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THE PETROGENESIS AND EMPLACEMENT OF PROTEROZOIC DYKE SWARMS, PART 1: INITIAL FINDINGS AND PATHS OF FURTHER RESEARCH

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ABSTRACT

Proterozoic dyke swarms intruding Archean shield terranes represent major events of igneous activity in the Earth's history. Recent debate has focussed on the role of source heterogeneity versus that of crustal contamination, in order to explain geochemical discrepancies between major- or trace-element compositions as opposed to isotope abundances. The emplacement of Proterozoic dyke swarms constitutes an episode of crustal addition, in previously permobile environments, that may record, or herald, fundamental changes in global tectonic processes. Study of these dyke swarms may reveal if crust-manufacturing processes were similar to, or different from, those of the Phanerozoic and how, if at all, they changed through time.

INTRODUCTION

The unique scale and frequency of the dyke swarms that were intruded into newly stabilized Archean cratons from Late Archean to Late Proterozoic time, make these dykes excellent sources for studying the geochemical evolution of dyke swarms and their mantle source, during this same period. The Kikkertavak dyke swarm and the Harp Lake dykes, emplaced into the Archean Hopedale Block of Labrador, were chosen to test the application of existing models pertaining to swarm magma composition and mantle source changes during the Late Archean to Middle Proterozoic. In addition, the direction of magmatic flow and swarm emplacement processes are examined. Geochronological studies have shown the Kikkertavak dykes to be about 2200 Ma (Rb–Sr whole rock date, B.J. Fryer, *in* Grant *et al.*, 1983), and the Harp dykes to be about 1200 Ma (Rb–Sr whole rock date, F.R. Voner, *in* Ermanovics *et al.*, 1982; Grant *et al.*, 1983).

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 Korstgård, 1981; Ermanovics *et al.*, 1982). The GSC focus has been to establish the petrological, geochronological and structural aspects of the Archean gneisses (e.g., Korstgård and Ermanovics, 1984, 1985). 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 (see above), 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 approximately 100 km west of the present study area, have been investigated by Meyers and Emslie (1977).

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 (Figures 1 and 2). It consists of polydeformed, mainly granodioritic to tonalitic gneisses having a predominantly northeast–southwest (Fiordian) trend. The Fiordian-trending fabrics are interpreted by Ermanovics *et al.* (1982) to be Late Archean and postdate the predominantly pretectonic Kanairiktok granite 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) 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 having some amphibolite bands. The gneisses are at amphibolite grade, 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 very conspicuous as rectiplanar and irregular intrusive masses throughout the

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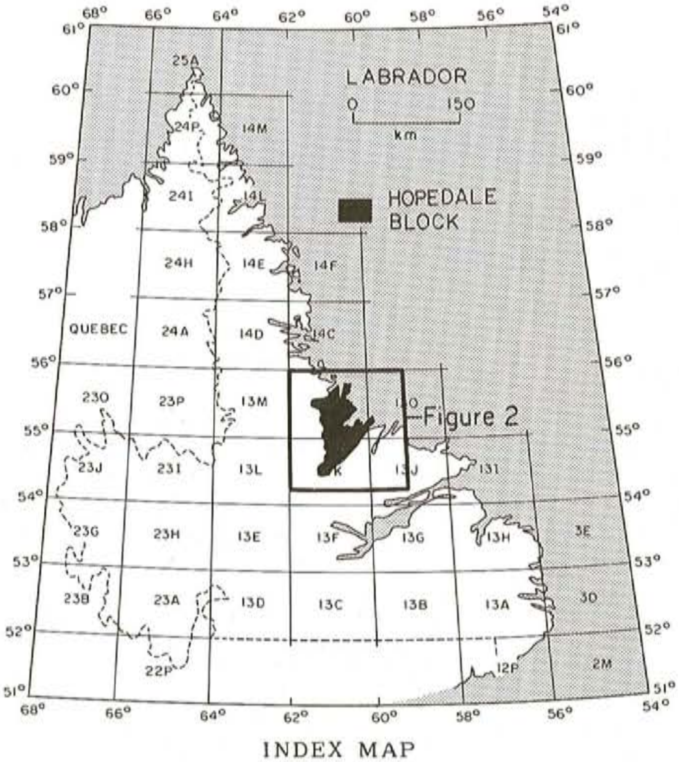

Figure 1. *Location of the Hopedale Block, Labrador.*

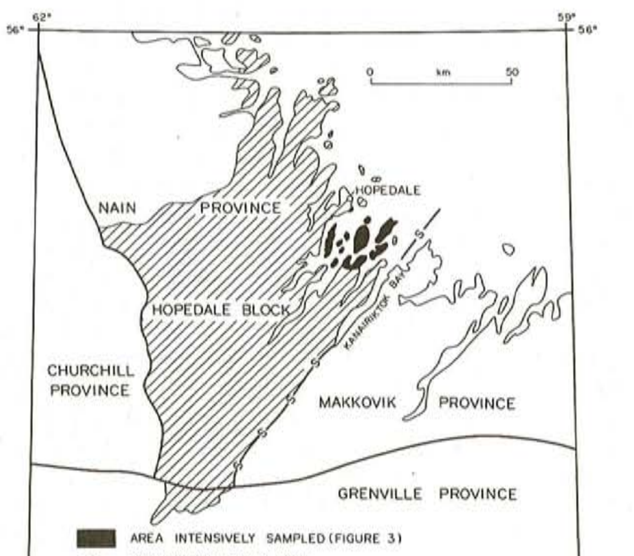

Figure 2. *The study area within the Hopedale Block.*

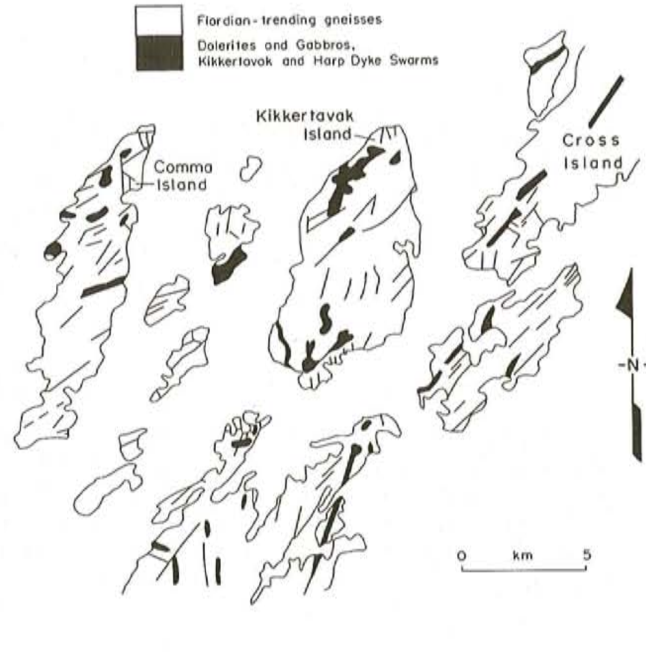

Figure 3. *Sketch map showing dyke trends in the intensively sampled area.*

whole Hopedale Block. They are superbly exposed along the ice-scoured coastline of the mainland and island archipelago, north of Kanairiktok Bay (Figure 3). Consequently, this area was chosen for detailed investigation, and fieldwork was undertaken mainly by boat. Wherever possible, centres, margins and wallrock contacts of dykes were sampled for geochemical analysis. Studies of dyke emplacement concentrated on very detailed mapping of primary dyke structures and contact kinematic indicators.

GEOCHEMISTRY AND PETROLOGY

The overall character of the two swarms appears very similar in hand specimen: the older Kikkertavak swarm consists of clinopyroxene–plagioclase diabase and olivine–pyroxene–plagioclase gabbro and the younger Harp dykes consist of olivine diabase and olivine gabbro (Ermanovics *et al.*, 1982).

In the field, the most diagnostic feature of the diabases in each swarm is colour. The low-grade, greenschist-facies alteration (and rare, localized shearing of the margins) of the Kikkertavak dykes, caused by northeast–southwest shearing and deformation in the mid-Proterozoic, e.g., the Kanairiktok shear zone (Ermanovics *et al.*, 1982), has led to a light green colouration, which is especially widely developed in the southern part of the Hopedale Block. The Harp dykes, however, often have a deep red-spotted, brown surface, due to their high iron content and the weathering of olivine crystals respectively, but appear unaltered. The gabbros, on the other hand, are seemingly indistinguishable and cannot be confidently assigned to a particular swarm on the basis of field criteria.

The locally very strong plagioclase phyricity of the Kikkertavak swarm, totally absent in the Harp dykes, points to considerable plagioclase fractionation within these dykes. Phenocrysts measure up to 10 cm in diameter and are usually euhedral or subhedral in shape, although a few multi-nucleic aggregates and porphyritic, cognate xenoliths are also present.

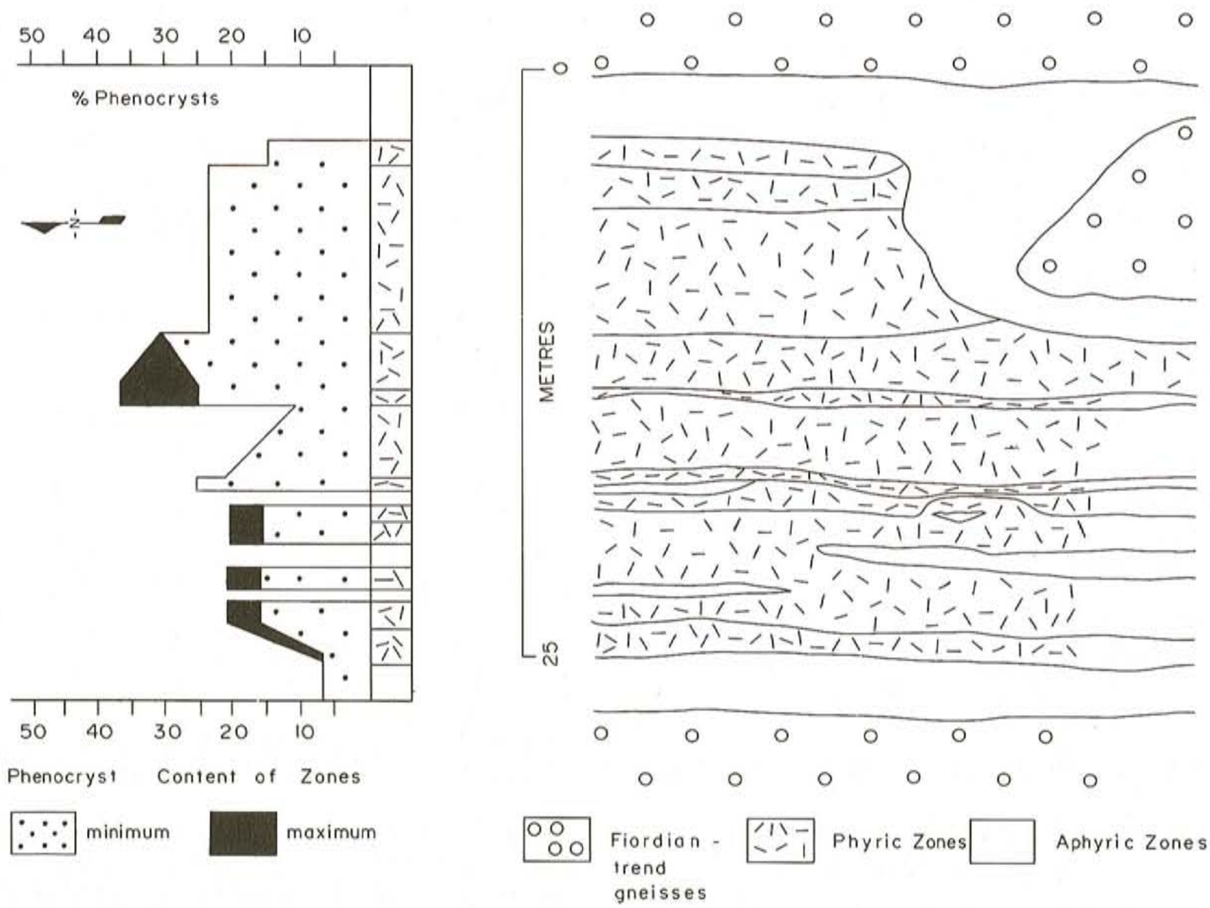

Figure 4. *Diagram showing marked zoning of phenocrysts in a Kikkertavak dyke, Cross Island.*

Reaction rims are absent, suggesting equilibrium with the surrounding melt. Division into phyric and aphyric zones within a dyke is commonly marked. Commonly, the phenocrysts are highly concentrated in the central portion of the dyke, suggesting flow differentiation (Komar, 1972). However, one particular dyke shows a very complex, layered, zoning pattern (Figure 4), suggesting that differential accretion caused the resulting zoning pattern (Platten and Watterson, 1987). The differential accretion theory argues that changing hydraulic conditions in the magma were responsible for the accretion or non-accretion of phenocrysts onto the advancing solid–liquid interface in the dyke: phenocryst concentration in the dykes need not change during intrusion and the magma is porphyritic throughout emplacement.

Dyke margins are chilled and no visible phenocrysts are seen accumulated to them. Their absence indicates that heat transfer was by conduction rather than by convection (Tarney and Weaver, 1987) and concurs with the differential accretion of phenocryst phases mentioned above. Convectional heat transfer would be expected to deposit coarse phenocrysts on dyke margins or to result in the thermal erosion of the country rock. Also, in the absence of wallrock cumulates, a convecting basaltic magma would partially melt gneisses of granodioritic or tonalitic composition, to produce selective contamination of the magma (Mohr, 1987). In contrast, conduction would be expected to insulate the country rock (granodioritic–tonalitic gneiss) as rapid cooling took place at the dyke–wallrock interface. Also, no evidence of corrosion is seen in the field: primary margin morphology (bayonet and step features) is preserved, and country rock or xenolith contacts with dykes are always sharp. Weaver and Tarney (1981) suggest that a lack of crustal contamination is a general feature of many Proterozoic dyke swarms.

Despite the lack of contamination, the heavy zoning of phenocrysts in the Kikkertavak swarm means that a primary magma composition is unlikely to be preserved in either the centre or the margins (Weaver and Tarney, 1983). The Harp dykes, however, are not visibly differentiated and, hence, samples may preserve the original magma geochemistry.

Therefore, the best approximation of a primary magma is not necessarily the most primitive of analyzed samples. Although work on the Scourie dykes (Weaver and Tarney, 1983) suggests that shallow level processes, (e.g., fractionation or mixing) may not affect many Proterozoic swarms, differentiation across the dykes complicates modelling. The trend of progressive magmatic evolution from the dyke margin to the centre as the fissure dilates with time is, therefore, complicated in the Kikkertavak dykes. Analyzing only the groundmass in these cases may obtain a clearer trend.

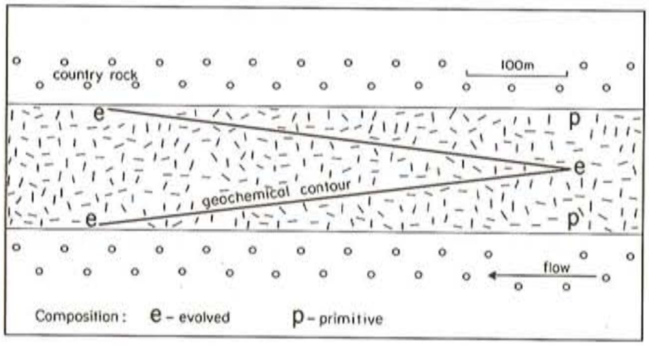

Figure 5. *Analysis of magma flow by geochemical contouring.*

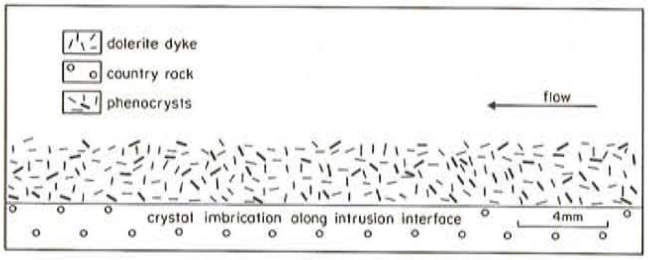

Figure 6. *Analysis of magma flow by crystal imbrication.*

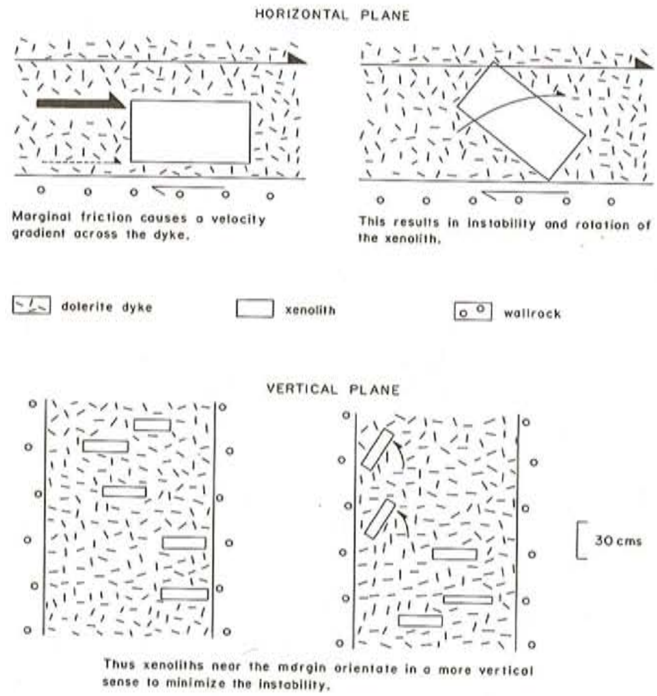

Figure 7. *Three-dimensional representation of xenolith orientations in a Harp(?) dyke, Cross Island.*

MAGMA FLOW AND DYKE EMPLACEMENT

Magmatic flow within the dykes, during intrusion, is one of the main objects of study of the IGCP research.

The Hopedale crustal block is not considered to have been tilted significantly after emplacement of the swarms: Fiordian metamorphic grade is fairly constant throughout. (However, the presence of low-angle mafic sheets in the north of the region, suggests a shallower crustal level may be exposed there.) Therefore, a component of lateral flow within the dykes should be apparent as a progressive evolution of magma composition along the length of a dyke (Figure 5). Flow direction can also be indicated by crystal or xenolith alignment within a dyke, especially if imbricated along wallrock contacts (Figure 6). This latter criterion would also give a monopolar, rather than a bipolar, flow direction.

Generally, dykes are free of xenoliths, but at one remarkable locality (Figure 7), 60 percent of a dyke consists of tabular xenoliths. This dyke quickly dies out vertically, suggesting that the xenoliths are the product of roof stoping. However, many xenoliths are not composed of locally indigenous granodioritic gneiss, but amphibolite or metaquartzite, suggesting derivation from elsewhere. The xenoliths are orientated with the largest plane striking parallel to the dyke wall and suggest horizontal flow. The xenoliths are usually horizontal in the centre of the dyke but subvertical at the northern margin (Figure 7). This change is still consistent with lateral flow since the dyke wall would exert a frictional shear force, and a horizontal xenolith adjacent to the dyke wall would have a stronger force applied to its outer edge by the magma flow. Thus, a moment of force would be created, rotating the xenolith around the 'a' axis (Figure 8). This instability could be minimized by orienting the xenolith parallel to the dyke wall, therefore, eradicating the differential force (Figure 8). The southern margin does not show this phenomenon due to the presence of an extremely large xenolith block (greater than one metre in length) that caused local turbulence in the flow.

The general lack of xenoliths in most dykes suggests dilation to be the mechanism of emplacement. The direction in which this dilation occurs depends on three factors; 1) pre-intrusive weaknesses in the host rock, 2) the regional stress field, and 3) the local stress field induced by magma pressure. If host rock weaknesses are exploited, then a dyke is probably not intruding along a principal stress direction resulting in an oblique dilation (Delaney *et al.*, 1986). The extrapolated closure of a Harp dyke in the horizontal plane (Figure 9), suggests a dilation direction perpendicular to the dyke wall, and if further studies on both swarms indicate the same, then pre-existing lineaments will not have influenced dyke emplacement. Therefore, emplacement involves interaction between regional and magmatic stresses. Nearer the centre of magma pressure, opening direction may be largely controlled by it, whereas at distal regions of the swarm, magma pressure wanes and the regional stress field will increase in influence (Odé, 1957).

This interaction is difficult to analyze in three dimensions, as both horizontal and vertical planes of the dyke must be examined. For example, Figure 9 shows a carefully

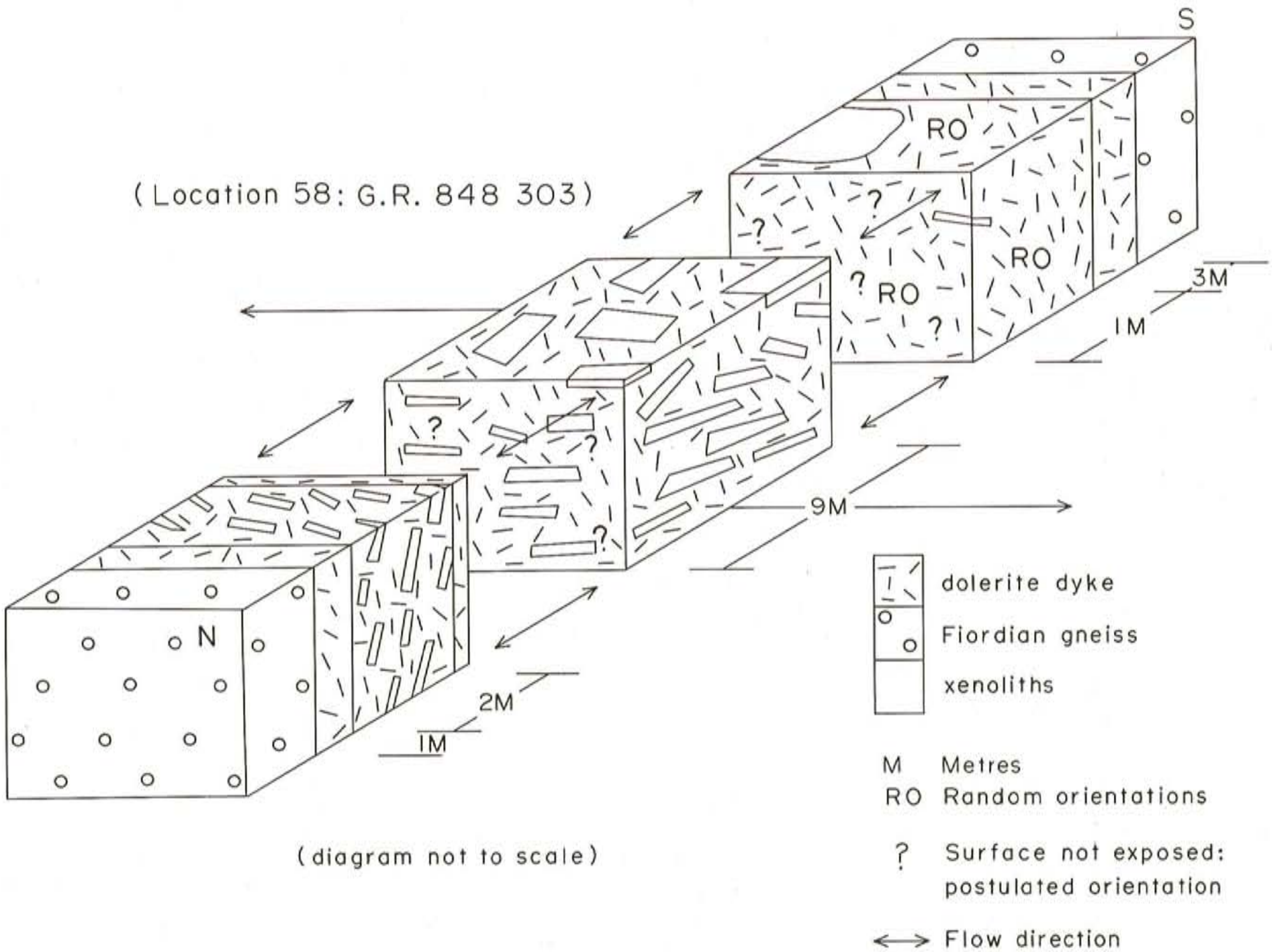

Figure 8. *Stress differentials at dyke margins and potential resultant rotations.*

measured Harp dyke mapped in the horizontal plane. The extrapolated horizontal closure leaves 15 percent of the dyke surface area unaccounted for. Corrosion of the gneissic wallrocks to this degree is highly unlikely as already discussed, therefore, some degree of dilation in the vertical plane must have occurred.

THE NATURE OF THE PROTEROZOIC MANTLE

The large scale of Proterozoic dyke swarms, points to the mantle as the original magma source. Work on the Scourie dykes (Weaver and Tarney, 1983), suggests that geochemical heterogeneities in the swarm cannot be modelled by shallow level fractionation or contamination, but evolve from heterogeneities in a previously metasomatized mantle. Although the Kikkertavak and Harp dyke swarms appear similar and homogeneous, the degassing and depletion of the mantle during the 1 Ga period between their respective intrusions may be reflected in their subsequent geochemistry.

FUTURE PLANS

The 338 samples taken during the last field season (1988) for sectioning, geochemical analysis and dating, should be sufficient for petrological studies. However, because the sampling was intensive but regionally restricted (Figure 2), further sampling may be necessary in outlying parts of the field area in order to analyze regional trends in swarm geochemistry and petrology.

In the summer of 1989, further work will focus on dyke emplacement processes, especially on their relationship to pre-intrusive foliations and joint patterns within the host gneisses. Fissure dilation directions may reveal information concerning the paleostress system operating during dyke emplacement.

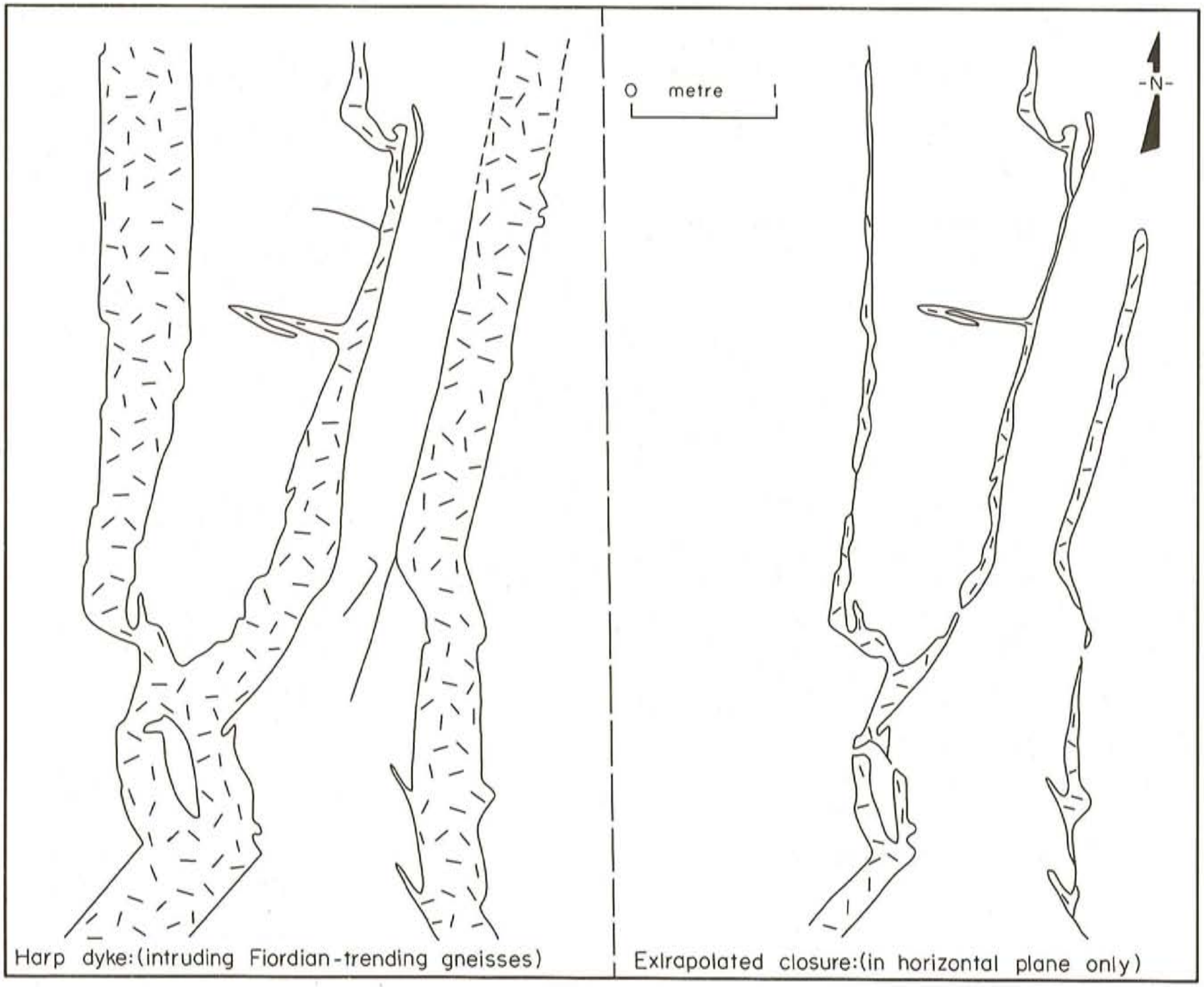

Figure 9. *Extrapolated closure of a Harp dyke as an indicator of the presence of vertical dilation components.*

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