1989) but, alternatively, they may represent detached host-rock bridges that were easily entrained by the magma due to their low density and that accumulated at the roof of the dyke. The dyke has chilled margins adjacent to the xenoliths, none of which have undergone any absorption; consequently the magma was not superheated when it entrained the xenoliths and did not contain the heat supply to melt them. Primary dyke-wallrock contacts are always sharp with chilled, sometimes glassy, margins but with no observed baking or induced ductility in the country rock. These features suggest that the country rock was relatively cold at the time of intrusion, which helps to explain the resistance to melting.

MAGMA FLOW AND DIFFERENTIATION

FLOW DIRECTION

The direction of magma flow in dykes has implications for the emplacement, structure and geochemical evolution of dyke swarms. The Kikkertavak dykes are predominantly vertical features throughout the Hopedale Block, therefore, it seems likely that no crustal tilting or deformation has occurred. Hence, studies of the primary flow directions in the dykes are possible.

Field relationships suggest a dominantly vertical flow direction for both the Kikkertavak and Harp dyke swarms. Dykes die out laterally, and isolated diabase veins injected into propagating *en échelon* crack arrays are common on horizontal surfaces but do not occur on vertical ones; at least a component of vertical magma flow is required to produce such field relationships. The study of crystal alignment in thin section was not successful; phenocrysts stuck on dyke margins are randomly orientated and did not yield any paleoflow information.

MAGMA DIFFERENTIATION

Diabase dykes in the Kikkertavak swarm are locally highly differentiated in terms of phenocryst content (Cadman, 1989). This is a function of flow processes acting on a previously homogeneous magma. Two cases have been found of differentiated material consisting of a massive plagioclase ultraphyric dyke core surrounded by aphyric to subphyric diabase (Plate 2). This structure suggests flow differentiation of material (Komar, 1972), with concentration of large, megaphyric material into the fast-flowing central portion of the dyke. Composite intrusion of aphyric and phyric magma batches is an alternative explanation, but chilling of phyric cores against aphyric margins was not seen. More commonly, dyke structure consists of thin, alternating layers of aphyric and phyric material either in the margins or the centres of dykes (Plate 3). This structure cannot be explained by flow differentiation or composite intrusion and is more likely to result from the differential accretion of phenocrysts onto the inward-advancing solid-liquid interface within the dyke. The degree of phenocryst accretion changes with time due to hydraulic changes in magma flow (Platten and Watterson, 1987). In contrast, the Harp dykes are always homogeneous and highly phyric, and do not contain megaphyric differentiation structures.

The end result of the differentiation processes is that no part of a dyke (and hence no sample) is representative of the magma composition that flowed through it. Thus, the differentiation processes are superimposed on the clinopyroxene (± plagioclase) fractionation shown in Figure 3. (It is also possible that some 'Kikkertavak' samples are mis-identified Harp dykes, which may produce the same effect.) The effect plagioclase differentiation has on the data is shown in Figures 5 and 6. In the most extreme theoretical case of plagioclase differentiation, part of the dyke becomes pure plagioclase. Taking the simplistic case of pure anorthite, this would lead to an oxide composition of 25 percent CaO, 25 percent Al_2O_3 and 50 percent SiO_2. (The central portion of the dyke shown in Plate 2 attained a value of 88 percent plagioclase, 80 percent as megacrysts and about 8 percent as groundmass.) Hence, portions of any original plagioclase-phyric magma in a differentiated Kikkertavak dyke will trend toward these oxide values if enriched in plagioclase phenocrysts or away from it, if depleted. Examples of such trend lines are shown in the CaO:MgO plot in Figure 5. Figure 6 shows an expanded part of Figure 5, with margin-centre and margin-margin sample pairs, taken from dyke centres and margins at the same locality. There is little difference between samples in margin-margin pairs, which is to be expected in vertical dykes such as the Kikkertavak swarm as there is no gravity component favouring the settling (or floating) of phases preferentially at one margin relative to the other. However, one margin-centre pair shows a wide disparity in oxide values and gives a trend line parallel to the anorthite depletion/enrichment trend. If the effect of ongoing magma evolution during the period between solidification of marginal and central portions of the dyke is discounted, original oxide values for the undifferentiated magma will plot somewhere on the line between the plagioclase-depleted margin and the plagioclase-enriched centre. The same margin-centre pair is plotted in Figure 7 for alkali index versus alumina. Again, there is considerable difference in Al_2O_3 enrichment between the samples as aluminum is a major component of anorthite. Such high alumina values as that yielded by the dyke centre sample, are rare in continental flood basalts and consequently other high values plotted here may be the result of plagioclase differentiation and enrichment from originally tholeiitic melts. Another margin-centre pair plotted in Figure 6 shows little disparity in oxide values and hence differentiation does not operate in all dykes. (Aphyric magmas, for example, obviously cannot be differentiated in terms of phenocryst content). Thus, the feldspar differentiation process blurs the calcium–magnesium correlation shown in Figures 3 and 5.

At the end of the differentiation processes, portions of the dyke become variably enriched or depleted in phenocrystic content, hence affecting the observed geochemistry. Given the large abundance of plagioclase phenocrysts and megacrysts in some Kikkertavak dykes and the lack of pyroxene phenocrysts of similar size, it would seem more likely that plagioclase, not pyroxene, is the main fractionating phase. However, although the concentration of plagioclase phenocrysts is locally very high, the amount of material possessing this texture is volumetrically small, for example, differentiated structures are not seen in the gabbroic parts of dykes, with the exception of the highly flow differentiated gabbro in Plate 2, and plagioclase megacrysts are also very rare.

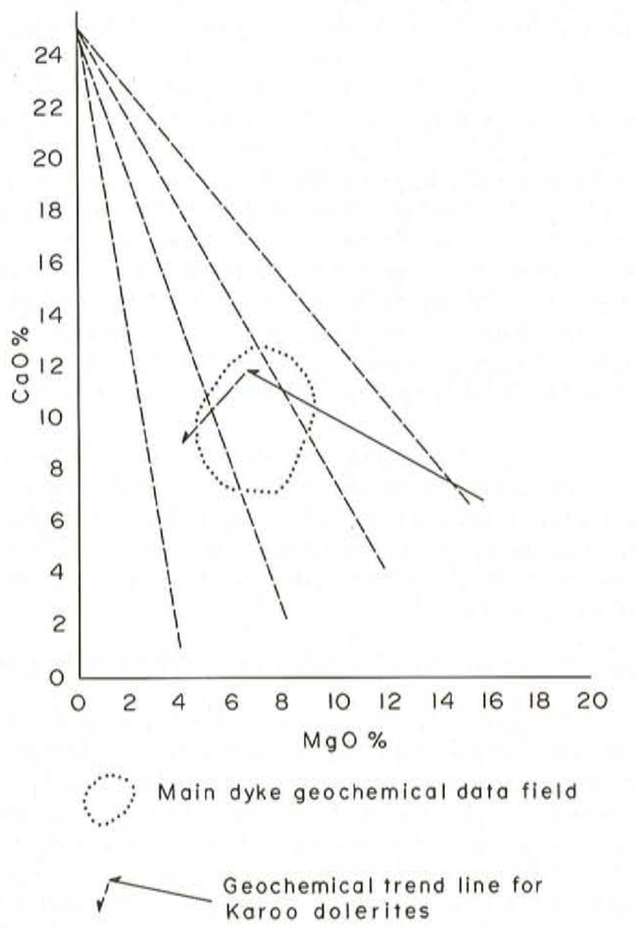

Figure 5. *Plot of CaO percent vs MgO percent showing paths of magma evolution due to differentiation of anorthite. Fractionation path for Karoo–Deccan flood basalts from Cox (1980) and Cox and Hawksworth (1985).*

The fine-grained margins of one Kikkertavak gabbro dyke possess very pronounced phyric–aphyric layering, including plagioclase megacrysts up to 5 cm long. This differential accretion structure ceased abruptly within 3 m of either margin, passing into >30 m of homogeneous gabbro, but without chilling of the gabbro against the marginal diabase.

Another example of the composite structure is shown in Figure 8 and Plates 3 to 6 of a Kikkertavak diabase dyke. The dyke contains a 2-m-wide aphyric margin, which is followed by a 1-m-wide 'phyric' zone of thin, alternating, phyric and aphyric layers (Plates 3 and 4) before reverting to aphyric diabase for a farther 2 to 3 m centreward. The 'phyric' zone is associated with differential accretion (Platten and Watterson, 1987). Inward from here, the structure of the dyke changes abruptly. Distinct, highly irregular bands could be traced along the length of the dyke (Plate 5). Commonly they are accompanied by thin, gabbroic cumulates (Plate 6), which quickly fade out centreward into aphyric or subphyric diabase. The bands and their associated gabbroic layers commonly thin rapidly and fade laterally, or are truncated by other bands and lunate trough structures. At other localities in the same dyke, large gabbroic xenoliths are found within the irregularly layered, central section of the dyke.

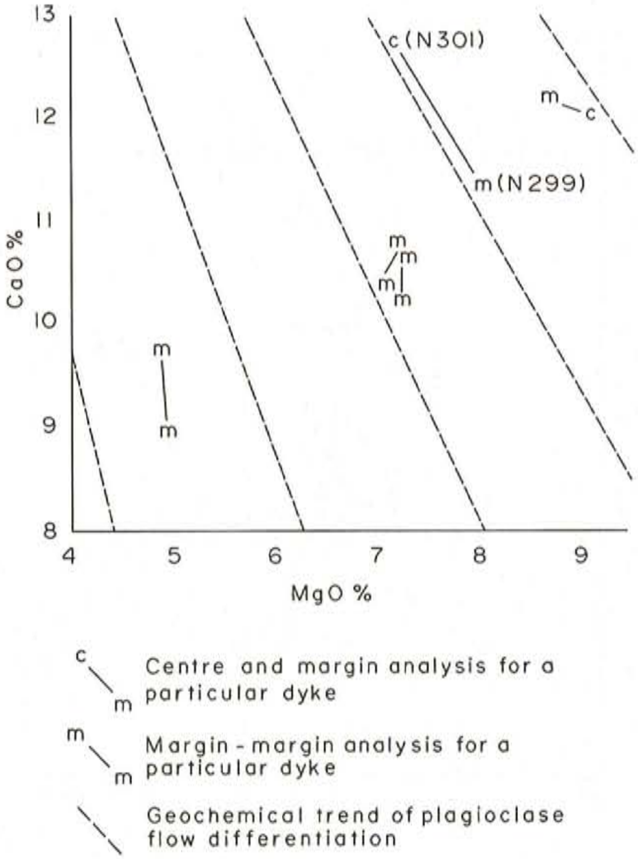

Figure 6. *Expanded section of Figure 5, showing margin-margin and margin-centre pairs from Kikkertavak dykes and their relationships to plagioclase (anorthite) differentiation.*

The structures in this dyke are interpreted in terms of variable flow regimes. The differential accretion structure found on both margins of this dyke suggests that originally, the margins formed a thin diabase dyke that expanded during flow to some 6 m in final width. The thin, margin parallel, laterally persistent, phyric–aphyric layering suggests low magma flow rates since features such as scouring or truncations are absent. The dyke then dilated abruptly, and the magma flow became faster, forming the inner 3-m-thick aphyric zone. Flow then became increasingly turbulent: each successive irregular layer in this dyke represents the deposits of a turbulent current, commonly scouring and eroding previously deposited layers. Size-grading of deposited crystal material resulted in the thin gabbroic cumulates seen at the start of many layers, and cognate xenoliths of gabbroic material were ripped up and deposited in the central core of the diabase dyke. The presence of these size-graded cumulates is proof that at least some shallow-level fractionation by sidewall accretion did occur in the dyke system. However, it is not likely that the required amount of material to produce the observed fractionation trends (Figures 3 and 4) could be removed from the liquid by sidewall accretion alone, given the limited widths of the dykes. Thompson (1974) shows that

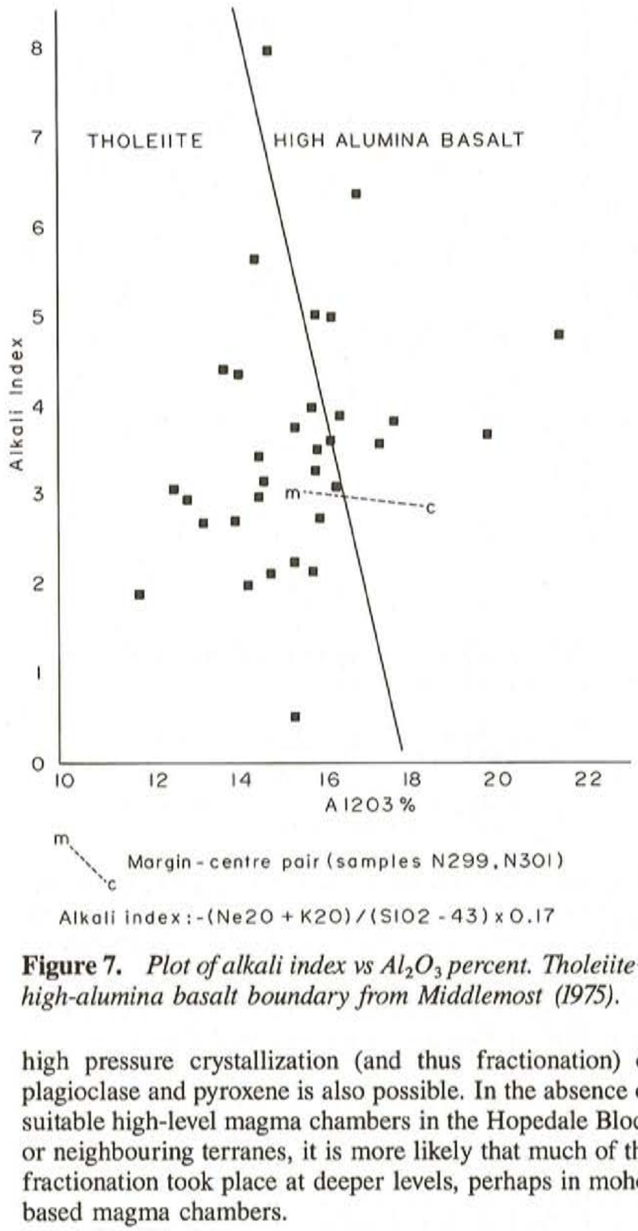

Figure 7. *Plot of alkali index vs Al_2O_3 percent. Tholeiite–high-alumina basalt boundary from Middlemost (1975).*

high pressure crystallization (and thus fractionation) of plagioclase and pyroxene is also possible. In the absence of suitable high-level magma chambers in the Hopedale Block or neighbouring terranes, it is more likely that much of the fractionation took place at deeper levels, perhaps in moho-based magma chambers.

PETROLOGICAL MODEL

The structures described above and the presence of cognate gabbroic xenoliths within Kikkertavak diabases suggest that the gabbros and diabases are both evolved from the same plagioclase megacrystic–phenocrystic magmas, the diabases forming the thinned vertical extensions of underlying gabbros. Upward thinning of Proterozoic dykes is also postulated for the Scourie dyke swarm in northwest Scotland (Tarney and Weaver, 1987). The differences in petrology can be explained by changes in flow regime. The large low-density, plagioclase megacrysts are easily entrained in the upwardly flowing magma. The heavy concentration of plagioclase megacrysts in a handful of dykes rather than uniformly throughout the whole swarm suggests their sidewall accretion in 'blind chutes' or blocked fissures. These were progressively bypassed by the main magma flows represented by the large, homogeneous gabbros, which probably fed surface flood basalts. As flow was diverted to these wider fissures, phenocrysts and megacrysts were accreted to the cooling margins of the narrower, slower flowing dyke segments, forming the differentially accreted texture previously described. Judging by their rarity in large volumes of gabbroic rock, the plagioclase megacrysts probably form a very small overall percentage of the original magma, but become super-concentrated in a small number of dykes. As more phenocrystic material was deposited, the remaining magmas ceased first to be megaphyric and then gradually became aphyric. Therefore, the thinnest diabases are commonly aphyric as they represent the last magmas to crystallize before stagnation of a particular flow occurred.

Build up of magma pressure beneath blocked or partially blocked fissures seems to have led to their redilation and consequent catastrophic increase in magma flow energy levels through the intrusion, resulting in the scouring textures associated with the deposition of gabbroic cumulates shown in Figure 6 and Plate 6.

DYKE EMPLACEMENT AND STRUCTURE

The absence of an extensive deformation after the emplacement of the Kikkertavak dyke swarm in the Hopedale Block, together with excellent exposure, allows the study of primary dyke geometry, except for those Kikkertavak dykes near the Kanairiktok shear zone, in which dyke margins become deformed. Kikkertavak and Harp dykes are always rectiplanar except for some slightly irregular larger gabbros in both swarms. Lack of stoping, and sharp dyke-wallrock contacts indicate that each swarm was injected into a cold, brittle, upper crustal environment under neutral or tensional stress fields, which readily accommodated dilation.

On an outcrop scale, evidence for the exploitation of pre-intrusive anisotropies in the host rock (for example, joints and foliation) is very rare in the map area: dykes always crosscut foliation and no correlation exists between dyke width and the degree of parallelism to planar fabrics in the host gneisses. *En echelon* crack arrays are always developed and the associated features (bayonets and steps) are very commonly preserved in dyke margins. Exploitation of local anisotropies may be expected where magmatic pressure exceeds the compressive stress acting perpendicular to the plane of the anisotropy (Delaney *et al.*, 1986). Although the angle between the foliation and the strike of the crack arrays and dykes was commonly acute, this does not occur here; probably because the foliation is locally variable in trend and, despite the regional consistency of both the Fiordian and Hopedalian trends, rarely forms long-range, planar features. It is inefficient for an extensive rectiplanar body such as a dyke to exploit local crustal anisotropies as it would constantly have to accommodate local variations in trend. The only exceptions to this are minor Kikkertavak dykes conformably intruding Hopedalian-trending gneisses near Hopedale village, where straight planar foliations are sometimes developed (see Figure 2 and Plate 1).

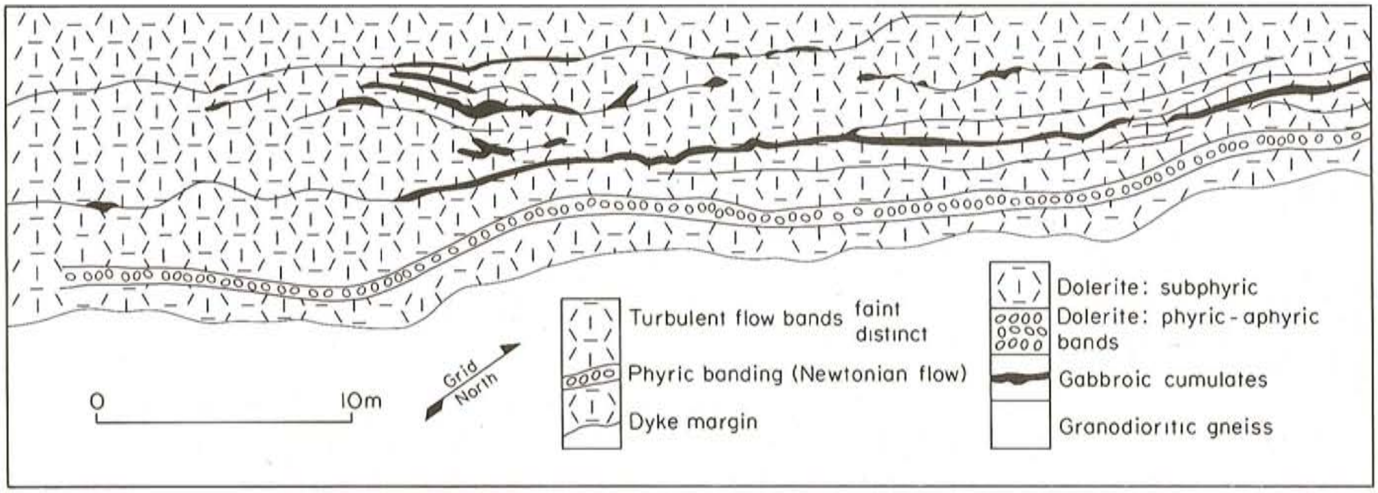

Figure 8. *Baseline-survey of flow structures in Kikkertavak diabase.*

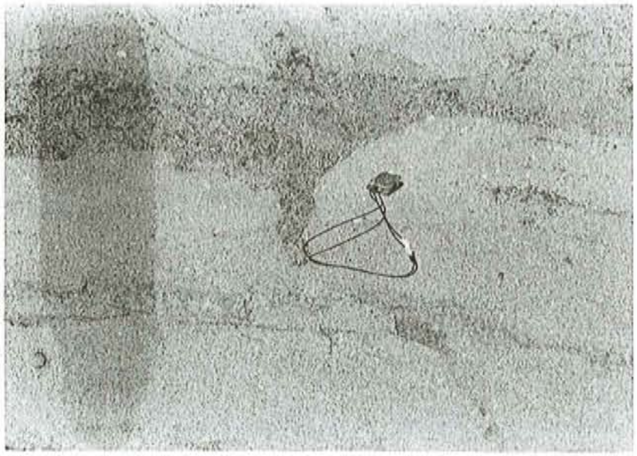

Plate 5. *Transition of flow regime: the photograph shows the marginal phyric–aphyric banding texture (left) and its transition to a more turbulent flow regime, marked by the dark, lateral bands of gabbroic material (centre and right). Note the irregularity of these bands compared to the phyric–aphyric layering on the left.*

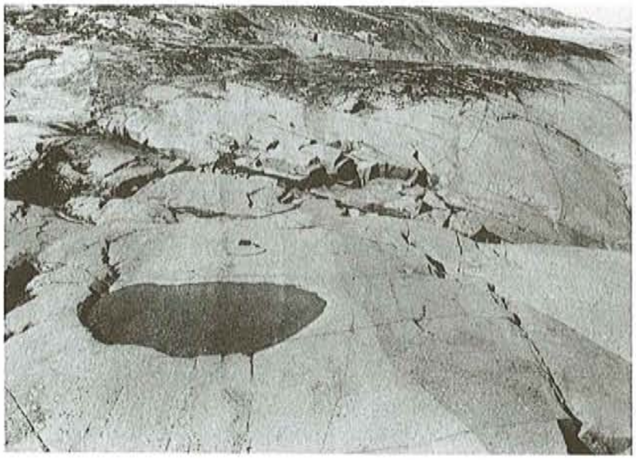

Plate 6. *Close up of a gabbroic band within sub-phyric diabase. Note that the plagioclase phenocrysts are dispersed rather than layered in the diabase.*

The Kikkertavak and Harp gabbros could easily be distinguished on the basis of trend; on a regional scale, there is a very strong correlation between the Fiordian trend and the trend of the Harp dyke swarm (Ermanovics and Raudsepp, 1979), particularly in the case of the large northeast-southwest-trending Harp gabbros. This suggests that crustal anisotropy is progressively more important for the larger intrusions as they are increasingly unaffected by local variations in foliation. However, Harp gabbros injected into Hopedale-trend gneiss continue to follow the Fiordian trend, suggesting that their paths of ascent were controlled either by a deeper Fiordian anisotropy or by a stress system coincident with the Fiordian trend. The gabbros of the Kikkertavak dyke swarm trend north-northeast–south-southwest and hence crosscut both Hopedalian and Fiordian fabrics and consequently may have a purely tectonic control. Smaller dykes, particularly in the Kikkertavak dyke swarm, do not conform to a uniform trend. However, since local anisotropies are not exploited, the orientation of the dykes must be controlled by the stress systems acting on the Hopedale Block at a regional or local level.

To see if individual dyke dilation directions could be related to a regional stress field, the horizontal dilation vector of Kikkertavak dykes sampled at random points in the field area was plotted against their strike. The plot (Figure 9) shows a very wide spread, not only of the orientation and dilation direction but also of the type of host-rock failure. Also plotted on the diagram is similar data for a local Kikkertavak dyke complex that shows almost as much variation as the regional data. The wide spread of regional data could perhaps be interpreted as variation in a regional, stress-induced pattern. However, intensive measurements of dilation and orientation data taken over 400 m of co-intrusive Kikkertavak dykes show almost as much scatter as the regional data. Therefore, the dilation and orientation of dykes is controlled by very local conditions.

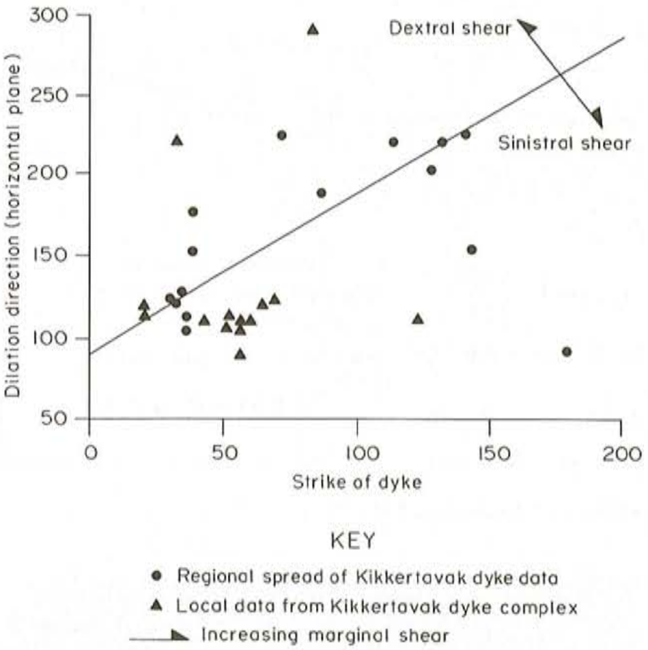

Figure 9. *Plot of the dilation vector in the horizontal plane versus the strike for randomly sampled Kikkertavak dykes and a local Kikkertavak dyke complex in the Hopedale Block.*

To see if the same is true for the Harp dykes, the dilation direction in the horizontal plane and orientation of three adjacent dykes at one locality were measured every 2 m along their length. The spread of data shown in Figure 10 shows again that dilation directions are extremely variable and thus, that these measurements cannot be used to infer the direction of the regional stress system operating at the time of intrusion.

The simplest dyke shown in Figure 10, dyke 2, shows up to 40° variation in both strike and direction of dilation. In places, dilation direction is orthogonal to the strike orientation of the dyke, i.e., the dyke opened by purely tensile failure. Other measurements, however, show varying amounts of dextral shear displacement have taken place on one margin relative to another during opening.

Dykes 1 and 3 show a larger spread of data due to their greater complexity: both dykes split into two branches, which act as conjugate shears. Thus, on the initial opening of the dyke, the branches dilate with opposing senses of shear displacement, which when summed cancel each other out, giving a more orthogonal opening direction over the whole system, as shown in Figure 11.

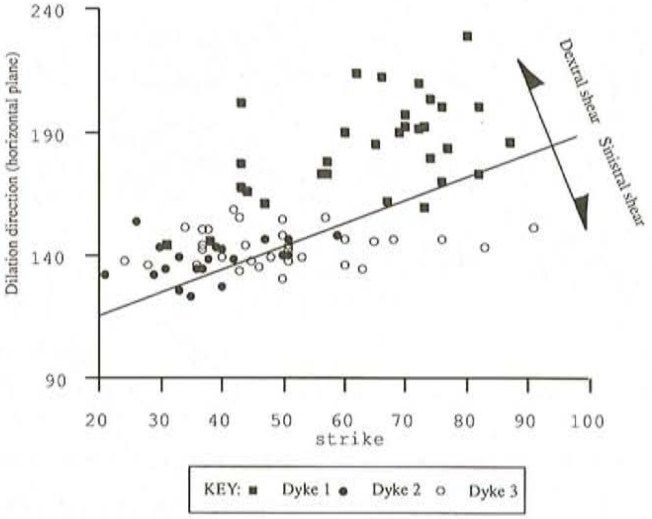

Figure 10. *Shows dilation direction as strike data for three closely spaced Harp dykes at the same locality. Each data point represents the strike and dilation direction of the dyke at a particular point along its length. Note that each dyke shows a wide scatter but occupies a different field on the diagram.*

Even if these affects are accounted for, the three occupy quite different areas of the diagram. Thus, it appears that no overall common opening direction can be found for different dykes intruded in one outcrop. It is possible that the dykes were intruded at different times and that the local stress system had changed, or that the dykes opened synchronously and affected each others dilation and orientation by changing the local stress field.

The conclusion reached is that local dilation directions cannot in general be used to determine the dilation direction of the swarm as a whole unless very large numbers of dilation directions are summed, and that the map pattern of the larger dykes is probably the best guide to the regional stress direction. Since the local data does not suggest any consistent sense of transtensional shear, the overall dilation direction vector is therefore likely to be orthogonal to the trend of the largest dykes.

There is little information concerning dilation in the vertical plane, primarily due to the absence of good vertical outcrop. However, where suitable outcrops are present, dykes are usually vertical and have no component of dilation in this direction.

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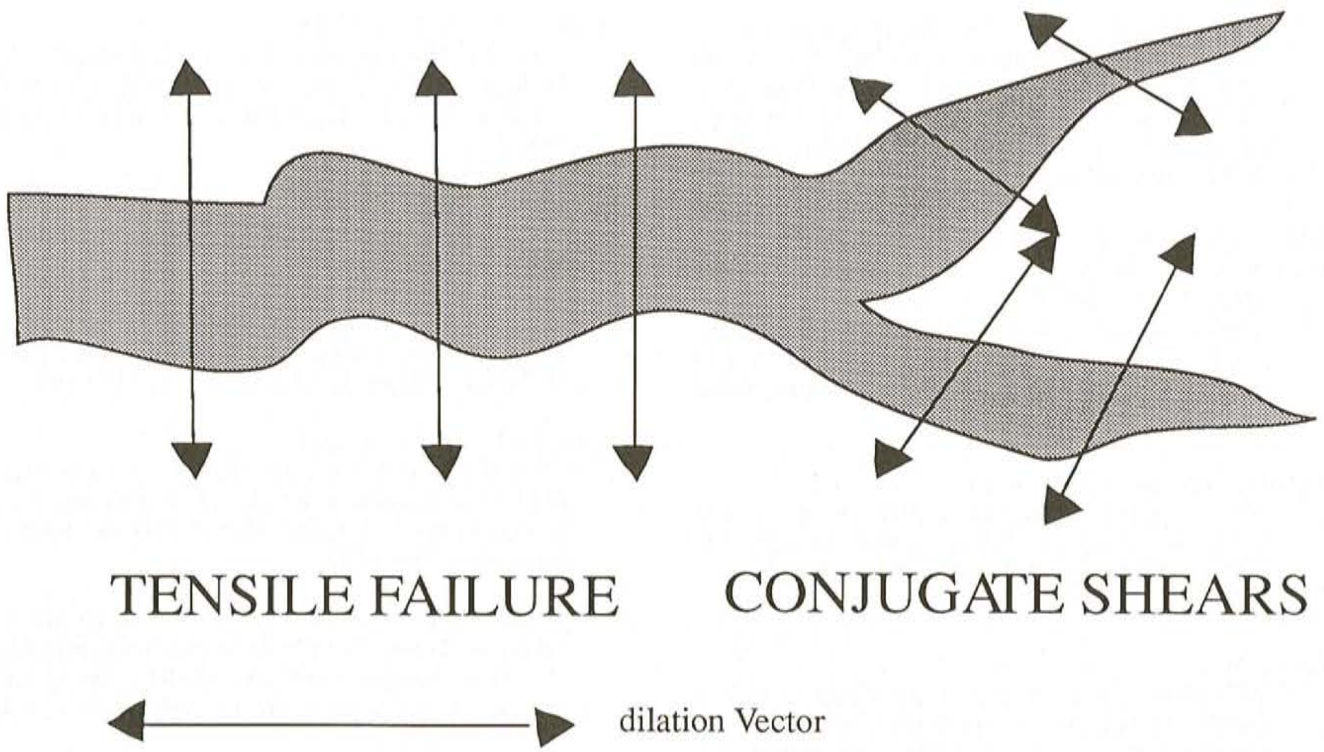

Figure 11. *Theoretical diagram showing the splitting of a dyke into two branches. The two branches of the dyke show very different directions and orientations to the single section of the dyke, which shows dilation at right angles to the orientation of the dyke. However, the sum of the dilation vectors, namely the direction of dilation and its magnitude (i.e., the width of the dyke) is the same as the dilation vector for the unsplit section. Similarly, individual dykes intruded synchronously may interact with each other so that, although showing markedly different dilation directions, the sum of the dilation directions shows a consistent opening direction.*

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