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The structural evolution of the Rauer Group, East Antarctica: mafic dykes as passive markers in a composite Proterozoic terrain

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Abstract: Archaean gneisses in the Rauer Group of islands, East Antarctica, record a prolonged history of high-grade deformational episodes, many of which predate that identified in mid-Proterozoic gneisses. Eleven generations of mafic dykes, belonging to discrete chemical suites, have been used as relative time markers to constrain this deformational history. Based on the timing of intrusion with respect to structures, dykes in the Rauer Group have been correlated with largely undeformed and dated dyke suites in the adjacent Vestfold Hills. This has allowed absolute ages to be inferred for the early- to mid-Proterozoic mafic dyke suites in the Rauer Group, and a correlation of the interspersed structural events. Most structures in the Rauer Group, however, developed in response to high-grade progressive deformation at approximately 1000 Ma. During this deformational episode, strains were repeatedly partitioned into sub-vertical, noncoaxial, high-strain zones recording NW-directed sinistral transpression, that separated zones of lower strain dominated by coaxial folding with axes parallel to the shear direction. Three additional mafic dyke suites intruded during this deformation which was followed by three stages of brittle-ductile deformation and a final suite of lamprophyre dykes. Due to the numerous intrusive time markers, the Rauer Group serves as an excellent illustration of how complicated gneiss terrains may be.

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Key words: Rauer Group, Vestfold Hills, Proterozoic granulites, mafic dykes, strain markers

Introduction

Many high-grade Precambrian terrains around the world have undergone long and extremely complicated deformational histories. The full extent of the structural complexity, however, is commonly not immediately obvious, because pervasive recrystallization and high strains that accompanied the high-temperature metamorphism have obliterated most structural-metamorphic information pre-dating the latest metamorphic peak. The structural history of these complicated terrains may be solved if a large number of time markers, such as mafic dykes, were emplaced throughout its evolution, and/or if foliations or structures that dominate in one area can be traced across terrain boundaries or unconformities, and can be shown to have overprinted earlier structures (e.g. Sheraton *et al.* 1980, Black *et al.* 1987, Dirks & Wilson 1990). Reactivated Archaean terrains in east Antarctica provide excellent examples of this (e.g. Collerson *et al.* 1983, Sandiford & Wilson 1984, Passchier *et al.* 1991, Dirks *et al.* 1994).

East Antarctica is dominated by granulite terrains that are part of a mobile belt, which developed around 1000 Ma ago, bounded by several isolated cratons of Archaean crust such as the Napier Complex, the southern Prince Charles Mountains and the Vestfold Hills (Fig. 1). In general, structures and metamorphic effects described from the mobile belt are related to the 1000 Ma tectonic events (e.g. Harley 1987, 1988, Harley & Hensen 1990, Harley & Fitzsimons 1991), even though Archaean crust is preserved in the mobile belt (e.g. Kinny *et al.* 1993) and adjacent Archaean cratons preserve extremely complicated pre-1000 Ma histories (Black *et al.* 1987, Passchier *et al.* 1991, Dirks *et al.* 1994). A good example of this exists in the Prydz Bay area, where strongly reactivated Archaean rocks in the Rauer Group are situated directly adjacent to relatively stable Archaean crust of the Vestfold Hills (Fig. 1). Both the Vestfold Hills and parts of the Rauer Group are characterized by a great number of cross-cutting mafic dykes. Whereas the dykes in the Vestfold Hills remain planar and are solely deformed by localized shear zones, faults and pseudotachylite (Dirks *et al.* 1994), those in the Rauer Group are affected by ductile deformation developed at granulite grade (Harley 1987, Harley & Fitzsimons 1991). This difference in deformational style has, thus far, prevented the direct correlation of structural-metamorphic events in the two terrains, in spite of the close proximity and the suggestion that the dykes in both terrains belong to the same suites (Sheraton 1984, Collerson & Sheraton 1986).

This paper describes the mafic dyke suites and their intrusive sequence (henceforth termed stratigraphy) within the Archaean component of the Rauer Group, and uses the dykes as structural markers to establish a detailed

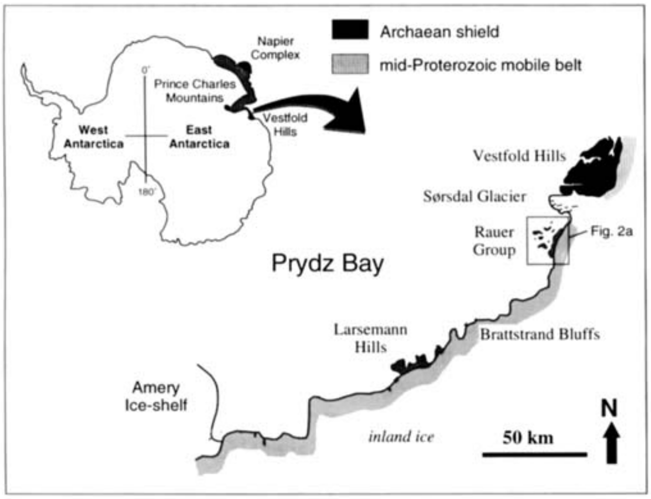

Fig. 1. Location map of the Prydz Bay area, East Antarctica, showing the geographical positions of the Rauer Group and the Vestfold Hills.

deformational history (Table I). We suggest that the mafic dykes and the Proterozoic structural evolution of the Rauer Group broadly correlate to events described in the Vestfold Hills. Also, we determine that Proterozoic P-T-t paths and tectonic models for the Rauer Group are more complicated in the Archaean component than those previously demonstrated for mid-Proterozoic gneisses (Harley 1988, Harley & Hensen 1990, Harley & Fitzsimons 1991).

Previous interpretations of the geological history

The Rauer Group (Fig. 2a) consists of numerous islands and promontories that largely comprise felsic and mafic granulite interlayered with paragneiss sequences and intruded by various generations of mafic dykes, pegmatites and granitic to tonalitic orthogneiss (Sheraton *et al.* 1984, Harley 1987). Sm-Nd model ages (T_{CHUR} 3220, 3570 Ma, Sheraton *et al.* 1984) and U-Pb zircon ages (2801 ± 6, 2810 ± 14 and 3269 ± 9 Ma, Kinny *et al.* 1993) indicate that a significant

Table I. Summary of the deformational and intrusive events recorded in the Rauer Group.

Event	Description
Mafic and ultramafic layering	Intrusion of early dykes or sills into Archaean orthogneisses and possibly metasediments.
D_1-D_2	High-grade (>1000°C) deformation events recorded in isolated pods and lenses which contain discordant internal foliations.
Dyke suites 1–3	Intrusion of high-Mg dykes (dyke suites 1–2) and Fe-rich dykes (dyke suite 3), which have gneissic layering S_4 axial planar to early fold generations. Dyke suite 2 contains an internal foliation that is folded and cross-cut by later (post suite 3) dykes. Dyke suite 3 contains corona textures indicative of overprinting granulite events.
D_3	Localized shearing on the margins of dyke suite 3.
D_4, *Pegmatite suite 1*	Granulite facies deformation event and development of a pervasive gneissic layering S_4, preserved in the subsequently least deformed areas of the dominantly Archaean orthogneisses. Recrystallization of D_3 mylonites.
Dyke suites 4–6	Intrusion of high-Mg, Fe-rich and high-Mg dyke suites, respectively.
D_5	Formation of discrete recrystallized shear zones which offset earlier structures.
Dyke suites 7–11	Fe-rich dyke suites (7–11) characterised by ilmenite bearing assemblages. Dyke suites 10 and 11 both contain orthopyroxene.
D_6, *Pegmatite suite 2, syntectonic granites, Dyke suites 12–14.*	Granulite facies deformation localized into non-coaxial high strain zones from 2 m to at least 500 m in width. Development of multiple, progressive overprinting gneissic foliations (S_6). Development of garnet-clinopyroxene assemblages in most Fe-rich dykes and formation of second stage garnet coronas on garnet and orthopyroxene in dyke suite 3. Multiple granites and pegmatites emplaced. Three generations of dyke suites intruded during progressive deformation. Dyke suite 12 is characterized by high modal clinopyroxene and biotite with ilmenite, dyke suite 13 is Fe-rich and dyke suite 14 comprises high-Mg dykes.
Pegmatite suite 3	Planar pegmatites with a dominantly N-S orientation and westerly dip.
D_7	Alternating generations of mylonite, pseudotachylite and ultramylonite with variable orientations, including parallel to pegmatite suite 3 and parallel to late, planar D_6 high strain zones.
Dyke suite 15	Lamprophyre dykes in N-trending orientations.
D_8	Extensional deformation recorded in N-S striking alternating pseudotachylite and ultramylonite generations, occasionally localized on the margins of dyke suite 15.
D_9	N-trending brittle fracture zones containing cummingtonite, localized on dyke suite 15 margins.

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proportion of felsic gneiss in the eastern half of the Rauer Group is of Archaean age. Additionally, Rb/Sr model ages of 1370 and 1390 Ma and an Sm-Nd model age of 1770 Ma (Sheraton *et al.* 1984) have been obtained from an orthogneiss in the south-eastern Rauer Group. Relatively young syntectonic granitic orthogneisses, which are especially voluminous in the western half of the Rauer Group, have been dated at 1000 ± 51/37 and 1027 ± 27 Ma using U-Pb in zircon (Kinny *et al.* 1993).

The deformational and metamorphic sequence in the Rauer Group was first described in detail by Harley (1987, 1988) who distinguished five deformational episodes, the first four of which occurred at granulite facies to upper amphibolite facies. Manifestations of the earliest events, D_{1H} and D_{2H} (H in the subscript number refers to deformational or metamorphic events recognized by Harley 1987), are restricted to foliations in relics and rafts of possible Archaean age that record extreme peak P-T conditions of 10–13 kbars and 1000–1050°C (Harley & Fitzsimons 1991, Harley *et al.* 1992). The rafts are enveloped in a gneissic layering S_{3H} which has been described as the dominant foliation in the Rauer Group. D_{3H} affected the orthogneiss with 1370 Ma Rb/Sr model ages (Sheraton *et al.* 1984), whereas syn-D_{3H} granitic gneisses produced the ages in the 1000–1030 Ma range (Kinny *et al.* 1993). Peak-metamorphic temperatures during this event were greater than 800°C at pressures ranging from 7–9 kbar (Harley *et al.* 1992). Post-peak decompression textures suggest that D_{3H} was followed by 2–4 kbars of uplift and 80–150°C of cooling (Harley 1988, Harley & Fitzsimons 1991).

Harley (1987) suggested that S_{3H} was transected by various sets of mafic dykes with granulite facies assemblages that locally preserve decompression textures. Therefore, the dykes were interpreted to have intruded during the latter stages of decompression following D_{3H}. However, Harley & Fitzsimons (1991) recognized that most mafic dykes were restricted to older (pre D_{3H}) lithological associations and more recently Harley *et al.* (1992) have suggested that most of the multiple suites of mafic dykes predate S_{3H}. S_{3H} and the vast majority of mafic dykes were deformed during a final pervasive folding event, D_{4H} (Harley 1987, 1988). Syn-D_{4H} assemblages are locally overprinted by decompression textures suggesting continued uplift through D_{3H}/D_{4H} (Harley 1988), in response to a single tectonic process. Syn-D_{4H} leucosome veins have been dated at 1004 ± 52 Ma (Kinny *et al.* 1992). The various foliations and structures are truncated by D_{5H} greenschist facies shear zones associated with planar pegmatites dated at 500 ± 12 Ma (Kinny *et al.* 1992), and a late set of alkaline dykes of indeterminate age.

In the adjacent Vestfold Hills (Fig. 1), the last recorded granulite-facies deformation occurred about 2480 Ma ago (Black *et al.* 1991a). Since then multiple mafic dyke swarms intruded at approximately 2400, 2240, 1750, 1380 and 1240 Ma (Collerson & Sheraton 1986, Black *et al.* 1991b, Lanyon *et al.* 1993), with the last set comprising 80–90 % of the total volume of dykes. Using these dykes as marker units, Passchier *et al.* (1991) and Dirks *et al.* (1994) have shown that the Vestfold Hills experienced at least seven discrete deformational episodes post-dating the granulite-facies events. The major deformations post-dating the emplacement of all mafic dykes are associated with discrete mylonite zones and a pervasive amphibolite facies overprint which most clearly affected the SW Vestfold Hills. Black *et al.* (1991b) inferred that an age of 1025 ± 56 Ma obtained from a mafic dyke in the Vestfold Hills was a recrystallization age associated with this metamorphic overprint.

The fact that all mafic dykes in the Vestfold Hills pre-date the 1000 Ma events, and many potentially similar dykes

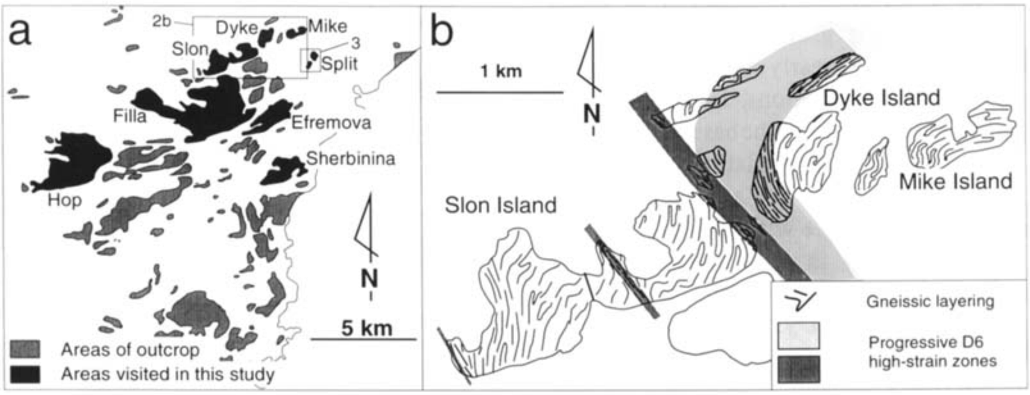

Fig. 2a. Location map of the Rauer Group (after Harley 1987). Detailed structural analyses were conducted in areas with dark shading. The positions of Figs 2b and 3 are indicated, **b.** Form surface map of several islands in the NE Rauer Group showing the general orientation of the gneissic layering in outcrop in relationship to progressively developed zones of D_6 high-strain. Gneissic layering on Dyke and Mike islands is a composite S_4-S_6 foliation whereas Slon Island is dominated by S_6 foliations.

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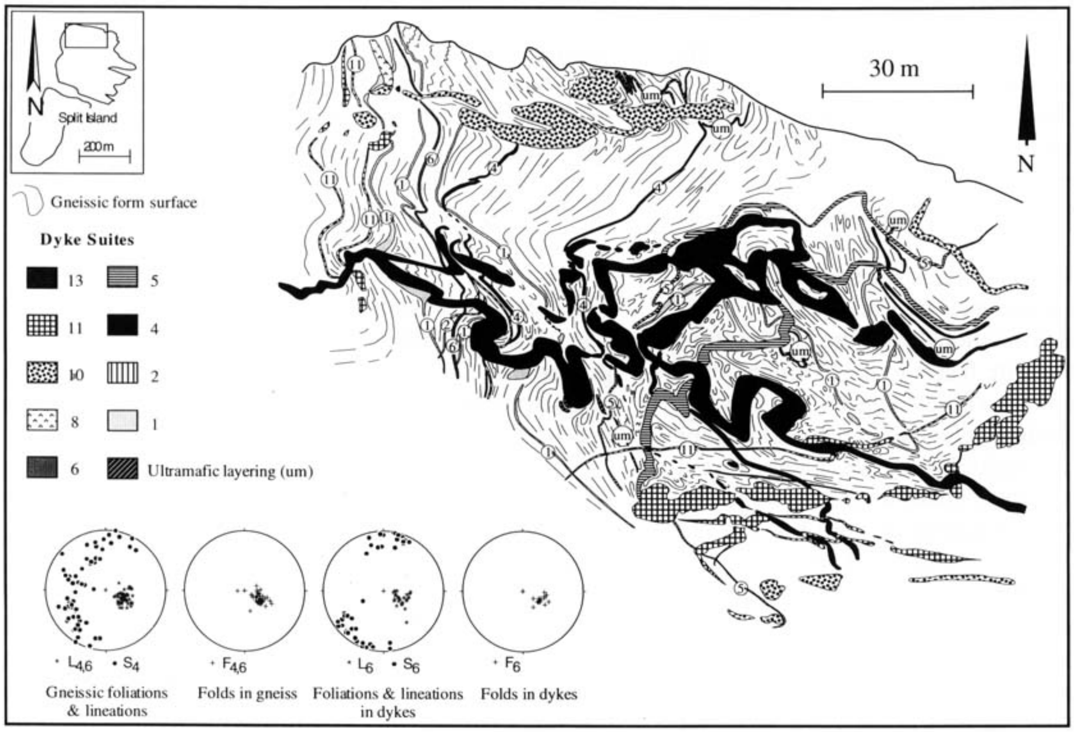

Fig. 3. Form surface map of northern Split Island showing typical deformation geometries of multiple generations of dykes and gneissic layering; note the colinearity of folds and lineations which resulted from various deformational episodes (see text for further discussion).

(Sheraton 1984) in the older lithological associations in the Rauer Group (Harley & Fitzsimons 1991) also predate the 1000 Ma events (Harley *et al.* 1992), suggests that the tectonic evolution of the Vestfold Hills and the older components of the Rauer Group are far more closely linked than previously thought (e.g. Kinny *et al.* 1993).

Deformational history and dyke stratigraphy

On the basis of consistent cross-cutting relationships (e.g. Fig. 3), at least 15 different mafic dyke generations can be recognized within the Archaean orthogneisses of the Rauer Group, 14 of which exhibit granulite-facies mineral assemblages. This does not include early mafic and ultramafic layering that predate all dyke generations. Individual mafic dykes have been correlated into suites on the basis of geometry, composition, texture and cross-cutting relationships, as well as on timing with respect to structures and metamorphic textures. The mafic dykes alternate with nine overprinting deformational events that vary in style and grade from penetrative granulite facies thrusting events to localized pseudotachylite formation. Dykes are numbered independently from deformational events (Table I), although strictly speaking most dykes were probably associated with extensional brittle fracturing. Implicit in the following descriptions is the succcession of cross-cutting dykes and structures from oldest to youngest. Mineral abbreviations are listed in Table II.

Mafic and ultramafic layering

Transposed and boudinaged mafic and ultramafic compositional layering always parallels the pre-S6 gneissic layering in D_6 low-strain areas of the Archaean orthogneisses. Mafic layering occurs as multiple thin layers (<2 cm) composed of fine-grained (<1 mm) hb and plag that are arranged within continuous bands up to 2 m wide (Fig. 4a). Individual mafic layers exhibit rootless isoclinal folds at cm scale, with axial planes parallel to the enveloping surface.

Locally, the ultramafic layering is defined by continuous boudin trains of ultramafic pods (<10 m in diameter) and lenses (< 1 m wide) with no obvious internal foliation. The lenses are composed of opx, cpx, plag, hb and bi that displays zoning both in mineral abundance ratios and grain size. Lens cores are rich in coarse-grained (<5 cm) opx, cpx ± bi with a variety of textural relationships, including symplectic and coarse crystalline intergrowths to cpx rims on opx. Lens rims are enriched in either bi or hb ± plag with grain-sizes down to 1 mm. The mafic and ultramafic layering may well

Table II. Mineral abbreviations used in the text.

bi	=	biotite	py	=	pyrite
mu	=	muscovite	cpy	=	chalcopyrite
sill	=	sillimanite	mt	=	magnetite
opx	=	orthopyroxene	ilm	=	ilmenite
cpx	=	clinopyroxene	plag	=	plagioclase
hb	=	hornblende	Kspar	=	alkali feldspar
gt	=	garnet	cc	=	calcite
qtz	=	quartz	cumm	=	cummingtonite

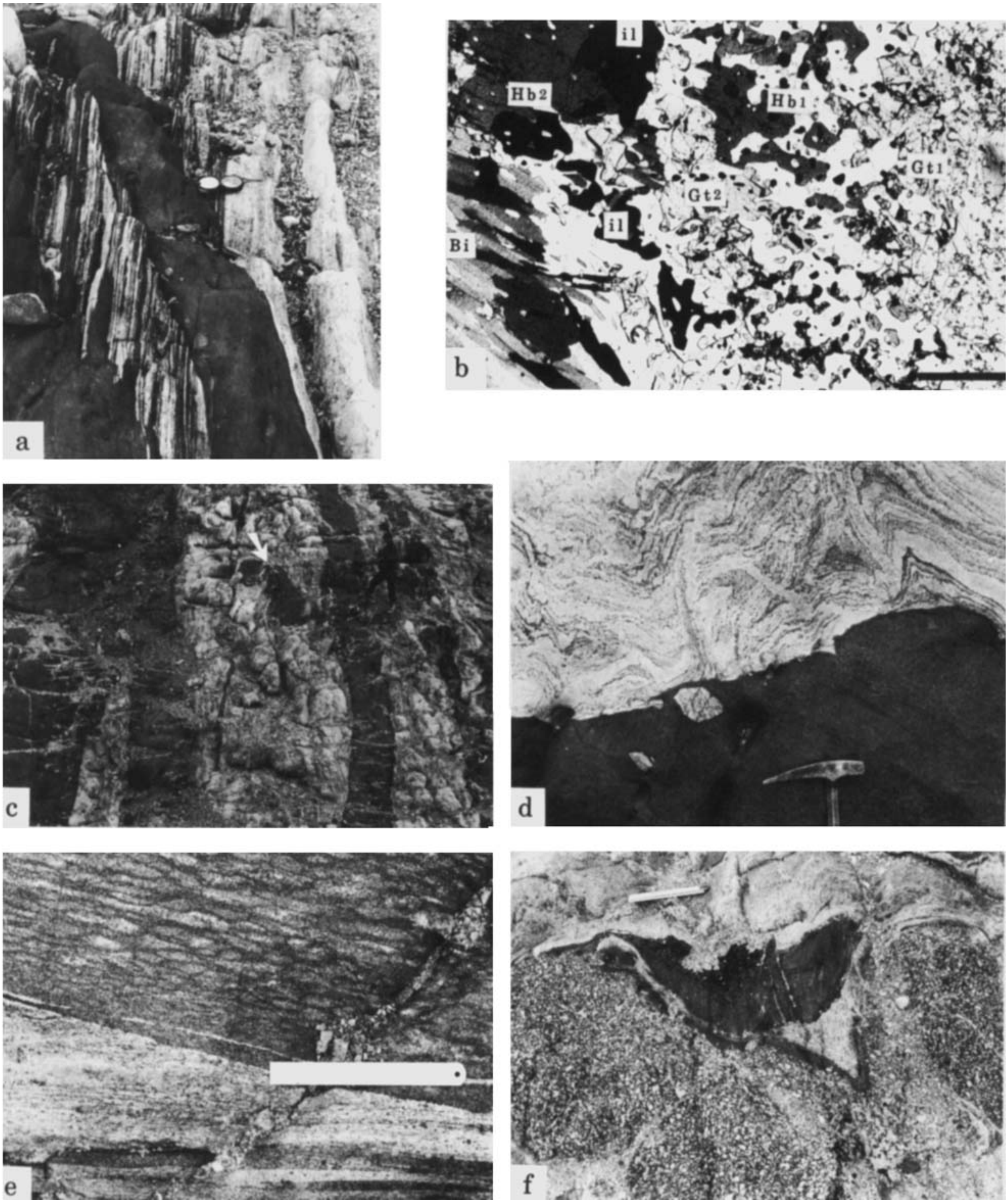

Fig 4. Photographs of some typical deformational features in the Rauer Group: **a.** Early mafic layering cross-cut by a mafic dyke, **b.** Multiple corona texture in suite 3 dyke. Core of gt (Gt1) is surrounded by a symplectic plag-cpx-hb(Hb1)-ilm and overgrown by gt (Gt2) which is replaced by a symplectic plag-bi-hb(Hb2)-ilm (scale bar is 0.25 cm), **c.** A folded suite 3 dyke (arrowed) with an envelope at high angles to transposed dykes of various suites, **d.** Suite 13 dyke cross-cutting S_4 gneissic layering containing multiple syn-D_4 pegmatites, **e.** Suite 5 dyke with a characteristic variegated texture. The narrow dark bands at the base of the photo are limbs of the same dyke isoclinally folded in a D_6 high-strain zone. **f.** Suite 7 dyke (lower hald of photo) with a characteristic freckled texture.

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represent early dykes or sills.

Deformations D_1 – D_2

Evidence for early deformation and metamorphism is preserved in isolated pods and lenses of felsic, mafic, pelitic and banded gneiss which contain foliations that are discordant with the prevailing form surface gneissosity in D_6 low-strain zones in the Archaean orthogneisses. Intrafolial folds within these pods and lenses suggests that possibly two high grade deformation events occurred. Harley & Fitzsimons (1991) suggest that metamorphic assemblages within some of these pods and lenses are indicative of extreme P-T values, that may reflect Archaean crustal conditions.

Dyke suite 1

Dyke suite 1 consists of coarse- (<1cm) to medium-grained (<0.5 cm) dykes composed of cpx(25%), opx(25%), bi(25%), plag(20%), hb(5%) and minor ilm. They occur as predominantly continuous mafic layers, up to 15 cm wide, that contain no obvious internal mineral foliation or lineation.

Dyke suite 2

Dyke suite 2 consists of coarse- (<1 cm) to medium-grained (<0.5 cm), melanocratic, grey-green dykes, up to 3 m wide, containing plag(40%), hb(30%), cpx(20%), opx(5%), bi(5%) and minor ilm. The constituent minerals are generally aligned and define a pervasive internal foliation that was crenulated, folded and boudinaged before being crosscut by later dykes. Leucocratic pods containing coarse plag, cpx, opx, hb, bi ± gt occur within this dyke suite where the internal foliation is boudinaged.

Table III. Representative microprobe analysis of core and rim garnets (Gt1 and Gt2 respectively in Fig. 4b) from multiple corona textures in dyke suite 3.

	924113B - core garnet	924113B - rim garnet
Oxides		
SiO_2	37.87	37.64
Al_2O_3	20.51	20.90
TiO_2	0.14	0.01
FeO	20.92	25.15
Fe_2O_3	1.21	0.76
MnO	3.52	3.13
MgO	1.45	3.28
CaO	14.11	8.84
Cr_2O_3	0.02	0.03
ZnO	0.00	0.00
Total	99.75	99.74
Cations		
SiO_2	3.002	2.987
Al_2O_3	1.917	1.956
FeO	1.387	1.669
Fe_2O_3	0.072	0.045
MgO	0.171	0.388
MnO	0.236	0.210
CaO	1.199	0.752
Total	7.994	8.011

Dyke suite 3

Dyke suite 3 consists of coarse- (<1 cm) to medium-grained (<0.5 cm) dykes, up to 1.5 m wide composed of variable proportions of opx, plag, hb, gt and bi. Both margins of this dyke typically preserve a less than 20 cm wide zone almost entirely composed of aligned, coarsely recrystallized bi and hb containing coarse gt and opx porphyroblasts. In contrast, the core of these dykes contain little bi and are extensively migmatized. Garnet porphyroblasts on the margins of these dykes are unique in the Rauer Group as they are surrounded by double or triple corona textures involving a first stage symplectite of plag, cpx, ilm, mt and hb overgrown by a second gt followed by a second stage of symplectic plag, hb and bi (Fig. 4b). Additionally, the composition (Table III) of the porphyroblastic gt is consistently quite different from the second generation of gt, which is more representative of the gt compositions observed in mafic gneisses throughout the Rauer Group (Harley 1988, unpublished data). On Dyke Island, within a D_6 high strain zone, the enveloping surfaces to a folded suite 3 dyke typically make high angles to the envelopes of later dykes (Fig. 4c) which are mostly sub-parallel (and sub-planar). This implies that the pre-deformation orientation of this dyke was significantly different to that of later dykes.

Deformation D_3 – mylonite 3

This deformation event is invoked to explain the foliated bi- and hb-rich margins that occur in suite 3 dykes containing garnets with unusual compositions surrounded by extraordinarily complex corona textures. In the absence of unequivocal evidence, we suggest that the foliated margins represent recrystallized mylonites. This is based on: the contrast in composition of the dyke margins compared to the dyke centres; the textural relationships observed between garnets with unusual compositions surrounded by multiple coronas, and the bi-hb dominated matrix; and, by comparison with the succession of dyke intrusions and structural events recognized in the adjacent Vestfold Hills.

Firstly, the grossular-rich composition of the gt porphyroblasts which contain inclusion trails of mineral phases including sphene, is highly unusual considering the Fe-rich bulk geochemical composition of the migmatitic dyke centres (Table IV). This suggests that the margins of the dykes were compositionally, quite different to the dyke centres prior to the development of the metamorphic textures.

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Table IV. Average whole rock compositions from selected dykes in the north-eastern Rauer Group.

	A	B	C	D	E	F	G	H	I	J	K
	high-Mg dykes				Fe-rich dykes						
Oxide (wt. %)											
SiO_2	48.57	49.97	45.99	49.57	54.45	48.29	48.62	47.87	47.33	47.36	47.06
TiO_2	0.94	0.77	1.01	0.87	1.6	2.16	1.57	2.09	1.97	1.97	2.39
Al_2O_3	9.24	12.44	13.66	12.14	14.70	12.93	13.50	13.44	12.75	13.06	11.98
Fe_2O_3	14.55	11.20	13.98	12.04	12.14	16.59	14.83	16.82	16.53	15.48	19.00
MnO	0.28	0.18	0.19	0.20	0.22	0.23	0.21	0.21	0.26	0.24	0.29
MgO	13.01	9.10	9.11	8.76	6.02	4.95	6.13	4.75	6.04	6.35	5.48
CaO	7.92	11.33	9.90	11.01	8.19	8.88	9.95	9.18	10.43	10.56	9.66
Na_2O	1.61	2.73	3.02	2.79	0.87	3.25	3.04	3.00	2.75	2.79	2.48
K_2O	3.08	0.66	1.28	0.82	1.28	1.06	0.72	0.48	0.43	0.58	0.61
P_2O_5	0.11	0.08	0.16	0.09	0.27	0.31	0.21	0.29	0.19	0.21	0.23
Total	99.27	98.45	98.29	98.29	99.74	98.65	98.75	98.13	98.67	98.60	99.18
Trace elements in parts per million											
Cr	1274	545	364	494	146	86	157	106	102	216	101
Ba	385	119	160	99	182	150	86	102	89	107	113
Sc	33	34	28	37	30	37	36	36	50	45	57
Ce	42	15	20	41	67	41	27	29	21	36	49
Nd	12	19	7	6	22	17	14	20	15	19	25
V	228	231	306	237	267	340	303	324	396	341	462
Co	71	50	67	56	35	48	52	50	53	47	51
Cu	57	94	115	54	25	61	82	92	159	104	154
Zn	194	89	125	114	123	152	125	130	130	123	147
Ni	407	199	333	192	96	66	97	83	57	69	51
Ga	15	14	17	15	21	20	19	21	19	19	21
Zr	94	75	46	84	236	170	124	181	122	138	142
Y	19	23	19	23	51	46	36	48	42	40	47
Sr	77	101	203	129	147	141	112	117	130	140	121
Rb	230	9	21	10	86	12	12	13	10	14	13
Nb	6	7	3	7	15	11	8	10	7	8	10

A. 2 samples - dyke suite 1
B. 2 samples - dyke suite 2
C. 2 samples - dyke suite 4
D. 1 sample - dyke suite 6
E. 1 sample - dyke suite 3
F. 3 samples - dyke suite 5
G. 2 samples - dyke suite 7
H. 2 samples - dyke suite 8
I. 3 samples - dyke suite 10
J. 6 samples - dyke suite 11
K. 3 samples - dyke suite 13

Secondly, the foliated bi-hb matrix of the dyke margins was crenulated during the early stages of the D_6 episode and is therefore inferred to predate S_6. Additionally, the second gt corona appears to have developed preferentially in high-stress orientations about the first symplectite during D_6, implying that the inner symplectite predates D6. As the metamorphic conditions prior to D_6 obtained high grades during D_4 (see below) it is inferred that the core gt and inner symplectite developed at that stage. Therefore, the textural and compositional variation must be due to recrystallization of a pre-D_4 textural and compositional difference in the dyke.

Thirdly, the textural and compositional difference between the cores and margins of the dykes may be explained by comparing the succession of dyke suites and deformational events in the Rauer Group and the Vestfold Hills. Dyke suite 3 of Dirks *et al.* (1994) in the Vestfold Hills, has comparable compositional and timing relationships with other dyke suites and structural events as those observed for dyke suite 3 in the Rauer Group (Table V). Also, dykes of suite 3 in the Vestfold Hills have significantly different orientations to later dyke suites, a feature also observed for dyke suite 3 in the Rauer Group. Furthermore, dyke suite 3 in the Vestfold Hills consistently display mylonitized margins (Dirks *et al.* 1994). In the south-west Vestfold Hills where there is a pervasive upper-amphibolite facies metamorphic overprint, the mylonitized margins are recrystallized to bi-hb-gt compositions. Considering the above, it appears reasonable to equate the unusual bi-hb-gt margins of dyke suite 3 in the Rauer Group to recrystallized mylonite zones.

Deformation D_4 – foliation S_4

Deformation event D_4 has produced a pervasive composite gneissic layering (S_4) which is the dominant form surface in the Archaean orthogneisses in areas of low D_6 strain. S_4 predates most dyke suites (Figs 3, 4d) and is defined by a combination of a domainal, granoblastic compositional layering aligned with leucosomes and transposed, multiple syn-D_4 pegmatite veins (*Pegmatite suite 1*). Metamorphic textures, such as those in bi-hb-gt assemblages in dyke suite 3, and the internal gneissic foliation in dyke suite 2, are inferred to have developed during D_4, because these features in the dykes and S_4, are cross-cut by younger dyke generations. At least two, and possibly three, generations of tight to isoclinal mm- to m-scale scale folds in S_4 (F_{4a-c}) pre-date emplacement of later dykes. Poles to S_4 in areas of low D_6 strain (e.g. Split Island, Fig. 3) display simple great circle distributions and D_4 fold axes parallel the ubiquitous D_6 lineation, reflecting high finite D_6 strains.

Dyke suite 4

Dyke suite 4 consist of coarse- (<1 cm) to medium-grained (<0.5 cm), homogeneous black dykes up to 0.2 m wide, composed of hb(50%), plag(35–40%), cpx(5–10%) and bi(5%). An apparently simple planar internal foliation in the dykes of suite 4 is defined by a pervasive alignment of elongate hb and bi.

Dyke suite 5

Dyke suite 5 consists of medium-grained (<0.5 cm), grey dykes less than 2 m wide. They are composed of hb(35%), plag(30%), cpx(15%), ilm(15%) and bi(5%) with minor gt and opx. Distinctive, light-coloured ellipsoidal pockets (<5 cm) of plag and cpx, rimmed by hb give the dykes a characteristic variegated texture (Fig. 4e). A shape alignment of the plag-cpx pockets, and a weak grain-shape alignment of elongate hb and recrystallized plag aggregates, define a foliation in the dyke.

Dyke suite 6

Dyke suite 6 consists of fine-grained (<1 mm), homogeneous dark grey to black dykes, which are up to 0.5 m wide and composed of hb(30%), plag(30%), cpx(20%), opx(15%), bi(5%) and minor ilm. The constituent minerals are weakly aligned and define a planar internal foliation.

Deformation D_5 – mylonite 5

Thin (<5 mm) black planar selvages of coarsely recrystallized and aligned bi and minor gt cross-cut S_4 on both Split and Dyke islands. The selvages typically occur along isolated planes but locally diverge in multiple anastomosing veinlets across which earlier structures are offset. The selvages are strongly folded in later deformational events and are cross-cut by most post-D_4 dykes; however, the exact timing relationship to all stages of dyke emplacement is unclear and their position in the succession of events is based on correlations with the Vestfold Hills (see below). The anastomosing appearance, the associated displacements of marker units and the compositional difference from the host gneiss suggest that the layers represent recrystallized mylonites, ultramylonites or pseudotachylites.

Dyke suite 7

Dyke suite 7 consists of fine- (<1 mm) to medium-grained (<0.5 cm), relatively thin (<0.5 m) dykes, composed of hb(40%), plag(40%), cpx(15%) and ilm(5%). Dispersed coarse- (<1 cm) to very-coarse (<2 cm), white (on weathered surfaces) plag grains give the dyke a distinctive "freckled" texture (Fig. 4f). The recrystallized groundmass contains a weak grain shape alignment of elongate hb and recrystallized plag aggregates defining an internal foliation.

Dyke suite 8

Dyke suite 8 consists of coarse- (<1 cm) to medium-grained (<0.5 cm) dykes, up to 5 m wide, with a general mineral composition of plag(40%), hb(30%), cpx(20%) and ilm(10%). These hb-rich dykes locally contains ellipsoidal plag-cpx pockets with hb rims similar to dyke 5 and plag "freckles" similar to dyke 7. Where a strong internal foliation is developed, it is defined by segregated domains of aligned and elongate hb with recrystallized plag aggregates and domains of granoblastic cpx-plag. This internal foliation is commonly boudinaged with coarse-grained (<2 cm) cpx-mt-bi-plag-qtz and cpy developed in the boudin necks.

Dyke suite 9

Dyke suite 9 consists of fine-grained (<1 mm), homogeneous light grey dykes that are relatively narrow (< 0.2 m) and contain hb-plag-cpx and ilm. The constituent minerals are weakly aligned and define a planar internal foliation.

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Dyke suite 10

Dyke suite 10 consists of medium- (<0.5 cm) to fine-grained (<1 mm) dykes that are less than 5 m wide and are composed of plag(30%), hb(20%), cpx(20%), opx(20%), ilm(10%) and minor bi. Numerous coarse- (<1 cm) to very coarse-grained (<2 cm) plag grains give dykes of this suite a "freckled" appearance with a higher density of feldspar grains than in dykes of suite 7. A locally strong internal foliation in the dyke is defined by domainal segregations of aligned and elongate aggregates of hb and plag, and of granoblastic plag, cpx and opx. In places these dykes contain multiple internal, possibly conjugate, foliations (Fig. 5a), which are defined by segregations of plag and cpx ± bi ± opx.

Dyke suite 11

Dyke suite 11 consists of fine-grained (<1 mm), grey dykes up to 5 m wide, that are typically homogeneous in composition and texture. They are composed of hb(30%), plag(30%), cpx(20%), opx(15%) and ilm(5%) with minor bi and gt. Planar internal foliations are similar to those in dyke suite 10. Where these dykes are relatively narrow (<0.2 m), they develop a variegated texture similar to dyke suite 5 with ellipsoidal pockets (<1 cm diameter) of plag and cpx, rimmed by hb aligned in the internal foliation. Elsewhere, these dykes resembles dykes of suite 6 in general texture and constituent minerals. However, dykes of suite 11 are geochemically distinct with a less magnesian composition than dykes of suite 6 (Table IV).

Deformation D_6 – foliation S_6 – folds $F_6a,b,c,...$

Deformation event D_6, involved the progressive development of multiple generations of granulite to upper-amphibolite grade, noncoaxial high-strain zones, that vary in width from 1 m to at least 500 m. The high-strain zones, which are sub-vertical, may be either planar or anastomosing and are characterized by the total transposition of earlier foliations and the development of a domainal mineralogical layering (S_6, Fig. 6). In otherwise homogeneous lithologies, high-strain zones are marked by the transposition and extreme attenuation of mafic dykes (e.g. Fig. 4e). Additionally, multiple generations of syntectonic leucosomes and pegmatites (*Pegmatite suite 2*) intruded within or marginal to D_6 high strain zones, generally with similar geometrical orientations (Fig. 6). However, where they intruded oblique to the high-strain zones or where flow heterogeneities occurred, complex fold geometries developed with the progressive deformation (e.g. Fig. 5b). By contrast, a generally weak axial planar foliation defined locally by bi ± sill ± leucosome veins (e.g. Fig. 5c) in felsic and pelitic gneisses, and by hb and plag ± bi in mafic dykes, characterizes S_6 in low strain zones. Where there is an absence of distinct marker units, such as dykes (which cross-cut S_4), S_6 in high strain zones is indistinguishable from S_4.

Early-developed S_6 foliations are re-oriented about later D_6 high-strain zones. Thus, in areas of incomplete transposition, a complex array of D_6 structures is developed. For example, some dykes on Mike Island preserve multiple, overprinting S_{6a-d} foliations that record a progressive anticlockwise rotation around L_6. The rotation of this foliation possibly reflects progressive clockwise rotations of the bulk rock between two D_6 high strain zones. Late D_6 high-strain zones are consistent in orientation, trending 120° and dipping steeply to the NE. Shear-sense indicators such as asymmetric extensional shear bands, in conjunction with a steeply south-east plunging mineral and elongation lineation (L_6, Fig. 6) indicates north-west directed sinistral transpression.

L_6 is partly defined by recrystallized feldspar aggregates in felsic layers and oriented hb in transposed dyke material and it is colinear with all fold generations developed during D_6 (Figs 3 & 6). The style of folds, however, is variable. In high-strain zones, F_6 structures are tight to isoclinal at scales of centimetres to metres and at least three colinear generations may be recognized. In low-strain zones, folds are open to tight and may be developed at scales from metres to kilometres. Zones of relatively low D_6 strain within the Archaean component are characterized by tight to isoclinal folds in the S_4 form surface, locally resulting in spectacular fold interference patterns with F_{4a-c} (e.g. Fig. 3).

The style of D_6 deformation expressed in any individual dyke is variable and dependent upon location relative to the high-strain zones in combination with the original intrusive geometry (e.g. Hoek 1991) and orientation of the dyke. In high-strain zones, dykes lying within the shortening field were either folded and/or boudinaged, whereas those in the extensional field were attenuated and boudinaged. In zones of highest strain, only isolated fold hinges are preserved and the deformed dykes appear to be simple planar features. At a larger scale, early formed high-strain zones in which dykes were mostly transposed, are folded between later formed high-strain zones and the transposed dykes define macroscopic folds. By contrast, zones of lowest D_6 strain preserve mafic dykes that behaved in a relatively ductile manner and developed mesoscopic tight to isoclinal folds. Where the limbs of these folded dykes were parallel or sub-parallel to the local flow plane, they exhibit thinning, migmatization and are locally boudinaged.

Contemporaneous with D_6 was the intrusion of multiple syntectonic granitic orthogneisses that dominate the outcrop in the western Rauer Group. Also, at least three generations of dyke suites (*12–14*) intruded and cross-cut the early-formed S_6 foliations but were subsequently deformed within and between later developed D_6 high-strain zones.

Dyke suite 12

Dyke suite 12 consists of fine- (<1 mm) to medium grained (<0.5 cm), thin (<0. 15 m) mafic dykes, composed of

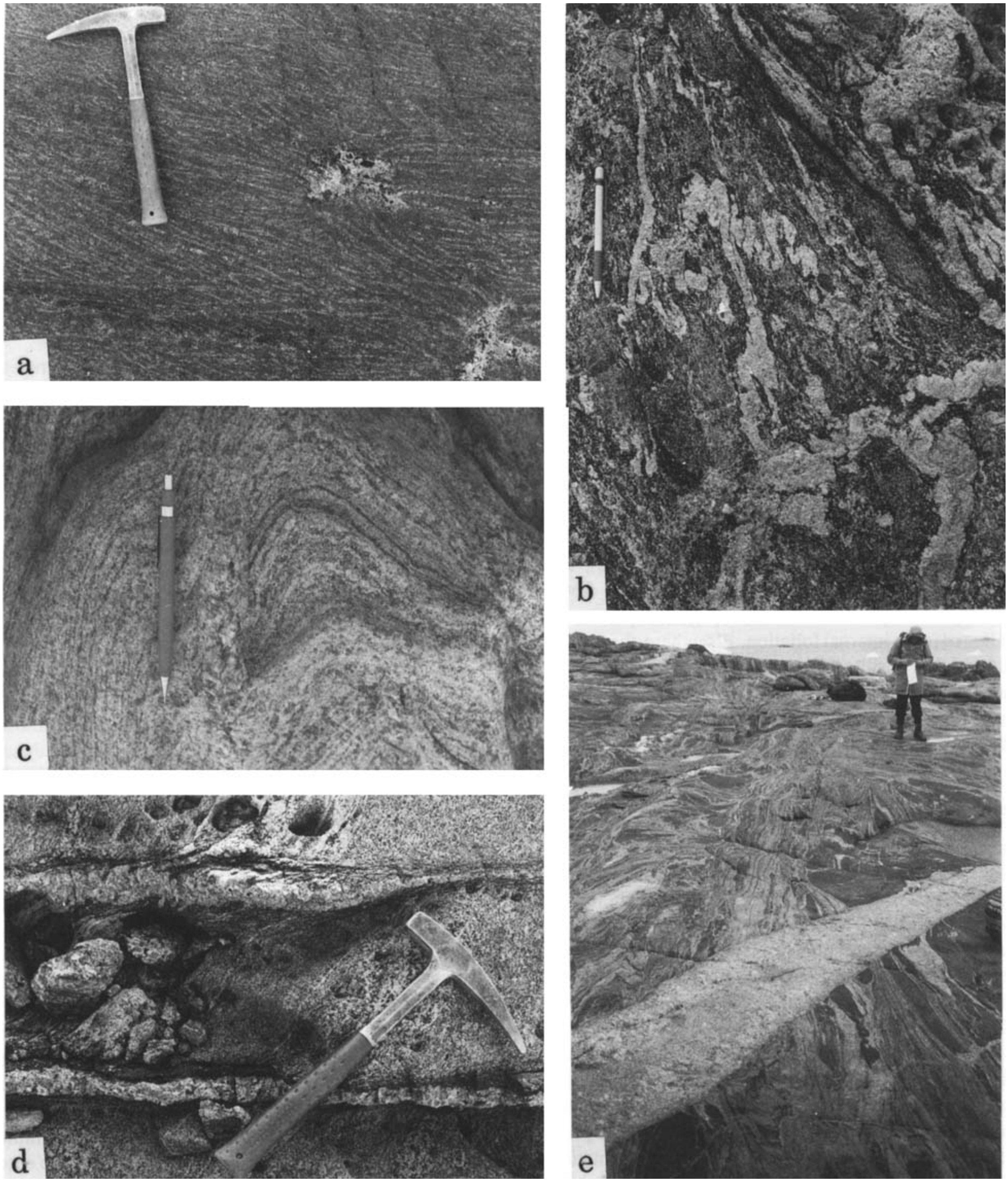

Fig. 5. Photographs of more typical deformation features in the Rauer Group: **a.** Mafic dyke with multiple, overprinting (conjugate ?) foliations showing foliation boudinaging on Dyke Island, **b.** Complex folds within a D_6 high-strain zone on southern Filla Island, **c.** Progressively developed fold of D_6 high-strain zone on Split Island displaying an axial planar leucosome, **d.** D_7 mylonite and ultramylonite on the margin of a suite 3 pegmatite, Filla Island. **e.** Planar suite 3 pegmatite cross-cutting a D_6 high strain-zone on north-east Slon Island.

plag(30%), cpx(30%), hb(15%), ilm(15%) and bi(10%). An internal foliation in dykes of this suite is defined by aligned hb and bi. Rare coarse (<1 cm) plag grains gives this dyke suite a sporadic "freckled" appearance. A dyke of suite 12 cross-cuts an early D_6 high-strain zone on Split Island.

Dyke suite 13

Dyke suite 13 consists of medium-grained (<0.5 cm), grey dykes, up to 5 m wide, composed of hb(30–40%), plag(30–40%), cpx(5–20%), opx(0–10%), ilm(10%), bi(5%) and minor gt. This dyke suite is characterized by multiple, possibly conjugate, internal foliations defined by segregations of plag and cpx ± bi ± opx, and numerous ellipsoidal plag-cpx pockets (<2 cm in diameter) rimmed by hb that are mostly restricted to the margins. The planar internal foliations are defined by elongated plag-cpx pockets in combination with mm-scale segregations of plag, cpx rich and hb, plag, bi rich domains.

Dyke suite 14

Dyke suite 14 consists of fine-grained (<1 mm), thin (<0.25), melanocratic dykes, composed of opx, cpx, plag and bi. Leucocratic segregations of coarse-grained (<1 cm) plag, cpx and opx are common and are isoclinally folded about an internal (S_6) foliation defined by aligned constituent minerals.

Pegmatite suite 3

Moderately west-dipping pegmatites, containing Kspar, qtz, plag, bi, gt and mt ± mu cross-cut all high-grade structures (Fig. 5e). The orientation of these pegmatites is dominantly north-south (Fig. 6), though other orientations do occur.

Deformation D_7 - psuedotachylite/ultramylonite-mylonite 7

D_7 is characterized by discrete shear zones mostly less than 10 cm in width (Fig. 5d) that generally record multiple stages of alternating pseudotachylite-ultramylonite and mylonite formation. Within the ductile stages of these shears, alkali feldspar generally deformed in a brittle to semi-brittle manner and mineral assemblages of gt-bi-qtz-py-cpy occur. A number of orientations occur (Fig. 6) with the most dominant being: (dip/dip direction – lineation pitch, shear-sense); 75/035–30NW, dextral thrust (parallel to latest D6 high strain zones); 50/260–10S, dextral (parallel to pegmatite suite 3, Fig. 5d); 50/005–90, thrust; and, 60/320-20NE, sinistral. These shear zones correspond to D_{5H} mylonite zones of Harley (1987).

Dyke suite 15

Dyke suite 15 consists of unmetamorphosed, planar, N-trending, bi-rich dykes that are up to 0.5 m wide. This dyke suite corresponds to the lamprophyre dykes of Kinny *et al.* (1993).

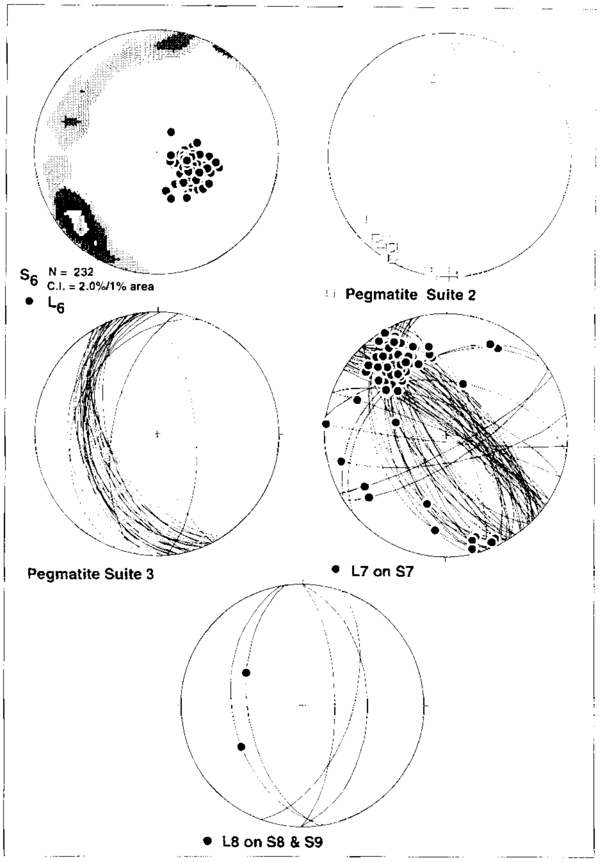

Fig. 6. Orientation data for the main structural elements on Filla, Slon and Dyke islands, which are typical for the entire Rauer Group (cf Fig. 3); data are presented as lower hemisphere equal area projections.

Deformation D_8 - pseudotachylite/ultramylonite 8

D_8 is characterized by discrete narrow (<2 cm) zones of alternating pseudotachylite and ultramylonite formation. These zones trend almost N and dip moderately to both E and W. Lineations and shear-sense indicators suggest a normal movement sense with small components of either dextral or sinistral shear. On Dyke Island, D8 ultramylonites and psuedotachylites are developed on the margins of suite 15 lamprophyre dykes.

Deformation D_9

N-trending fracture zones, characterized by variably developed calcite veins and alteration zones containing cummingtonite, are also developed on the margins of lamprophyre dykes on Dyke Island. These fracture zones may be associated with D8 but are distinct in style.

Correlations and age constraints

The protracted history of multiple dyke intrusions alternating with a succession of structural events in the Rauer Group strongly suggests that there is an overlap with comparable events described in the adjacent Vestfold Hills (Passchier *et al.* 1991, Dirks *et al.* 1994). Such correlations can be made using both the geochemistry of the dykes and the timing of structural events relative to dyke emplacement, and enable the use of absolute age data from the Vestfold Hills to constrain the structural-metamorphic and tectonic history of the Rauer Group.

Geochemical correlations

Detailed studies of the mafic dykes in the Vestfold Hills have established the existence of geometrically, compositionally and chronologically distinct dyke generations that can be subdivided into Mg-rich tholeiites, Fe-rich tholeiites and lamprophyric dykes. Essentially, five different dyke suites were emplaced after the last granulite event to affect the Vestfold Hills. The oldest, E-W trending dyke suite, consists mainly of high-Mg tholeiites (Group I, Kuehner 1986) in combination with some high-Fe tholeiites, and was emplaced at 2424 ± 72 Ma (Collerson & Sheraton 1986, Kuehner 1986). A second suite of rare high-Mg tholeiites (Group II, Kuehner 1986), associated with a norite complex in the northern Vestfold Hills, was emplaced at around 2241 ± 4 Ma (Lanyon *et al.* 1993). The third dyke suite consists of NW-trending high-Fe tholeiites dated at 1754 ± 16 Ma (Lanyon *et al.* 1993) which locally occur in combination with high-Mg dykes (Group III, Kuehner 1986). Suite 3 dykes are consistently associated with sheared margins that preserve up to three generations of amphibolite-grade mylonites (Passchier *et al.* 1991, Dirks *et al.* 1994). A fourth dyke suite comprises high-Fe tholeiites, dated at 1380 ± 7 Ma (Lanyon *et al.* 1993), which intruded at the same time as lamprophyres of ultramafic and alkaline compositions (Kuehner 1986, Seitz 1992, Dirks *et al.* 1994,). A fifth suite of high-Fe tholeiites was dated at 1241 ± 5 Ma (Lanyon *et al.* 1993), and comprises at least six different dyke swarms that have progressive clockwise cross-cut relationships and trend from N to NNE (Dirks *et al.* 1994). Lanyon *et al.* (1993) further identified a N-trending alkaline dyke of unknown age cross-cutting the youngest Fe-tholeiites in the northern Vestfold Hills.

Unlike the Vestfold Hills mafic dyke suites, which preserve igneous mineral assemblages and textures, the mafic dyke suites in the Rauer Group contain granulite-facies assemblages and textures. This does not preclude the possibility of geochemical correlations, as mineralogical changes associated with high-grade metamorphism of mafic rocks generally result in only minor chemical changes (Rollinson & Windley 1980, Weaver & Tarney 1981, Sheraton 1984). Large ion lithophile elements (LILE: e.g. Rb, K, Ba) are predominantly affected, especially in the presence of a fluid phase, while moderately incompatible (e.g. Nb, Sr, Ce) and high field strength elements (HFSE: e.g. P, Zr, Ti, Y) remain relatively unaffected and are likely to preserve primary igneous characteristics. These elements are therefore useful in the correlation of dykes between the Rauer Group and the Vestfold Hills.

Geochemically, the Rauer Group dykes can be divided into a high-Mg group and a high-Fe group (Table IV), which resemble the principal compositional groups of the Vestfold Hills (Fig. 7). The high-Mg dykes of the Rauer Group are characterized by higher MgO, Cr and Ni, as well as lower total-Fe, TiO_2, P_20_5, Zr and Y relative to the high-Fe dykes (Table IV). Incompatible element plots of the high-Mg dykes (Fig. 8a), although variable, show a relative enrichment of LILE and negative anomalies of Nb, Sr, P and Ti. When compared to the high-Mg dykes of the Vestfold Hills, similar patterns of Sr, Nd, P, Zr, Ti and Y are apparent.

Incompatible element plots for the high-Fe dykes (Fig. 8b) are typically "flat" with only weak relative enrichment of the LILE. A strong negative anomaly is displayed by Sr and weak negative anomalies of Nb, P and Ti are evident. A similar pattern of moderately incompatible and HFSE is again apparent when compared to the Fe-rich tholeiites of the Vestfold Hills.

The Rauer Group dyke suites that we would correlate on the basis of relative intrusive timing, with lamprophyric dykes in the Vestfold Hills (see below), have major element characteristics (particularly Mg, Ni and Cr, Fig. 7) and incompatible element trends (Fig. 8a) that are broadly similar to the high-Mg groups. If the correlation is valid, the characteristic geochemical signatures of the Vestfold Hills lamprophyric dykes are not readily apparent, possibly due to the effect of high-grade metamorphism preferentially depleting LILE and the more mobile alkaline elements. This would be particularly true in the case of high fluid activity associated with metamorphism (e.g. Sheraton 1984). Considering the characteristic primary mineralogy of the lamprophyres in the Vestfold Hills which have high modal abundance of hydrous phases, such as calcic amphiboles and phlogopite (Delor & Rock 1991), an assumption of local high fluid activity with high-grade metamorphism is reasonable.

Structural correlations

The earliest unequivocal dykes in the Rauer Group include two high-Mg suites (Table V). In the Vestfold Hills, the earliest Proterozoic intrusive rocks likewise are dominated by high-Mg suites, and it is possible that dyke suites 1 and 2 in the Rauer Group correlate with any of the high-Mg dykes that occur in suites 1, 2 and 3 in the Vestfold Hills.

The earliest Fe-rich dykes in the Rauer Group, suite 3, are correlated with the 1754 ± 16 Ma Fe-tholeiites of the Vestfold Hills. Characterized by a significantly different orientational trend to the bulk of the Vestfold Hills dykes, they have hydrated, sheared margins containing bi and hb which

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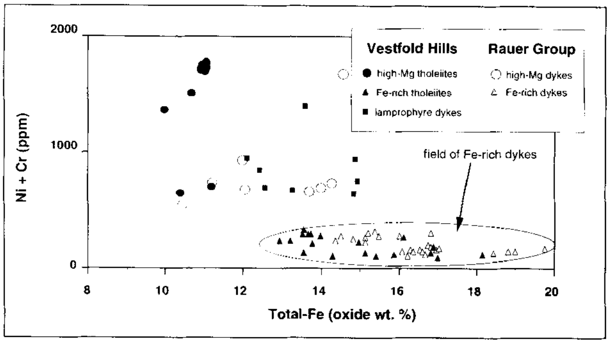

Fig.7. Ni + Cr versus total Fe co-variation for mafic dyke suites from the Rauer Group and the Vestfold Hills. The compositional fields for Fe-rich dykes from both areas closely overlap. The high-Mg dykes, which consistently plot away from the Fe-rich dykes, are less closely grouped, although the Vestfold Hills lamprophyres do closely overlap with the high-Mg dykes in the Rauer Group.

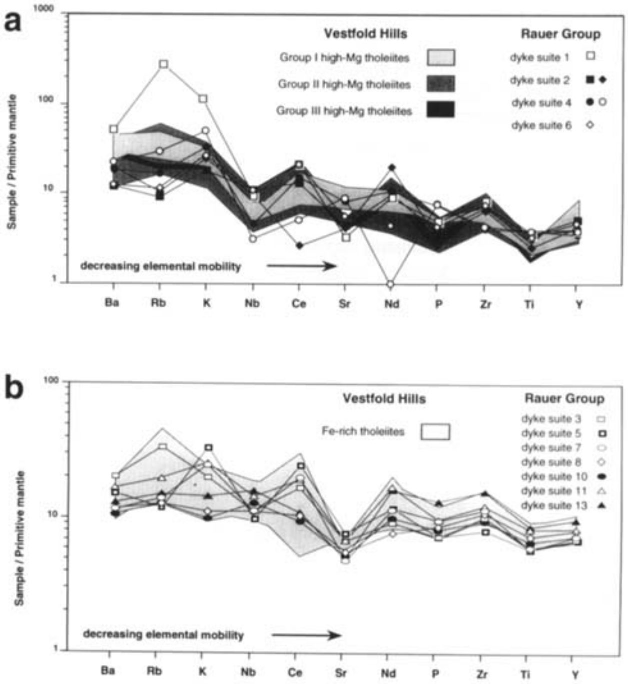

Fig. 8. Incompatible element plots for selected dykes from the Rauer Group and the Vestfold Hills, normalized to primitive mantle abundances after Wood *et al.* (1979): **a.** High-Mg dykes. Plots of Vestfold Hills dykes are based on Group I, II and III high-Mg tholeiite dykes as determined by Seitz (1992). Dyke suite 4 and 6 in the Rauer Group correlate stratigraphically with lamprophyric dykes in the Vestfold Hills, **b.** Fe-rich dykes. Samples for the Vestfold Hills were taken in conjunction with detailed mapping in the Hidden Valley area (Dirks *et al.* 1994).

formed before the emplacement of all younger dykes. On Dyke Island (Fig. 2a), the envelopes of deformed dykes of suite 3 also occur at high angles to the later dyke suites (Fig 4c), while the margins are recrystallized to a hydrous assemblage that is significantly different in composition to the cores of the dykes. It seems likely that the foliated, recrystallized margins of dyke suite 3 represent a shearing episode (*mylonite 3*) that probably correlates with the D_{5D} mylonites of Dirks *et al.* (1994) in the Vestfold Hills (D in the subscript number refers to deformations or metamorphic events recognized in the Vestfold Hills by Dirks *et al.* 1994).

Coarse porphyroblasts of gt and opx overprint both the core and margins of dyke suite 3. These porphyroblasts are surrounded by complex coronas involving a second stage of gt growth which are absent from all other dykes. Dyke suite 2 likewise contains a prominent foliation defined by aligned opx and cpx, and is extensively migmatized; both these textures are cross-cut by later dykes. Traces of S_4 foliation in the host orthogneiss are also transected by later dykes but appear to be axial-planar to folds in dyke suite 1. Thus, D_4 events in the Rauer Group occurred between two major episodes of dyke emplacement, which probably coincided with the time interval between D_{5D} shearing along dyke 3 and the emplacement of the 1380 Ma suite of dykes in the Vestfold Hills. This episode coincided with the formation of extensional pseudotachylite and ultramylonite (D_{6D}) overprinted by ductile extensional mylonites (D_{7D}) probably in association with progressive heating (Dirks *et al.* 1994). It is probable that these extensional events correlate with the D_4 granulite-facies deformation in the Rauer Group, although it has not been established if the granulite event is extensional.

Three sets of suite 4 dykes, comprising lamprophyric, Fe-tholeiitic and lamprophyric compositions, were emplaced in the Vestfold Hills after the extensional event (Keuhner 1986, Dirks *et al.* 1994). Similarly, the first three dyke suites that post-date the D_4 granulite event in the Rauer Group have high-Mg (dyke suite 4), high-Fe (dyke suite 5) and high-Mg (dyke suite 6) compositions (Tables IV & V). It is therefore not unreasonable to correlate this sequence of dykes with the 1380 Ma dykes in the Vestfold Hills. Likewise, the multiple *c.* 1240 Ma Fe-tholeiite dykes in the Vestfold Hills probably correlate with dyke suites 7–11 in the Rauer Group which are all Fe-rich in composition (Fig. 8b, Table IV). If so, the recrystallized discrete D_5 mylonite zones in the Rauer Group, although poorly constrained with regard to both timing and kinematics, most likely correlate with the compressional D_{8D} mylonites of Dirks *et al.* (1994) in the Vestfold Hills, and therefore formed sometime between 1380 Ma and 1240 Ma.

An age of 1004 ± 52 Ma (sample F106, U-Pb zircon, Kinny *et al.* 1993) obtained from a discordant aplitic leucogneiss constrains D6. This sample was obtained from a ductile shear zone ascribed to late D_{4H} of Harley (1987), that corresponds to a late D_6 high strain zone. This implies that dykes 12–14 did not intrude at about 1240 Ma but were emplaced at about 1000 Ma. A late origin for these mafic dykes is consistent

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Table V. Correlation of structural elements between the Rauer Group and Vestfold Hills. The Rauer Group scheme incorporates information from Harley (1987, 1988) and Harley & Fitzsimons (1991). Vestfold Hills scheme after Dirks *et al.* (1994), Seitz (1992) and Paschier *et al.* (1991). Letters in the "Age" column refer to: (*a*) Lanyon *et al.* (1993), (*b*) Kinny *et al.* (1993), (*c*) Collerson & Sheraton (1986), (*d*) Black *et al.* (1991a), (*e*) Black *et al.* (1991b), (*f*) Sheraton *et al.* (1984).

Age (Ma)	Vestfold Hills		Rauer Group	
3270 b			Orthogneiss	
2800 b,d	Orthogneiss?		Orthogneiss	
	Sediments deposited		Mafic granulite	*relative*
	Volcanic deposits		*Mafic and ultramafic layering*	*timing*
			Sediments deposited	*uncertain*
2500 d	D_1 - D_2 multiple orthogneisses		D_1 - D_2 - granulite (age uncertain)	
2477 d,c	Intrusion of quartz diorite			
	D_3 - granulite grade mylonites			
	D_4 - ? amphibolite grade mylonites			
	Pegmatite 1			
2240 a	High-Mg tholeiites and Fe-tholeiite dykes	*(suites 1, 2)*	*Dyke suites 1,2* (high-Mg)	
1754 a,c	Fe-rich tholeiite dykes	*(suite 3)*	*Dyke suite 3* (Fe-rich)	
	D_5 - amphibolite grade mylonites		D_3 - mylonites	
	D_6, D_7 - pseudotachylites reactivated to mylonites and ultramylonites		D_4 - pervasive granulite grade gneissic foliation, *pegmatite suite 1*	
1400 f			Orthogneiss intruded	
	Ultramafic alkaline dykes		*Dyke suite 4* (high-Mg)	
1380 a,c	Fe-tholeiite dykes	*(suite 4)*	*Dyke suite 5* (Fe-rich)	
	Alkaline dykes		*Dyke suite 6* (high-Mg)	
	D_8 - mylonite and ultramylonite		D_5 - mylonite	
1241 a,c	Fe-tholeiite dykes	*(suite 5)*	*Dyke suites 7–11* (Fe-rich)	
			Sediments deposited	
1000 a,b,c,e	D_9, D_{10} - local pervasive foliation in SW and amphibolite grade mylonites		D_6 - pervasive granulite to upper-amphibolite grade gneissic foliation	
	Pegmatite 2 - (syndeformational)		*dyke suite 12*	syn-D6
			dyke suite 13 (Fe-rich)	syn-D6
			dyke suite 14 (high-Mg)	syn-D6
			pegmatite suite 2	syn-D6
			granite suite	syn-D6
500 b			*pegmatite suite 3*	
			D_7 - amphibolite grade mylonite-ultramylonite and psuedotachylite	
	Lamprophyre dykes	*(suite 6)*		
	D_{11} - psuedotachylite and utramylonite			
			Dyke 15 (Lamprophyre)	
			D_8, D_9 - brittle-ductile and brittle	

with their variable composition compared to the consistently Fe-tholeiitic composition of the 1240 Ma Vestfold Hills dykes. D_6 ages in the Rauer Group are in good agreement with the age of 1025 ± 56 Ma (U-Pb zircon) obtained by Black *et al.* (1991b) for the metamorphism in the Vestfold Hills. Dirks *et al.* (1994) associated this metamorphism with structural events (D_{9D}, D_{10D}) characterized by the formation of a weak foliation and shear zones with identical kinematics to D_6 structures in the Rauer Group. Late pegmatites in the Vestfold Hills, which Dirks *et al.* (1994) suggested intruded during the 1000 Ma shearing events, would therefore correlate with pegmatite suite 2 in the Rauer Group. Structural events post-dating D_6 in the Rauer Group, such as the emplacement of pegmatite suite 3 dated at 500 ± 12 Ma (U-Pb zircon, Kinny *et al.* 1993), cannot be clearly correlated with post-1000 Ma events in the Vestfold Hills at this stage.

Discussion and conclusions

Comparisons of mafic dykes between the Archaean conponent of the Rauer Group and the Vestfold Hills, based on geochemistry and relative structural position, show that one-

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to-one correlations can be made with a reasonable degree of confidence (Figs 7 & 8, Table V), and implies that both terrains were juxtaposed since the latest Archaean (cf. Kinny *et al.* 1993). This correlation places the structures of the Rauer Group in an absolute time frame because crystallization ages of the Vestfold Hills dykes are well constrained (Table V). For example, the overprinting metamorphic assemblages restricted to dyke suite 3 (Fig. 4b), and the D_4 structures transected by all later dyke suites, suggests that high-grade events affected part of the Rauer Group between 1750–1380 Ma (Table V). This is in agreement with Harley & Fitzsimons (1991), who invoked a complex pre D_{3H} history in the Archaean component on the basis of petrological observations, and may explain the presence of orthogneisses in the the southern Rauer Group that have produced Rb/Sr model ages (Sheraton *et al.* 1984) at the lower end of this range. It is now also apparent that the precursors to the predominantly dyke free metasedimentary gneisses in the Rauer Group must have been deposited in the interval 1240–1050 Ma (Table V).

In the Vestfold Hills the Proterozoic deformation history involved minor strains accommodated on discrete mylonites, ultramylonites and pseudotachylites (Passchier *et al.* 1991, Dirks *et al.* 1994), whereas the corresponding deformation history for the Rauer Group was dominated by repeated and pervasive, non-coaxial high-grade deformation events. However, this Proterozoic deformation in the Rauer Group was not distributed homogeneously. During all pervasive high-grade events, for which structural geometries have been preserved, strain was partitioned into zones of high, non-coaxial strain, separating areas of lower strain dominated by simple folding (e.g. Fig. 2b). This process is most clearly illustrated in areas with a great number of dykes, which act as passive three dimensional strain markers in the host rock and which record attenuation and rotation towards parallelism in areas of highest strain.

In individual high-strain zones there has been dynamic recrystallization of existing mineral assemblages, and almost complete transposition of all earlier foliations (including the dykes) into a new planar gneissic layering which in isolation appears identical to the foliations it has transposed. Myers (1978) described the development of layered gneiss in response to an increase in strain in a variety of relatively homogeneous igneous rocks. In the Rauer Group this process was repeated a great number of times such that multiple generations of both unrelated and syntectonic gneissic foliations developed. Therefore, whereas Myers (1978) was able to distinguish original igneous textures in zones of lower strain, in the Rauer Group low-strain zones mostly preserve earlier gneissic foliations which have an identical appearance. Thus, different generations of gneissic foliations are only distinguishable due to their overprinting relationship and cross-cuts with the mafic dykes, together with the presence or absence of characteristic mineral assemblages.

Repeated transposition in high-strain zones is a common feature in the structural evolution of many gneiss terrains. Hence, in areas where there is a paucity of structural markers such as mafic dykes and relatively homogeneous lithologies, it may be difficult to distinguish different generations of gneissic foliations. This could have major implications for the structural interpretations of such high-grade gneiss terrains.

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