THE GEOLOGY OF THE FYFE HILLS—KHMARA BAY REGION, ENDERBY LAND

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Abstract The gneisses of the Fyfe Hills-Khmara Bay region in Enderby Land form part of the Archaean Napier Complex. They are composed predominantly of supracrustal rocks forming the "Layered Series", but also include a component of probable intrusive origin forming the "Massive Series". Both series have been affected by four phases of deformation and multiple metamorphic and intrusive episodes. The available isotopic data are used to constrain the age of each of these events.

F_1 folds and associated structures indicate intense flattening during prograde granulite facies metamorphism. These folds are of unknown age but age thought to have formed during an episode of continuous metamorphism culminating with the development of 2500 Ma old F_2 folds. The highest metamorphic temperatures (M_1) of 820-950°C at pressures of 8-11 kb occurred during D_2

Tholeiitic dykes, intruded parallel to the axial surfaces of developing F_3 folds, are thought to correspond to a suite of similar dykes in neighbouring regions dated at 2400± 250 Ma. The metamorphic assemblages of these dykes indicate temperatures (M_2) of 650-750°C at pressures similar to M_1. Elsewhere post-M_1 isobaric cooling is indicated in the host gneisses by retrograde corona and exsolution textures.

The final deformation phase (D_4) occurred during the excavation of the gneissic pile. The effects of D_4 are restricted to retrograde zones that exhibit a wide range of amphibolite facies mineral assemblages (M_3), indicating progressive, near isothermal, decompression. The initiation of the shear zones may have been coeval with the 1000 Ma Rayner event in nearby crystalline blocks. Tectonism ceased with the intrusion of Early Palaeozoic pegmatites, and before the intrusion of rare mafic alkaline dykes which have been dated at 490 Ma elsewhere in Enderby Land.

The Fyfe Hills area is crucial in the interpretation of the evolution of the Precambrian crystalline rocks of Enderby Land. This is largely the result of the 4.0± 0.2 Ga U-Pb age obtained by Sobotovich et al. (1976). Although this age is disputed (Grew and Manton, 1979) it has generated a number of independent isotopic studies (DePaolo et al., 1982; Grew et al., in press; Black and James, this volume; McCulloch and Black, this volume). Much of the data generated by these studies has been collected and interpreted without the constraints imposed by detailed field work. The aim of this contribution is to elucidate the field relationships in the Fyfe Hills-Khmara Bay region and provide a framework for the interpretation of the available isotopic studies. This work is based on a combined total of 14 man-weeks field mapping in the Fyfe Hills and the adjacent islands of Khmara Bay during the 1979/80 Austral summer.

REGIONAL SETTING OF FYFE HILLS

The geology of Enderby Land has been reviewed by Ravich and Kamenev (1975) and Sheraton et al. (1980). The Fyfe Hills are near the western margin of the older of two metamorphic complexes within Enderby Land; that is, the Archaean Napier Complex which is bounded on its continental side by the Proterozoic Rayner Complex. This bipartite division of the crystalline basement is supported by the restriction of unmetamorphosed Amundsen Dykes to the Napier Complex. These dykes, dated at 1190 Ma (Sheraton and Black, 1981) occur as highly deformed relicts within the Rayner Complex.

Grikurov et al. (1976) divided the Napier Complex into two series; the predominantly orthogneissic Raggatt Series and the predominantly paragneissic Tula Series. Sobotovich et al. (1976) regarded the Fyfe Hills as part of the Raggatt Series, and argued that the 4.0± 0.2 Ga age indicates that the Raggatt Series is older than, and hence forms the basement to, the Tula Series. Kamenev (1982) suggested that the layered gneisses of the Fyfe Hills are derived from a primary enderbitic or quartz diorite body by processes of metasomatism and metamorphic differentiation. However both Sandiford and Wilson (in prep.) and DePaolo et al. (1982) have argued that the Fyfe Hills gneisses are derived from predominantly supracrustal precursors and hence are of Tula Series affinities. James and Black (1981) have suggested that the intimate association of the Tula and Taggatt Series in the Amundsen Bay area is the result of tectonic interleaving, but neither isotopic nor field studies have yet been able to successfully distinguish the relative ages of the two series.

LITHOLOGICAL RELATIONSHIPS

Published geological maps of Enderby Land suggest that the boundary between the Napier and Rayner complexes passes between the Fyfe Hills and the islands of Khmara Bay (Ravich and Kamenev, 1975; Sheraton et al., 1980; James and Black, 1981). However, our mapping has shown that this region (shown in Figure 1) is dominated by high grade granulite facies gneisses with the petrographic, isotopic (DePaolo et al., 1982; Grew et al., in press) and field characteristics of the Napier Complex. The high grade gneisses form 90% of the outcrop, the remaining 10% being retrograde zones composed of amphibolite grade schists, mylonites and pegmatites.

The high grade gneisses form a layered sequence at least 3 km thick. Charnockitic and enderbitic gneisses (felsic granulites) form 60% of

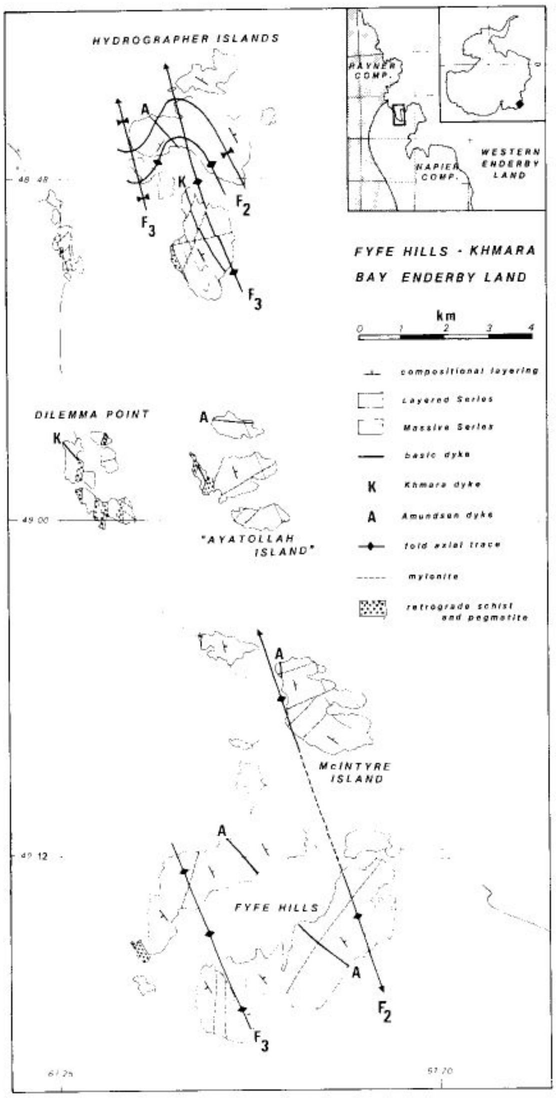

Figure 1. Geological map of the Fyfe Hills-Khmara Bay area, Enderby Land. Only those members of the Massive Series that show evidence of being derived from intrusive sheets are shown.

outcrop and are interlayered with mafic granulites (15%), ultramafic gneisses (3%), meta-pelites (10%) and minor meta-ironstones and calcsilicates.

Contacts between compositional types are generally concordant and parallel to the bulk compositional layering. However, at a few localities (McIntyre Island and Hydrographer Island) discordant contacts between meta-pelite and relatively massive sheets of charnockite are interpreted as primary intrusive contacts (Sandiford and Wilson, in prep.). The recognition of these discordant contacts allows the division of this sequence into two series: (1) the "Layered Series" derived from a supracrustal sequence composed of high Mg-pelites and Fe-rich sediments together with felsic, mafic and ultramafic volcanic and volcanogenic strata; the occurrence of a celsian-spessartine-Mn clinopyroxene-magnetite paragenesis at Fyfe Hills is particularly interesting as the association of Ba and Mn in chemical precipitates is indicative of submarine exhalative environments; the "Layered Series" comprises at least 70% of outcrop and is characterised by a pronounced layered compositional heterogeneity with individual units rarely exceeding 10 m in thickness and more typically 1-5 m thick: and (2) the "Massive Series" comprising relatively thick (> 50 m) compositionally homogeneous sheet like bodies which appear to be derived from the subconcordant intrusion of intermediate to mafic igneous rocks into the pre-existing Layered Series.

It is tempting to correlate the "Layered" and "Massive Series" with the Tula and Raggatt Series respectively. However, because Sobotovich et al. (1976) suggested the Fyfe Hills rocks are members of the Raggatt Series, we prefer not to use these terms in the present context. Furthermore, until a more detailed picture emerges of the field relationships between orthogneissic and paragneissic sequences throughout the Napier Complex the regional extent of the "Massive/ Layered Series" distinction cannot be evaluated.

STRUCTURAL GEOLOGY

Four generations of structures deform both the Layered and the Massive Series (Figure 1). A set of E-W trending antiformal culminations dominate the structure of the area. The E-W plunging antiform (F_2) passing through southern Khmara Bay and northern Fyfe Hills folds a set of earlier mesoscopic folds (F_1) and associated structures and is itself folded about an antiform (F_3) passing through southern Fyfe Hills. F_{1-3} folds are dissected by retrograde shear zones formed during the final phase of deformation (D_4). Metamorphosed basic dykes, the "Khmara dykes", (Sandiford and Wilson, in prep.) were intruded immediately prior to or early in D_3 while the generally unmetamorphosed Amundsen Dykes were intruded between D_3 and D_4.

The D_1 event is characterised by mesoscopic isoclinal folding, boudinage and a pervasive gneissic layering. Macroscopic F_1 closures are comparatively rare compared with the more central and easterly exposures of the Napier Complex (James and Black, 1981; our own observations, 1979/80). Most D_1 structures are associated with uniform medium grained granoblastic polygonal to interlobate textures, although rare S_1 flaser textures are preserved in some enderbitic gneisses, suggesting the D_1 occurred during prograde granulite facies metamorphism but before metamorphic culmination (M_1). Mafic boudins in felsic hosts may be separated in the plane of the compositional layering by up to 20-30 times individual boudin length, suggesting an oblate D_1 finite strain ellipse with X:Y:Z> 30:30:1 and indicative of intense subvertical flattening. The D_1 mesoscopic geometry and morphology together with the paucity of large scale closures suggests crustal thinning during D_1

The D_2 event resulted in abundant reclined meso and macroscopic folds. The overall F_2 configuration is similar to the "rucked-up" F_2 gneissic pile that James and Black (1981) have described in the Amundsen Bay area. Microstructural equilibration of the highest grade assemblages during D_2 is apparent in many meta-pelites indicating that metamorphic culmination (M_1) occurred during D_2 and furthermore suggests a close temporal relationship between D_1 and D_2. F_2 folds are best developed in meta-pelites, and are commonly associated with boudinage. Pegmatites formed in the "pressure shadow" of these boudins have yielded 2.5 Ga zircon ages (Grew et al., in press), a date which we interpret as the age of the D_2 event. Late shearing along the axial surfaces of some F_2 folds has resulted in recrystallisation of partially hydrated assemblages and may reflect localised reintroduction of H_2O in the waning stages of D_2. However the microstructures and assemblages associated with these axial surfaces are reminiscent of D_3 microstructures and possibly reflect D_3 reworking of suitably oriented D_2 structures.

The D_3 event produced a series of upright, open to tight meso- and macroscopic E-W trending folds with shallow variously plunging axes. An axial plane schistosity (S_3) is locally developed and characterised by fine grained granoblastic textures formed by the recrystallisation and partial hydration of the highest grade assemblages and a near vertical extension lineation (L_3).

The "Khmara dykes" form subvertical E-W trending planar bodies approximately parallel to the S_3 axial surface; their macroscopic form suggests that they have not been folded. However, examination of the dyke margins revealed folded apophyses with axial planar S_3 fabrics. Furthermore the dykes contain the fine-grained granoblastic textures typical of S_3 fabrics in the host gneisses. These features suggest to us that the dykes have been intruded either prior to or during the development of the F_3 folds in orientations precluding the development of macroscopic folds. Griffin (in prep.) has noted a similar temporal and spatial relationship between metamorphosed tholeiitic dykes and F_3 folds in Amundsen Bay. These dykes are petrographically and chemically similar to the B_2 tholeiitic dykes of Sheraton and Black (1981) which have been dated at 2.4 ± 0.25 Ga. However, Sheraton and Black (1981) consider the B_2 dykes to postdate D_3 folding, a relationship which has been used by James and Black (1981) to constrain the age of the D_3 event.

Subvertical retrograde zones that truncate all previous structures as well as the Late Proterozoic Amundsen Dykes are the only manifestations of D_4. The zones vary from narrow ductile shear zones to zones of amphibolite facies schist and mylonite up to 300 m wide; they locally contain abundant migmatite and pegmatite. Structures within the shear zones are commonly complex, a fact that reflects continuous or episodic reworking during a prolonged history. The mylonitic foliation (S_4) formed parallel to the walls of the mylonite zones generally contains a near vertical extension lineation (L_4) and indicates that the retrograde zones developed in reponse to differential displacement between rigid blocks of granulite during an essentially vertical tectonic regime.

METAMORPHIC GEOLOGY

Three dynamic metamorphic/microstructural "events" have been recognised. These are: (1) a prograde granulite facies event (M_1) initiated prior to D_1 and culminating during D_2; (2) a retrograde granulite facies event (M_2) coeval with D_3; and (3) a retrograde amphibolite facies event (M_3) coeval with D_4. Superimposed on these metamorphic assemblages are the effects of static re-equilibration to lower grade conditions, namely, a range of corona and exsolution textures and mineralogical zoning. The mineral assemblages diagnostic of each "event" are listed in Table 1 and an evaluation of the conditions of metamorphism is presented below (see also Figure 2).

The stability of mesoperthite, sapphirine-quartz and sub-calcic clinopyroxene testifies to the unusually high temperatures (T) prevailing during M_1. Two pyroxene geothermometry (Wood and Banno, 1973; Wells, 1977) yields temperatures in the range 820-950°C. The presence of fine exsolution lamellae in coexisting M_1 pyroxenes suggests that these are underestimates, and probably counteracts the overestimation inherent in these thermometric methods (Wood, 1975). Exsolution temperatures in coarsely exsolved pyroxenes range from 770-830°C. The preferred M_1 temperature range of 820-950°C is comparable with, although slightly lower than, estimates for the highest grade assemblages eslewhere in the Napier Complex (Ellis, 1980; Grew, 1980).

M_1 pressure estimates based on coexisting garnet, orthopyroxene, plagioclase and quartz (Newton and Perkins, 1982) fall in the range 8-10 kb, while Harley's (1981) garnet-orthopyroxene barometer yields pressures in the range 7-10 kb. These estimates are consistent with the absence of garnet in tholeiitic compositions (Green and Ringwood, 1967), the occurrence of sapphirine-quartz and sillimanite-hypersthene assemblages to the exclusion of cordierite (Newton, 1978), and resemble pressure estimates from the Tula Mountains in the central Napier Complex (Ellis, 1980; Grew, 1980). However, a number of lines of evidence indicate that the Fyfe Hills rocks represent deeper crustal sections than are exposed in the Tula Mountains: (i) the restrictions of garnet-clinopyroxene assemblages to Fyfe Hills, albeit to bulk compositions enriched in Mn and/or Ca, (ii) the occurrence of sillimanite and hypersthene in preference to cordierite in coronas

TABLE 1: Diagnostic mineral assemblages and preferred pressures (P) and temperatures (T) for the metamophic events M_1, M_2 and M_3. Mineral abbreviations: mp = mesoperthite; ap = antiperthite; q = quartz; px = pyroxene (c = clino, o = ortho, s = subcalcic); kf = k-feldspar; pl = plagioclase; hb = hornblende; bt = biotite; gt = garnet; m = muscovite; cc = calcite; cu = cummingtonite; ol = olivine; sp = spinel; se = serpentine; sap = sapphirine; sil = sillimanite; ky = kyanite; gd = gedrite; st = staurolite; cd = cordierite; mg = magnetite; ce = celsian; gru = grunerite; = > mineral reactions or transformations; mp/ap either mp or ap.

Rock Type	M_1	M_2	M_3 (early)	M_3 (late)
Felsic granulite	mp/ap, q, opx, cpx mp = >	kf, pl, q, opx, bt kf + pl px = >	hb, bt	kf, pl, hb, q, m
Mafic granulite	cpx, opx, pl, q px + pl = >	cpx, opx, gt, pl, hb gt + q px = >	hb, bt, pl, q, gt, cc hb, bt	hb, bt, pl, q, cc, cu
Ultramafic	cpx, opx, ol/pl, sp, hb	cpx, opx, bt, gt, hb		bt, se, cc
Metapelite	mp/ap, sap, opx, gt sil, q, sp sap + q = >	kf, pl, opx, gt, sil sil + opx sil = >	gt, pl, q, by, ky, gd ky ky + ge + gt = >	gt, pl, q, bt, sil, st, cd, m st + sil + cd
Fe- (Mn) meta-sediment	mg, q, opx, cpx, gt, ce, scpx scpx = >	cpx + opx		mg, q, gru, gt
T	820-950 C	650-750 C	600-700 C	570-670 C
P	8-11 kb	7-10 kb	7-9 kb	3-5 kb

between M_1 sapphirine and quartz in Fyfe Hills, (iii) the absence of osumilite from Fyfe Hills and its replacement by the previously unrecorded higher pressure assemblage sapphirine-hypersthene-quartz ± k-feldspar. In view of this evidence it is believed that 7 kb is an underestimate for Fyfe Hills M_1 pressures, and the preferred range is 8-10 kb. The anhydrous nature of M_1 assemblages, occurrence of mesoperthite and general scarcity of M_1 melt phases suggests extremely dry metamorphism.

A significant temperature reduction between M_1 and M_2 is indicated by two-feldspar, as opposed to mesoperthite, bearing M_2 assemblages and the general scarcity of exsolution lamellae in M_2 pyroxenes. M_2 garnet-clinopyroxene assemblages in rocks of tholeiitic composition give rise to temperature estimates of between 630 and 700°C (Ellis and Green, 1979) and 700-800 (Ganguly, 1979), while pyroxene solvus thermometry yields temperatures up to 830°C. The discrepancy may be due either to the comparative insensitivity of the pyroxene solvus thermometers at temperatures below 900°C (Davis and Boyd, 1966), or overestimation inherent in these thermometers (Wood, 1975). An M_2 temperature range of 650-750°C is preferred. The Newton and Perkins (1982) barometer yields pressures in the range 6-9 kb, which is consistent with the occurrence of garnet in tholeiites (Green and Ringwood, 1967) and sillimanite in aluminous gneisses (Holdaway, 1971). These data suggest that near isobaric cooling of up to 200°C followed the M_1 event. Elsewhere isobaric cooling is indicated by the ubiquitous occurrence of sillimanite-hypersthene coronas between M_1 sapphirine-quartz assemblages.

The diverse amphibolite facies assemblages formed during M_3 are reflecting the influence of a variety of bulk compositions and a range in P-T conditions. Rocks of aluminous composition are used here to establish the prevailing metamorphic conditions as the comparatively narrow stability fields of their constituent phases allow for excellent documentation of this complex metamorphic event. However it should be noted that the application of geobarometric and thermometric techniques to these rocks is complicated by the presence of strongly zoned minerals, in particular garnet and feldspar. The earliest formed M_3 assemblages in rocks of aluminous composition include kyanite, gedrite, garnet, plagioclase, quartz and biotite. Garnet-biotite thermometry (Thompson, 1975; Ferry and Spear, 1978) gives garnet core termperatures of 650 ± 50°C and rim temperatures of 570 ± 50°C. The core temperatures are consistent with the field occurrence of migmatites and anatectic pegmatites at $P_{(H_2O)}$ approaching $P_{(total)}$. Kyanite at temperatures of 650°C implies pressures greater than 7 kb (Holdaway, 1971) whie the experimental data of Green and Vernon (1974) suggest the assemblage kyanite + amphibole + quartz in the absence of cordierite is stable only above 9-10 kb. On the other hand Ghent's (1976) garnet-plagioclase-quartz-kyanite barometer yields pressure estimates below 6.5 kb for the earliest formed M_3 assemblages, using an ideal solution model for garnet. This estimate is believed to be unrealistically low and can be explained by continued chemical adjustment of the system during subsequent exhumation or to an incorrect activity model for grossular. The preferred conditions for earliest M_3 assemblages are pressures of 7-9 kb at 630-660°C.

A succession of reactions in rocks of aluminous composition due to changing metamorphic conditions during the M_3 event led to the formation of: (1) epitaxial overgrowths of staurolite on kyanite; (2) sillimanite by replacement of kyanite; and (3) cordierite by reaction between kyanite and/or sillimanite, and garnet and gedrite. Late M_3 assemblages which crystallised in the stability field of cordierite give garnet-biotite and garnet-cordierite (Thompson, 1975; Wells, 1979) core temperature estimates of 620 ± 50°C and rim temperatures of 545 ± 50°C, at pressures of 4-5 kb; the Ghent (1976) barometer gives pressure estimates in the range 3-4.5 kb using an ideal solution model for garnet. These data suggest that when late-formed M_3 assemblages crystallised pressures were less than 5 kb and temperatures were in the range 620 ± 50°C. This implies near isothermal decompression of 2.5-4 kb during active recrystallisation of M_3 assemblages. The rimward zoning common to both early and late formed M_3 assemblages is believed to indicate a cooling interval of 60-90°C before closure of the systems, and after the period of isothermal decompression. Interestingly, many of the reactions which took place during M_3 (a retrograde event with respect to M_2 and M_1), were of prograde character, that is they involved an increase in entropy; this is suggestive of either very rapid exhumation or thermal buffering by shear heating during the development of M_3 mylonites.

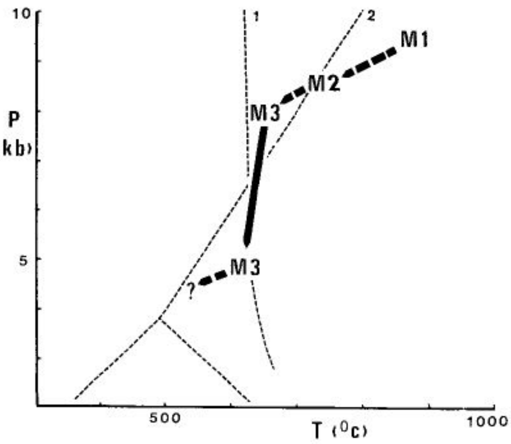

Figure 2. Pressure (P) temperature (T) evolutionary path of the Fyfe Hills gneisses. The heavy dashed line corresponds to inferred sections of the path while the solid line represents the documented path during M_3. Reaction 1 is the wet garnite solidus taken from Kerrick (1972). Reaction 2 is the alumino-silicate phase diagram of Holdaway (1971).

DISCUSSION OF THE RELEVANT ISOTOPIC DATA

A correlation of the structural, metamorphic and igneous history of the Fyfe Hills area with the relevant isotopic data is presented in Table 2. The M_1-D_2 event and the intrusion of the Amundsen Dykes are well constrained. The ages of the "Khmara dykes" (and hence the D_3-M_2 event) and the D_4-M_3 event are less certain, but can be bracketed by the available data. As yet there are no isotopic data pertaining to the age of D_1 and the age of emplacement of the "Massive Series".

Our chronological correlations differ significantly from the conclusions of James and Black (1981). These authors suggest that D_3 occurred about 2.5 Ga ago in the waning stages of granulite facies metamorphism and correlate D_1 D_2 and the metamorphic culmination with what we contend is a poorly resolved isotopic event > 3.0 Ga. We believe that the similarity of the isotopic, structural, and metamorphic

TABLE 2: Correlation of the geologic history of the Fyfe Hills area with the available isotopic data. References: 1. DePaolo et al., 1982; 2. Grew et al. (in prep.); 3. Sheraton & Black (1981); 4. Grew & Manton (1979). (z) — zircon age; (r) — whole rock age. *Age of B_3 dykes of Sheraton and Black (1981).

Event	Age (Ga)	System	
1 Deposition of Layered Series	3.4-3.8	Nd/Sm(r)	1
2 Emplacement of Massive Series ?	?		
3 D_1	?		
M_1	2.5	Rb/Sr, Nd/Sm(r), U/Pb(z)	1,2
4 D_2	2.5	U/Pb(z)	2
5 Intrusion of Khmara Dykes	2.4 ± 0.2	Rb/Sr(r)	3
D_3/M_2	> 2.35*	Rb/Sr(r)	3
6 Intrusion of Amundsen Dykes	1.19	Rb/Sr(r)	3
7 D_4/M_3	? 1.0-0.5	U/Pb(z)	2,4
8 Mafic alkaline dykes	0.49		3

histories of the Amundsen Bay and Fyfe Hills areas suggests that the 2.5 Ga date corresponds to the M_1 and D_2 events at both localities. The observations of Griffin (in prep.) and ourselves, that metamorphosed tholeiitic dykes in both areas are in fact pre- or syn-D_3 and not, as suggested by previous workers, post-D_3 lends some support to this suggestion. However, the poorly resolved age for these dykes of 2.4 ± 0.25 Ga does not provide conclusive evidence. An absolute minimum age for D_3 is provided by the unmetamorphosed 2.35 Ga old B_3 dykes of Sheraton and Black (1981).

An important implication of the relative timing of D_2 and D_3 and hence M_1 and M_2 pertains to the thermal evolution of the terrain. Our data suggest that M_1 temperatures represent a disturbed geotherm that decayed relatively rapidly to a steady state situation in less than 150 Ma. However, this conclusion is not necessarily valid if the scheme of James and Black (1981) is adopted. Accordingly the prolonged isobaric cooling of up to 600 Ma may simply reflect the cooling of the Archaean crust.

The structual and metamorphic relationships suggest that D_1 occurred during prograde metamorphism (M_1) that culminated in D_2. In view of the large heat flux necessary to produce metamorphic temperatures in excess of 900°C followed by near isobaric cooling of up to 200°C, a geologically short time interval between D_1 and D_2 is envisaged. It is tempting to appeal to the *Massive Series* as the source of heat for M_1, implying an age not substantially greater than 2.5 Ga. This suggestion is consistent with the thermal character of M_1 and especially post M_1 isobaric cooling, but in the absence of rigorous isotopic or field constraints it remains unsubstantiated.

The interval of approximately 1 Ga between deposition and the first apparent tectonism implies remarkably stable crustal conditions for the Archaean. However is is possible that the effects of earlier tectonic events have been obscured by the intense deformation during D_1 and D_2 and by the pervasive recrystallisation during M_1. Indeed such events may be responsible for the isotopic disturbance at 3.1 Ga (James and Black, (1981).

The near isothermal decompression path indicated by M_2 assemblages suggests that the exhumation of these deep-seated gneisses was rapid enough to preclude thermal relaxation. However it is possible that the effects of thermal relaxation during an extended exhumation could be buffered by the generation of heat within the mylonites via a shear heating mechanism. The data of Grew et al. (in prep.) suggesting a thermal event at 1.0 Ga may correspond to the initiation of exhumation during the Rayner event. However, until there is a more precise correlation of the 1.0 Ga event with M_3 retrogression, the behaviour of the Napier Complex during the Rayner event will remain an enigma. Active tectonism during exhumation appears to have ceased with the intrusion of Early Palaeozoic pegmatites (Grew and Manton, 1979). Mafic alkaline dykes containing richterite, aegirine-augite and baryte and found only on Hydrographer Island almost certainly correspond to the dyke at Priestley Peak described by Sheraton and England (1980) and for which Sheraton and Black (1981) have obtained a 490 Ma age. These dykes show only minor metamorphic alteration and cut the shear zones without apparent displacement.

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