BMR Journal of Australian Geology & Geophysics, 8, 119-128

ARCHAEAN AND PROTEROZOIC GEOLOGICAL RELATIONSHIPS IN THE VESTFOLD HILLS–PRYDZ BAY AREA, ANTARCTICA

J.W. Sheraton & K.D. Collerson[1].

The Archaean cratonic block of the Vestfold Hills, Princess Elizabeth Land is one of only three well-documented examples in East Antarctica. It is characterised by tectonically interlayered tonalitic to granitic orthogneisses (Mossel gneiss) and garnetiferous paragneisses (Chelnok supracrustal assemblage) as well as subordinate units of predominantly mafic granulite (Tryne metavolcanics). This sequence is cut by a second suite of orthogneisses (Crooked Lake gneiss), ranging in composition from gabbro-diorite to tonalite and granite, which was emplaced synchronously with the last major phase of deformation. Cutting the gneisses are several suites of Proterozoic tholeiitic dykes, including a high-Mg suite, which range in age from about 2350 Ma to 1300 Ma. Most dykes are unmetamorphosed, but, in the southwestern part of the Vestfold Hills, high-pressure garnet-bearing assemblages developed during a late Proterozoic (about 1100 Ma) thermal event. Granulite facies gneisses that crop out southwest of the Vestfold Block, along the coast of Prydz Bay, show the regional effect of this younger metamorphism and form part of an extensive late Proterozoic high-grade terrain, which makes up much of the East Antarctic Shield. Gneisses in the Rauer Group of Islands, within 30 km of the Vestfold Hills, are lithologically similar (predominantly orthogneisses) to those of the Vestfold Block, and contain metamorphosed relics of Vestfold dykes; however, they include only a minor component derived by remetamorphism of Archaean continental crustal rocks. In contrast, gneisses further to the southwest were mainly derived from aluminous sedimentary protoliths, and are quite different in composition to those of the Vestfold Block and Rauer Group. They do not appear to have been intruded by mafic dykes (mafic granulite is very rare) and apparently represent a Proterozoic cover sequence of similar age to metasedimentary sequences in MacRobertson Land. Intrusion of locally fayalite-bearing granitic rocks took place about 500 Ma ago.

Introduction

Several Archaean cratonic blocks have been recognised in the East Antarctic Precambrian Shield in recent years: they include the Napier Complex of Enderby Land (Grikurov & others, 1976; Sheraton & others, 1980), much of the southern Prince Charles Mountains of MacRobertson Land (Tingey, 1982), and the Vestfold Hills of Princess Elizabeth Land (Collerson & Arriens, 1979; Oliver & others, 1982a; Collerson & others, in press). The Archaean blocks are separated by an extensive late Proterozoic high-grade terrain (Fig. 1), but the extent to which these younger metamorphics comprise remetamorphosed Archaean is difficult to establish, in view of the poor exposure and limited isotopic data.

Rb-Sr and Sm-Nd dating has indicated ages of between about 2400 and 3000 Ma for granulite-facies gneisses in the Vestfold Block (Collerson & Arriens, 1979; Collerson & others, in press). Dolerite dykes that cut these gneisses have given ages of between about 2350 and 1300 Ma (Arriens, 1975; unpublished data). Most of these dolerites belong to the same suites as those that cut Napier Complex metamorphics in Enderby Land, almost 1000 km to the west (Sheraton & Black, 1981). Late Proterozoic metamorphic rocks that crop out to the southwest of the Vestfold Hills, along the coast of Prydz Bay (Fig. 2), are also of granulite facies, but are not cut by dolerites (Tingey, 1981). Only in the Rauer Group of Islands, about 30 km southwest of the Vestfold Block, can such dykes be recognised in a disrupted state, suggesting remetamorphism of Vestfold Block gneisses. This younger tectonothermal event has been dated by P.A. Arriens at 1073 ± 111 Ma (initial $^{87}Sr/^{86}Sr$ 0.7086 ± 0.0013) in felsic gneisses from Filla Island (Tingey, 1981). The contact between the Archaean and Proterozoic terrains is not exposed, being hidden under the Sørsdal Glacier, but transitional relationships can be observed on one island of the Rauer Group immediately south of the Sørsdal Glacier. In the southwestern part of the Vestfold Block, both country rocks and dykes were extensively recrystallised under high-grade conditions during the Late Proterozoic event, although there was only limited associated deformation (development of shear zones).

An extensive sampling program was undertaken in the Vestfold Hills–Prydz Bay area during December 1980 and January 1981 with the object of comparing the chemical and

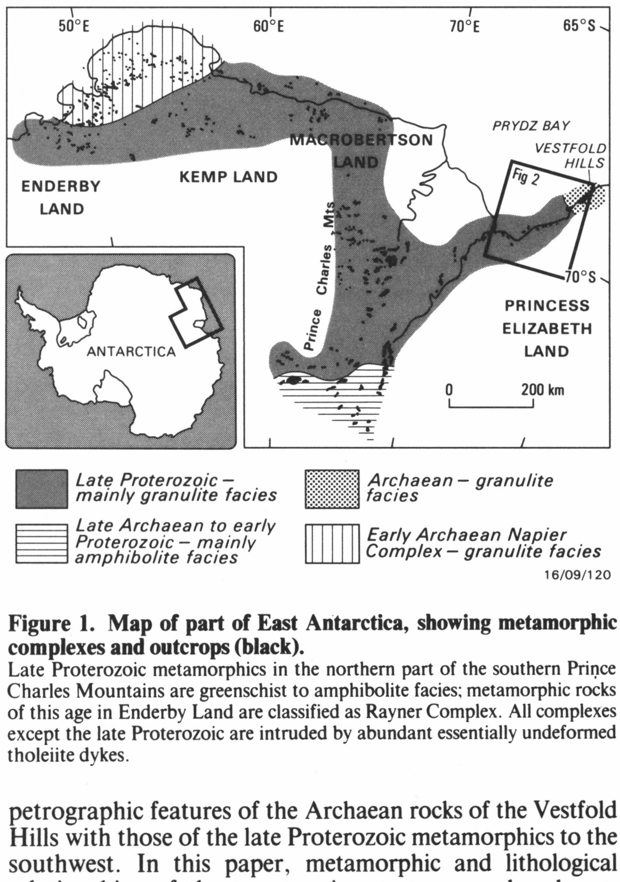

Figure 1. Map of part of East Antarctica, showing metamorphic complexes and outcrops (black).
Late Proterozoic metamorphics in the northern part of the southern Prince Charles Mountains are greenschist to amphibolite facies; metamorphic rocks of this age in Enderby Land are classified as Rayner Complex. All complexes except the late Proterozoic are intruded by abundant essentially undeformed tholeiite dykes.

petrographic features of the Archaean rocks of the Vestfold Hills with those of the late Proterozoic metamorphics to the southwest. In this paper, metamorphic and lithological relationships of the two terrains are compared and contrasted. The chemical and isotopic characteristics will be considered elsewhere.

Archaean metamorphics

Archaean metamorphics of the Vestfold Block were subdivided by Oliver & others (1982a) into 4 major units: layered 'grey gneiss', layered paragneiss, and two types of felsic orthogneiss (homogeneous, and with a diffuse layering). This classification was subsequently revised by Collerson & others (in press), who erected a relative chronology based on

[1] Research School of Earth Sciences, Australian National University, GPO Box 4, Canberra, ACT 2601

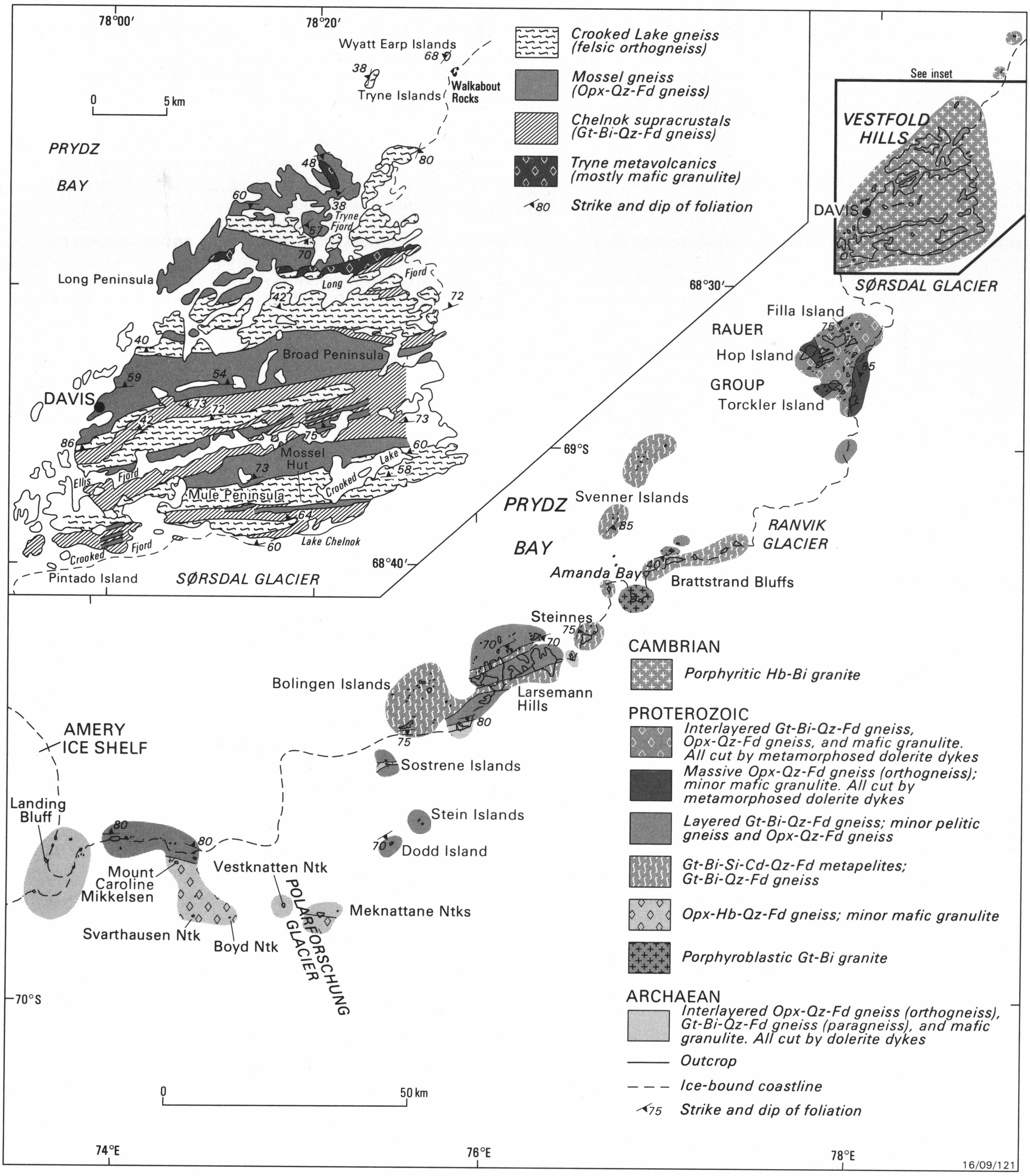

Figure 2. Geological map of the Vestfold Hills and Prydz Bay coast.

field relationships (Table 1), which is used in the following brief descriptions. Details of the structural evolution of the Vestfold Block have been given by Oliver & others (1982a) and Parker & others (1982), and of the conditions of metamorphism by Collerson & others (1983).

Mafic rocks (Tryne metavolcanics and subordinate mafic units within the Chelnok supracrustal assemblage).

The Tryne metavolcanics are the oldest, predominantly mafic, rocks recognised in the Vestfold Block. They occur in different states of preservation, as mappable units up to 0.5 to 1 km wide (Fig. 3), as boudinaged xenoliths or tectonic intercalations within the felsic Mossel gneiss (Fig. 4), and as xenoliths within the Crooked Lake gneiss (Fig. 5). They are medium to fine grained and commonly exhibit a layering defined either by deformed primary (felsic to mafic) compositional variations or by predominantly tonalitic (using the classification of Streckeisen, 1976) partial melts (Fig. 6). Although most of the mafic units were probably derived from volcanic protoliths, minor fragmented occurrences of pyroxenite, metagabbro, and metaleucogabbro suggest the presence of differentiated plutonic bodies within the sequence (Fig. 7). Mafic granulite layers consist of orthopyroxene (10–25%), clinopyroxene (5–30%), greenish-brown hornblende (up to 30%), reddish-brown biotite (up to 10%), plagioclase (50–60%), opaque minerals (up to 3%), and

Table 1. Geological history of Vestfold Hills–Prydz Bay area.

Event	Metamorphism	Approx. age (Ma)
1. Extrusion of protoliths of Tryne metavolcanics; deposition of Chelnok supracrustals; intrusion of mafic bodies.		> 3000?
2. High-grade metamorphism and deformation (D_1); partial melting of Tryne metavolcanics and formation of Mossel gneiss (mostly tonalitic).	Granulite facies	about 3000
3. Intrusion of mafic dykes.		
4. Emplacement of dioritic to granitic intrusives (Crooked Lake gneiss) and localised partial melting of older units; deformation (D_2).		2400–2500
5. Formation of steeply-dipping shear zones (D_3).		
6. Intrusion of high-Mg tholeiitic dykes.		about 2350
7. Intrusion of dolerite dykes.		about 1850
8. Deposition of sediments; emplacement of granitic intrusives.		
9. Intrusion of abundant dolerite dykes of at least two distinct suites.		about 1300
10. Deposition of sediments, including pelitic and psammitic types.		
11. Emplacement of tonalitic to granitic intrusives; deformation and high-grade metamorphism in rocks of the Prydz Bay coast; localised high-pressure metamorphism in southwestern part of Vestfold Hills, but only minor deformation.	Granulite facies	about 1100
12. Intrusion of granitic pegmatites.		
13. Emplacement of hornblende-biotite granite (Landing Bluff and Polarforschung Granites).		500
14. Intrusion of alkaline dykes, including lamprophyres.		

minor quartz, apatite and K-feldspar. A sample (81285364) from east of Pintado Island, in the extreme southwest of the Vestfold Hills, contains secondary garnet rimming pyroxene. Felsic layers are commonly of tonalitic composition, and contain up to 30 per cent quartz in addition to plagioclase, clinopyroxene, orthopyroxene, and minor hornblende, biotite, and Fe-Ti oxides.

Layered paragneiss (Chelnok supracrustal association).

Paragneiss is widespread in the southern half of the Vestfold Block (Fig. 2), where it forms tectonic units of variable thickness, interlayered on a regional and local scale with Mossel gneiss (Fig. 8). The most abundant, commonly migmatitic, varieties are semi-pelitic in composition, and include biotite-garnet-quartz-feldspar gneiss and biotite-orthopyroxene-garnet-quartz-feldspar gneiss. Unlike the Mossel and Crooked Lake gneisses, most contain abundant perthite, although a few have more sodic compositions. Garnet commonly makes up less than 10 per cent of the gneiss, but in a few layers, reaches 60 per cent (Fig. 9). Reddish-brown biotite (3–10%) is widespread, but other aluminous minerals (cordierite, sillimanite, and spinel) are rare, in marked contrast to the late Proterozoic metasediments of the Prydz Bay coast. Sapphirine-bearing assemblages have been reported by Collerson & others (in press), but, unlike those in Enderby Land, do not include either quartz or osumilite (cf. Sheraton & others, 1980). Oliver & others (1982a) and Collerson & others (in press) have reported the localised occurrence of orthopyroxene-cordierite-quartzite, calc-silicate (scapolite + diopside + quartz ± sphene) gneiss, marble, and quartz-magnetite rocks.

Superimposed, late Proterozoic metamorphism in the southwestern Vestfold Hills is reflected in the development of secondary garnet around orthopyroxene grains, and in extensive recrystallisation of quartz and feldspar.

Layered orthopyroxene-quartz-feldspar gneiss (Mossel gneiss).

This unit forms a major part of the layered gneiss complex in the Vestfold Block (Fig. 2, 10). It is composed of a number of components, including layered quartzo-feldspathic orthogneiss with intrafolial folds, sheets of homogeneous orthogneiss, boudins of mafic granulite, and discordant pegmatite veins, which contain blue quartz, plagioclase, and orthopyroxene. It has been shown by Collerson & others (in press) that part of the felsic component of Mossel gneisses formed by partial melting of Tryne metavolcanic mafic units. The latter show clear evidence of in situ anatexis (Fig. 11) and commonly occur as xenoliths in Mossel gneiss in areas of relatively low strain (Fig. 12).

The Mossel gneiss is predominantly biotite-orthopyroxene tonalite, with subordinate granodiorite and granite. Tonalitic gneiss contains orthopyroxene (4–14%), reddish-brown biotite (up to 7%), quartz (10–35%), plagioclase (45–70%) and minor perthite, opaque minerals, apatite, and zircon. Granitic gneiss contains abundant perthite, but less orthopyroxene and biotite. In contrast to the Crooked Lake gneiss, clinopyroxene and hornblende are generally present in only minor amounts.

Felsic orthogneiss (Crooked Lake gneiss).

This unit intrudes all the previously discussed groups and is one of the most abundant in the Vestfold Hills (Fig. 2). It commonly has sharp, semi-concordant contacts (Fig. 13) and, according to Oliver & others (1982a) and Collerson & others (in press), was emplaced synkinematically with the period of deformation (D_2) that resulted in the development of macroscopic folds in the layered gneisses. In areas where the effects of this deformation are strong, i.e. Mule Peninsula and Broad Peninsula, the Crooked Lake gneiss shows a pronounced diffuse layering, a simple anastomosing schistosity, and variably developed elongation lineation (Fig. 14). However, elsewhere, particularly on Long Peninsula, where deformation was less intense, the gneiss appears more massive and commonly exhibits only a weak fabric (Fig. 15). Country rock (Fig. 5, 16) and cognate xenoliths are abundant near contacts, and commonly aligned parallel to the contacts.

The most abundant lithology is tonalitic, quartz dioritic, and dioritic orthogneiss; more potassic varieties (granite, granodiorite, monzonite, etc) are less common, and contain perthite, which locally approaches mesoperthite in composition. Both perthite and plagioclase (commonly antiperthite) locally form porphyroblasts. Orthopyroxene, clinopyroxene, green to greenish-brown hornblende, and brown to reddish-brown biotite each form up to 15 per cent of the most melanocratic orthogneiss. Hornblende is relatively more abundant in diorite, and clinopyroxene in diorite and tonalite; they tend to be present in only minor amounts in granite, in which orthopyroxene is the predominant mafic mineral. However, orthopyroxene commonly shows marginal alteration to biotite (with minor hornblende) and quartz. Feldspar and quartz are locally recrystallised to a fine-grained granoblastic mosaic. Accessory minerals comprise opaque oxides (up to 2%), apatite, and zircon.

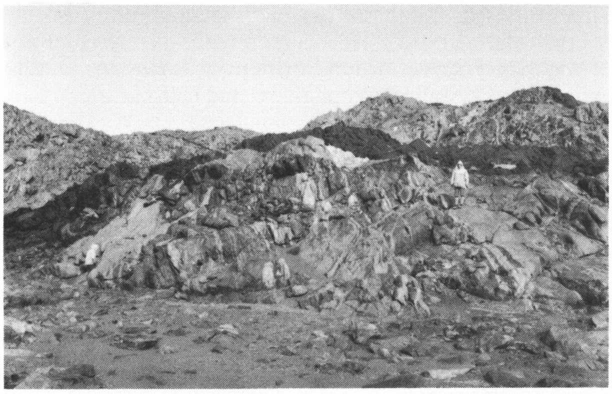

Figure 3. Tryne metavolcanics cut by Crooked Lake gneiss and dolerite dyke, Tryne Crossing.

Figure 4. Boudinaged Tryne metavolcanic layer in Mossel gneiss, Mule Peninsula.

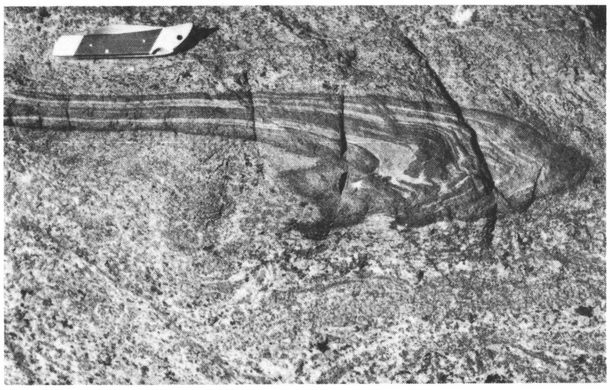

Figure 5. Folded Tryne metavolcanic xenolith in Crooked Lake gneiss, Mule Peninsula.

Figure 6. Migmatitic Tryne metavolcanics, Tryne Crossing.

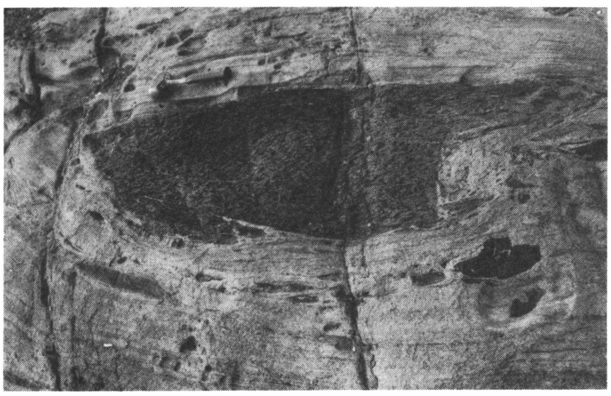

Figure 7. Boudinaged metagabbro layer in Mossel gneiss, Long Peninsula.

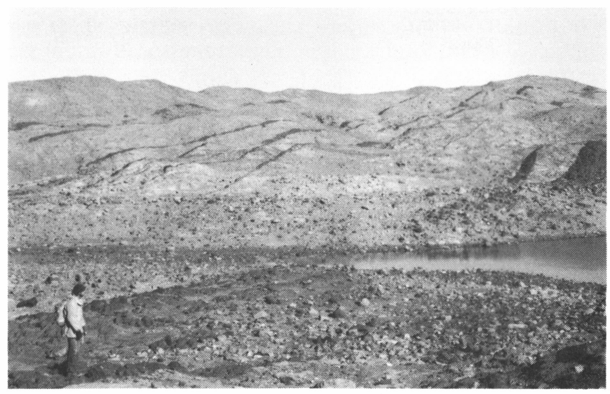

Figure 8. Contact between Chelnok supracrustals (light colour) and Mossel gneiss, cut by dolerite dykes, Broad Peninsula.

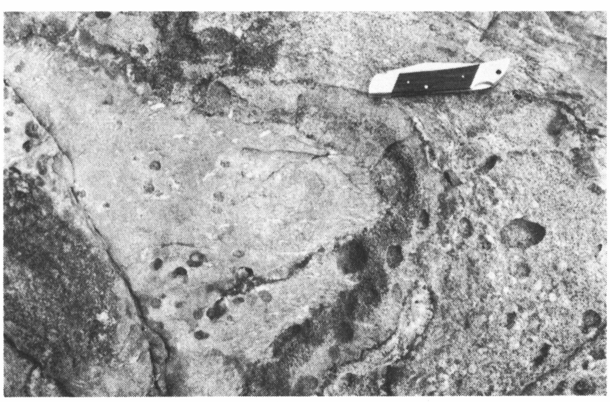

Figure 9. Primary layering in garnet-rich Chelnok metapelite, Mule Peninsula.

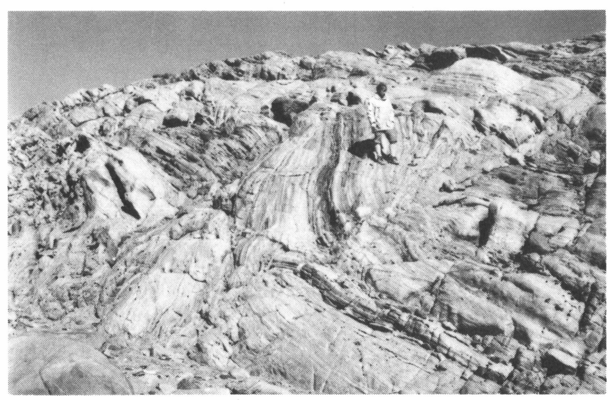

Figure 10. Monoclinal fold (F_3) in Mossel gneiss, Broad Peninsula.

Mafic dykes

Apart from a few early folded and metamorphosed mafic dykes (Fig. 17), the majority of dykes cutting Archaean gneisses of the Vestfold Block are essentially unmetamorphosed and form a dense swarm with a predominant north- south orientation (Fig. 18). Only in the southwestern part of the area do the effects of the late Proterozoic metamorphism become pronounced.

The most abundant are dolerites with subophitic to gabbroic textures. Clinopyroxene (augite or subcalcic augite: 30–40%), zoned reddish-clouded plagioclase (commonly An_{55-70}: 55–60%), and opaque minerals (ilmenite, magnetite, and rare pyrite, pyrrhotite, and chalcopyrite: 3–7%) are major constituents, and small amounts of dark green to greenish-brown hornblende, dark brown or reddish-brown biotite, quartz, and apatite are commonly present. One sampled dyke (81285246) contains about 5 per cent hypersthene with overgrowths of augite, and a few contain pigeonite; some quartz-free dykes contain minor rather altered olivine, and these are commonly porphyritic, with plagioclase phenocrysts. Preliminary Rb-Sr dating has indicated an age of about 1300 Ma for the majority of the dolerites, although one chemically distinct suite is significantly older (about 1850 Ma: unpublished data). The Amundsen Dykes of Enderby Land are petrographically similar, and one group has been dated at 1190 ± 200 Ma (Sheraton & Black, 1981).

Many dolerites show some degree of uralitisation of pyroxene, but in the southwestern part of the Vestfold Hills, particularly between Crooked and Ellis Fjords, all mafic dykes examined have been metamorphosed during the late Proterozoic event. Such metadolerites have granuloblastic textures and are generally fine-grained (about 0.1 mm), although relict igneous phases (e.g. clinopyroxene porphyroclasts) have locally survived. They contain pyroxene (orthopyroxene and clinopyroxene, up to 30%), dark greenish-brown hornblende (5–15%), reddish-brown biotite (up to 5%), plagioclase (35–55%), Fe-Ti oxides (2–5%), and minor quartz and apatite. Metadolerites in the extreme southwest (in and around Crooked Fjord) also contain up to 25 per cent garnet, which forms poikiloblastic aggregates 1–2 cm across associated mainly with clinopyroxene, surrounded by areas rich in hornblende, pyroxene, and plagioclase. However, its distribution is extremely patchy, some parts of individual dykes being full of garnet-rich spots, whereas others, a few metres away, are essentially garnet-free. Garnet development is not simply a function of degree of deformation, as many garnet-rich metadolerites show little evidence of deformation. A largely recrystallised hornblende pyroxenite dyke (81285368), from Kazak Island, chemically an olivine tholeiite, consists of clinopyroxene + orthopyroxene (50%), brown hornblende (40%), plagioclase (10%), and minor biotite and opaque oxides.

The other major group of mafic intrusives are high-Mg dykes, petrographically identical to a suite of tholeiites in Enderby Land; both have given Rb-Sr isochron ages of about 2350 Ma (Sheraton & Black, 1981; unpublished data), consistent with cross-cutting relationships that indicate that they predate the dolerite and hornblende pyroxenite dykes. The high-Mg dykes are characterised by abundant orthopyroxene (bronzite or hypersthene: 25–40%), together with augite (15–25%), andesine-labradorite (35–60%), reddish-brown biotite (up to 2%), and relatively uncommon (less than 2%) opaque minerals (magnetite, ilmenite, and traces of pyrite and chalcopyrite); minor olivine (up to 2%), quartz, and K-feldspar are present in some dykes, but primary hornblende is absent. Phenocrysts consisting of orthopyroxene with overgrowths of clinopyroxene are commonly present. Metamorphosed high-Mg dykes contain slightly less pyroxene, but more biotite (about 5%) and quartz; a few have secondary garnet.

Rare alkaline dykes show considerable, probably deuteric, alteration, and include ankaramite, alkali olivine basalt, and trachybasalt. They contain clinopyroxene and, in some cases, olivine phenocrysts in a fine-grained groundmass of biotite, reddish-brown amphibole, altered feldspar (albite + K-feldspar), and abundant (8–15%) opaque minerals (magnetite, ilmenite, and rare pyrite and chalcopyrite). Most of those examined have carbonate-rich ocelli. Other alkaline dykes include lamprophyres, composed of olivine, phlogopite, clinopyroxene, and rare plagioclase, carbonate, and amphibole, and carbonatitic pyroxenites.

Late Proterozoic metamorphics

Late Proterozoic metamorphics crop out on the south side of Prydz Bay, from the Rauer Group to Landing Bluff (Fig. 2). Rocks of similar age make up most of the outcrops on the east side of the Amery Ice Shelf, northern Prince Charles Mountains (Tingey, 1981, 1982), MacRobertson and Kemp Land Coast, and the western part of Enderby Land, where they are classified as the Rayner Complex (Sheraton & others, 1980) (Fig. 1). Over nearly all this area the predominant metamorphic grade is granulite facies, and nowhere are the rocks intruded by unmetamorphosed dolerite dykes. In the Prydz Bay area, the most abundant rock types are orthopyroxene and garnet-bearing gneisses and a variety of metasedimentary rocks, and there is minor mafic granulite. Granitic intrusives crop out at several places.

Orthopyroxene-quartz-feldspar gneiss

This is only abundant in the Rauer Group and Munro Kerr Mountains. Its composition, which ranges from granite to diorite, indicates that it is largely of igneous origin, although it is commonly interlayered with garnet-bearing gneisses and rarely with metasediments (Fig. 19). Apart from orthopyroxene (up to 12%), also commonly present are small amounts of reddish-brown biotite and, in some of the more melanocratic rocks, clinopyroxene and hornblende. Much of the gneiss (tonalite and subordinate quartz diorite and diorite) contains plagioclase, but little or no K-feldspar, whereas more potassic compositions (granodiorite to granite) have abundant perthite. Common accessory minerals are apatite, zircon, and opaque oxides.

Foliated intrusive rocks crop out at many places in the Rauer Group and include orthopyroxene-clinopyroxene granite at the eastern coastal outcrops, orthopyroxene-biotite tonalite near Hop Island, orthopyroxene granodiorite on Torckler Island (Fig. 20), and orthopyroxene-clinopyroxene-fayalite granite at the southernmost coastal outcrop of the Rauer Group. At the last locality, the granite gneiss is cut by variably deformed, metamorphosed mafic dykes.

Mount Caroline Mikkelsen, Svarthausen Nunatak, and Boyd Nunatak in the Munro Kerr Mountains are largely made up of relatively homogeneous orthopyroxene-quartz-plagioclase gneiss (tonalite). Variable, but generally small, amounts of perthite, clinopyroxene, dark greenish-brown hornblende, reddish-brown biotite, apatite, zircon, and opaque minerals are also present.

CONTENTS

Front cover: Precambrian high-grade metamorphic rocks of the Vestfold Hills-Prydz Bay area, Princess Elizabeth Land, East Antarctica. The geology of these rocks is described in this issue in a paper by Sheraton & Collerson.

R81/103(6) Cat. No. 83 0273 2

Garnet-quartz-feldspar gneiss

Garnet-bearing, generally migmatitic, felsic gneiss is common throughout the Prydz Bay area, particularly in the Larsemann Hills and coastal outcrops of the Munro Kerr Mountains. It is considerably more potassic than the orthopyroxene-quartz-feldspar gneiss, but K-poor, sodic gneiss crops out locally. In many places it shows evidence of partial melting (Fig. 21). Some is clearly of intrusive origin (granite) and forms homogeneous, subconcordant layers. Such granite gneiss typically contains up to 5 per cent garnet and 2–5 per cent reddish-brown biotite; orthopyroxene is present in a few samples from the Rauer Group. K-feldspar is commonly perthitic (orthoclase or microcline), and accessory minerals comprise apatite, zircon, opaque minerals, and rare monazite. More heterogeneous, strongly layered gneiss is commonly associated with metasediments and is probably, at least in part, itself of sedimentary origin. Garnet (mostly less than 10%), biotite (up to 10%), quartz (20–45%), plagioclase (commonly oligoclase, 15–50%), and K-feldspar (perthitic orthoclase or, rarely, microcline, 25–45%) are major constituents, and small amounts of cordierite, sillimanite, or spinel may be present. A few layers are particularly garnet-rich (up to 40%). Localised retrogressive effects include alteration of feldspar, and chloritisation of biotite.

Metapelites

Aluminous metasediments are common in the outcrops between the Ranvik Glacier and Bolingen Islands, including the Svenner Islands. However, they are much less common in the Rauer Group, where the only significant rocks of probable sedimentary origin are some of the garnet-bearing gneisses described above.

Metapelites in the area southwest of the Rauer Group are characterised by the presence of abundant garnet (up to 30%), sillimanite (rarely more than 10%), and cordierite (up to 25%). Reddish-brown biotite (mostly less than 5%), quartz (typically 20–50%), plagioclase (generally less than 10, but locally up to 50%), and perthite (up to 50%) are the other main constituents, together with small amounts of green spinel (up to 2%), opaque oxides, zircon, and rare apatite, monazite, and graphite. Some metapelites in the Brattstrand Bluffs area contain coexisting spinel and quartz, although in some cases the spinel is rimmed by sillimanite or cordierite. Cordierite is locally altered to pinnite. A marked foliation defined by aligned biotite grains, and lineation by oriented acicular sillimanite crystals may be present, but the are commonly deflected around garnet porphyroblasts; there is also evidence for both earlier (inclusions in garnet) and later (randomly oriented) crystallisation of sillimanite. K-feldspar and cordierite are commonly poikiloblastic. At a number of places, such as the Bolingen Islands, metapelites are interlayered with impure quartzite (up to 85 percent quartz).

Mafic rocks

Mafic granulite is only common in the Rauer Group. It is also present in minor amounts in the Søstrene Islands–Larsemann Hills area, at Hovde Island, and in the Munro Kerr Mountains; elsewhere it is very rare.

Much of the mafic granulite in the Rauer Group represents metamorphosed mafic dykes, probable correlatives of the Vestfold Hills dolerites, although some may be remnants of the Tryne metavolcanics. Cross-cutting relationships are preserved in the northeastern Rauer Islands (Fig. 22); although the dykes are strongly folded and partly concordant, several distinct orientations are apparent (Fig. 23). Boudinaged, but not strongly folded dykes cut granitic gneiss at several places (e.g., Torckler Island and the coastal outcrop to the southeast), whereas elsewhere most mafic bodies are strongly deformed and essentially concordant (Fig. 24). Much of the granulite is rich in greenish-hornblende (15–25%) and also contains orthopyroxene (5–20%), clinopyroxene (5–15%), and plagioclase (45–60%), together with small amounts of opaque oxides (up to 3%), apatite, and, less commonly, biotite and quartz. Textures are commonly granuloblastic. Strongly deformed granulite from Filla Island contains hornblende (20–25%), reddish-brown biotite (15–20%), and quartz (about 10%), but no pyroxene. One sample (81285126) from Hop Island contains a little garnet with a reaction rim of orthopyroxene + plagioclase.

Granulite from further west is petrographically similar, although hornblende is rather less abundant (up to 15%), and biotite more so (up to 5%). Biotite flakes are commonly aligned, imparting a distinct foliation. None of the mafic granulite from this area shows evidence of derivation by metamorphism of mafic dykes, although the possibility cannot be discounted.

Ultramafic rocks are extremely rare, but hornblende pyroxenite crops out in the Søstrene Islands and a pod of olivine-orthopyroxene hornblendite in the southwest Larsemann Hills.

Granitic intrusives

Apart from the more or less foliated orthopyroxene-bearing granitoids and subconcordant garnet-biotite granite gneiss mentioned above, undeformed cross- cutting granite and pegmatite veins are common throughout most of the area from the Rauer Group to the Polarforschung Glacier. White to pink quartz-feldspar pegmatites contain small amounts of garnet, biotite, and, locally, graphite. Larger bodies of even-grained granite at Steinnes and the eastern Larsemann Hills also contain reddish-brown biotite (up to 10%) and, less commonly, garnet, in addition to quartz, oligoclase, and orthoclase.

Possibly syn-metamorphic, pink to white porphyroblastic garnet-biotite granite makes up most of the outcrops in the southern part of Amanda Bay. It is somewhat foliated, owing to the alignment of K-feldspar porphyroblasts and gneiss inclusions, and is cut by pegmatite veins. Similar granite at Brattstrand Bluffs is interlayered with garnet-biotite gneiss. The granite contains perthite (50–55%), quartz (25–35%), plagioclase (10–15%), reddish-brown biotite (2–3%), garnet (1–3%), and minor opaque minerals (magnetite, ilmenite, and rare pyrite), apatite, zircon, spinel, and monazite. K-feldspar commonly shows partial inversion to microcline (wavy extinction) and feldspar and biotite are locally rather altered.

Younger post-orogenic pinkish-grey granite crops out around Sandefjord Bay (the Landing Bluff Adamellite of Tingey, 1981) and at Vestknatten and Meknattane Nunataks (Polarforschung Granite of Tingey, 1981). A Rb-Sr isochron age of 504 ± 17 Ma with an initial $^{87}Sr/^{86}Sr$ of 0.7184 was obtained by P.A. Arriens for the Landing Bluff Adamellite (Tingey, 1981). It is a porphyritic hornblende-biotite granite containing up to 5 per cent dark greenish-brown hornblende and up to 10 per cent dark brown biotite. The Polarforschung Granite has a slightly higher proportion (40–50%) of K-feldspar (microcline perthite), poikilitic phenocrysts of which, locally, have a preferred orientation. One sample (81285399) from Meknattane Nunataks contains about 1 per cent of fayalite. A distinctive and relatively abundant

Figure 19. Folded interlayered garnet-quartz-feldspar gneiss and orthopyroxene-quartz feldspar gneiss, Torckler Island, Rauer Group.

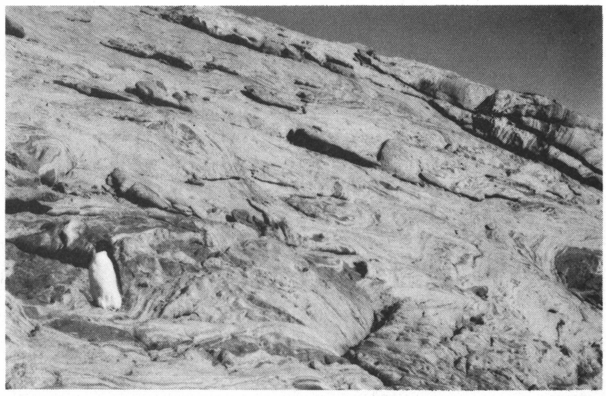

Figure 20. Partially melted orthopyroxene-quartz-feldspar gneiss, Torckler Island, Rauer Group.

Figure 21. Partially melted garnet-quartz-feldspar gneiss, Torckler Island, Rauer Group.

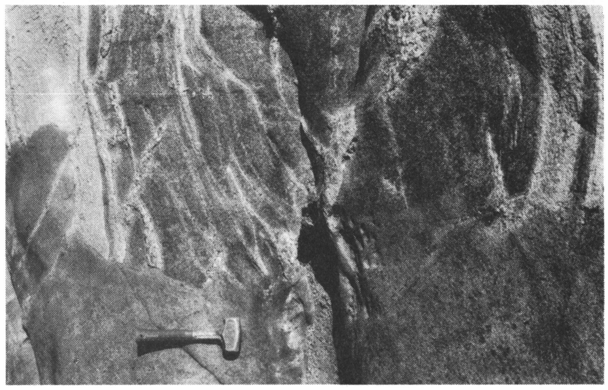

Figure 22. Intrusive relations of metadolerite dyke, Rauer Group.

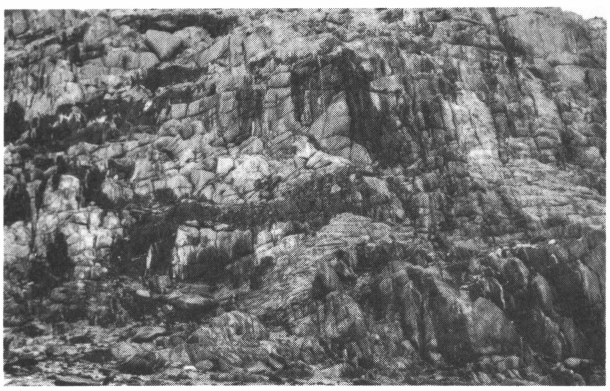

Figure 23. Partially discordant metadolerite dykes, northeastern Rauer Group.

Figure 24. Subconcordant metadolerite dykes, northeastern Rauer Group.

accessory mineral suite, common to both intrusives, comprises magnetite, chalcopyrite, pyrite, ilmenite, apatite, zircon, sphene, metamict allanite, metamict chevkinite or perrierite, and fluorite. The granite is cut by white biotite aplite veins. Tingey (1981) reported that the contact with gneiss at Meknattane Nunataks is very sharp. A xenolith of clinopyroxene-orthopyroxene-biotite-quartz-plagioclase gneiss (81285400) at that locality contains unaltered pyroxene.

Discussion and conclusions

A tentative summary of the geological history of the Vestfold Hills–Prydz Bay area is given in Table 1. Events 1 to 7, 9, 11, and 14 have been recognised in the Vestfold Block, and are largely based on Oliver & others (1982a) and Collerson & others (in press). However, the relative ages of the oldest units (1) have not been conclusively established. Both the high-Mg dykes (6) and the main suite of dolerites (9) are, petrographically, chemically, and isotopically, virtually identical to equivalent suites in Enderby Land (Sheraton & Black, 1981), but no analogues of the 1850 Ma Vestfold Block dolerites (7) have been found in the latter area. Rare alkali basalt and lamprophyre dykes (14) have not yet been dated, but, by analogy with dated alkaline intrusives in the Prince Charles Mountains (Walker & Mond, 1971; Sheraton & England, 1980; Sheraton, in press), may be of Phanerozoic age.

Rb-Sr and Sm-Nd isotopic data for gneisses from the Rauer Group indicate that only a minor proportion was derived by remetamorphism of Archaean continental crustal rocks, in spite of the general lithological similarity with Vestfold Block gneisses and the presence of metamorphosed mafic dykes (L.P. Black & M.T. McCulloch, personal communication, 1983). Most rocks have middle Proterozoic crustal formation ages (about 1600–1800 Ma), and apparently represent a younger suite of granitic intrusives (or extrusives) and subordinate semi-pelitic sediments (8). Such ages are consistent with the emplacement of abundant dolerites at about 1300 Ma, but are by no means sufficiently well constrained to show whether the gneiss precursors are predominantly older or younger than the 1850 Ma dolerites. Whereas much of the granitic orthogneiss, such as that in the southeastern Rauer Group, is cut by metadolerite dykes, there was also extensive syn-metamorphic intrusion of granitic magma. Thus, homogeneous orthopyroxene-quartz-feldspar gneiss containing xenoliths crops out at Torckler and Hop Islands, and foliated porphyroblastic garnet-biotite granite around Amanda Bay. In contrast, orthopyroxene-hornblende-quartz-plagioclase gneiss in the Munro Kerr Mountains is associated with minor mafic granulite and may predate the dolerite dykes. Geophysical (gravity and magnetic) data do not show any major change in crustal structure across the boundary between Archaean and late Proterozoic rocks (Wellman & Williams, 1982), but no data are available for the area to the southwest of the Rauer Group.

The extensive sillimanite and cordierite-bearing metapelites and associated garnetiferous gneisses of the Prydz Bay coast (10) are quite different in composition to all except a very minor proportion in the Vestfold Block and Rauer Group, and their age of deposition is not known with certainty. They were apparently not intruded by dolerite dykes (mafic granulite is very rare) and may have been deposited after the emplacement of such dykes in an older basement. Alternatively, the sediments may be older and dyke intrusion restricted to a deeper crustal level. Isotopic data indicate derivation of the metasediments from predominantly middle Proterozoic, rather than Archaean, precursors, but are consistent with weathering of middle Proterozoic rocks, such as the largely orthogneiss terrain of the Rauer Group (L.P. Black & M.T. McCulloch, personal communication, 1983). Relatively rapid deposition after dolerite dyke emplacement and before high-grade metamorphism at about 1100 Ma is our preferred interpretation. High-grade metasediments of generally similar composition and, possibly, similar depositional age crop out in the northern Prince Charles Mountains–Mawson Coast area of MacRobertson Land; greenschist-facies metasediments that postdate the emplacement of dolerite dykes in the southern Prince Charles Mountains may also be of similar age, but have a generally more calcareous composition (Tingey, 1982).

High-grade metamorphics of late Proterozoic age (1000–1100 Ma) extend for at least 2000 km west of Prydz Bay, and make up most of the northern Prince Charles Mountains and Mawson Coast of MacRobertson Land (Tingey, 1979, 1982), Kemp Land and western Enderby Land (Rayner Complex of Grikurov & others, 1976, and Sheraton & others, 1980), and Dronning Maud Land (Yoshida, 1979; Yoshida & others, 1982); slightly older ages (1300–1400 Ma) have been reported for amphibolite to granulite-facies gneisses of the Windmill Islands, 1400 km to the east (Compston & others, 1982; Oliver & others, 1982b). They are essentially coeval with metamorphics of a wide area of Gondwanaland, such as those formed during the Kibaran orogeny in southern Africa (Clifford, 1974), and the Vijayan gneisses of Sri Lanka (Crawford & Oliver, 1969). Regional correlations are discussed in more detail by James & Tingey (in press).

Gneisses of the Rayner Complex, within a few tens of kilometres of the Archaean Napier Complex in Enderby and Kemp Lands, appear on chemical and isotopic evidence, to be largely remetamorphosed Archaean rocks (Sheraton & Black, in press). In contrast, late Proterozoic gneisses in a wide area of MacRobertson Land include a high proportion with only a short previous crustal history, as well as some possibly derived from much older continental crust (Tingey, 1982). Many of the gneisses from this area were derived, either directly or by partial melting, from sedimentary protoliths (Sheraton & Black, in press). These relationships are thus analogous to those in the Vestfold Hills–Prydz Bay area, except that there Proterozoic reworking of the Archaean craton was apparently even more restricted. Furthermore, the development of relatively high-pressure (and lower-temperature) garnet + clinopyroxene-bearing assemblages in Archaean mafic rocks and Proterozoic tholeiite dykes immediately adjacent to late Proterozoic terrains has also been noted in the transitional zone between the Napier and Rayner Complexes in Kemp Land by Sheraton & others (1980). As in the southwestern Vestfold Hills, this late Proterozoic overprinting was not accompanied by major deformation, although, locally, in both the Vestfold Hills and Napier Complex garnet also crystallised in shear zones of probable similar age (Sheraton & others, 1980).

The granite at Landing Bluff is similar in age to pegmatites and granites, as well as minerals, (about 500 Ma) over wide areas of the East Antarctic Shield (Grew, 1978, 1982), notably the southern Prince Charles Mountains (Tingey, 1982) and can be correlated with the widespread 'Pan-African' orogeny (Clifford, 1974). Fayalite-bearing intrusives (including syenite, monzonite, and granite) have also been reported from Queen Maud Land and the Mirny area, and may be of similar early Palaeozoic age (Ravich & Kamenev, 1975).

Acknowledgements

The efforts of members of the Australian National Antarctic Research Expeditions at Davis were a major factor in ensuring the success of the field program on which this paper is based, and are gratefully acknowledged. Logistic support was provided by the Antarctic Division, Department of Science and Technology, Hobart. We thank N.G. Ware and K.J. Ellingsen for help with microprobe analyses, and R.J. Tingey for critically reading the manuscript.

References

Arriens, P.A., 1975 — The Precambrian geochronology of Antarctica. *1st Australian Geological Convention, Adelaide, Abstracts*, 97–8.

Clifford, T.N., 1974 — Review of African granulites and related rocks. *Geological Society of America Special Paper* 156.

Collerson, K.D., & Arriens, P.A., 1979 — Rb–Sr isotope systematics in high-grade gneisses from the Vestfold Hills, East Antarctica (Abstract). *Journal of the Geological Society of Australia*, 26, 267–268.

Collerson, K.D., Reid, E., Millar, D., & McCulloch, M., in press — Lithological and Sr–Nd isotopic relationships in the Vestfold Block: implications for Archaean and Proterozoic crustal evolution in the East Antarctic Shield. *4th International Symposium on Antarctic Earth Sciences, Adelaide, August, 1982.*

Collersen, K.D., Sheraton, J.W., & Arriens, P.A., 1983 — Granulite facies metamorphic conditions during the Archaean evolution and late Proterozoic reworking of the Vestfold Block, eastern Antarctica. *6th Australian Geological Convention, Canberra, Abstracts*, 53–54.

Compston, W., Williams, I.S., Collerson, K.D., Lovering, J.F., & Arriens, P.A., 1982 — A reassessment of the age of the Windmill Metamorphics, Casey area, East Antarctica. *4th International Symposium on Antarctic Earth Sciences, Adelaide, Abstracts*, 35.

Crawford, A.R., & Oliver, R.L., 1969 — The Precambrian geochronology of Ceylon. *Special Publication of the Geological Society of Australia*, 2, 283–306.

Grew, E.S., 1978 — Precambrian basement at Molodezhnaya Station, East Antarctica. *Bulletin of the Geological Society of America*, 89, 801–813.

Grew, E.S., 1982 — The Antarctic margin. *In* Nairn, A.E.M., & Stehli, F.G. (editors), The ocean basins and margins. Volume 6. *Plenum, New York*, 697–755.

Grikurov, G.E., Znachko-Yavorsky, G.A., Kamenev, E.N., & Ravich, M.G., 1976 — Explanatory notes to the geological map of Antarctica (scale 1:5 000 000). *Research Institute of the Geology of the Arctic, Ministry of Geology of the USSR, Leningrad.*

James, P.R., & Tingey, R.J., in press — The geological evolution of the East Antarctic metamorphic shield — a review. *4th International Symposium on Antarctic Earth Sciences, Adelaide, August, 1982.*

Oliver, R.L., James, P.R., Collerson, K.D., & Ryan, A.B., 1982a — Precambrian geologic relationships in the Vestfold Hills, Antarctica. *In* Craddock, C. (editor), Antarctic geoscience. *University of Wisconsin Press*, 435–444.

Oliver, R.L., Cooper, J.A., & Truelove, A.J., 1982b — Some petrological and zircon geochronological observations of gneisses from Herring Island, Wilkes Land and Commonwealth Bay, King George V Land. *4th International Symposium on Antarctic Earth Sciences, Adelaide (Abstracts)*, 130.

Parker, A.J., James, P.R., Mielnik, V., & Oliver, R.L., 1982 — Metamorphism and fabric development in Archaean gneisses of the Vestfold Hills, Antarctica. *4th International Symposium on Antarctic Earth Sciences, Adelaide, Abstracts*, 134.

Ravich, M.G., & Kamenev, E.N., 1975 — Crystalline basement of the Antarctic platform. *Wiley, New York.*

Sheraton, J.W., in press — Geochemistry of mafic igneous rocks of the northern Prince Charles Mountains, Antarctica. *Journal of the Geological Society of Australia.*

Sheraton, J.W., & Black, L.P., 1981 — Geochemistry and geochronology of Proterozoic tholeiite dykes of East Antarctica: evidence for mantle metasomatism. *Contributions to Mineralogy and Petrology*, 78, 305–317.

Sheraton, J.W., & Black, L.P., in press — Geochemistry of Precambrian gneisses: relevance for the evolution of the East Antarctic Shield. *Lithos.*

Sheraton, J.W., & England, R.N., 1980 — Highly potassic mafic dykes from Antarctica. *Journal of the Geological Society of Australia*, 27, 129–135.

Sheraton, J.W., Offe, L.A., Tingey, R.J., & Ellis, D.J., 1980 — Enderby Land, Antarctica — an unusual Precambrian high-grade metamorphic terrain. *Journal of the Geological Society of Australia*, 27, 1–18.

Streckeisen, A.L., 1976 — To each plutonic rock its proper name. *Earth-Science Reviews*, 12, 1–33.

Tingey, R.J., 1979 — East Antarctica — the key piece of Gondwanaland (abstract). *Journal of the Geological Society of Australia*, 26, 275.

Tingey, R.J., 1981 — Geological investigations in Antarctica 1968–1969: the Prydz Bay–Amery Ice Shelf–Prince Charles Mountains area. *Bureau of Mineral Resources, Australia, Record* 1981/34.

Tingey, R.J., 1982 — The geological evolution of the Prince Charles Mountains — an Antarctic Archaean cratonic block. *In* Craddock, C. (editor), Antarctic geoscience. *University of Wisconsin Press*, 455–464.

Walker, K.R., & Mond, A., 1971 — Mica lamporphyre (alnoite) from Radok Lake, Prince Charles Mountains, Antarctica. *Bureau of Mineral Resources, Australia, Record* 1971/108.

Wellman, P., & Williams, J.W., 1982 — Extent of Archaean and late Proterozoic rocks under the ice cap of Princess Elizabeth Land, Antarctica, inferred from geophysics. *BMR Journal of Australian Geology & Geophysics*, 7, 213–218.

Yoshida, M., 1979 — Tectonics and metamorphism of the region around Lutzow-Holmbukta, East Antarctica. *Memoirs of the National Institute of Polar Research, Tokyo, Special Issue*, 14, 28–40.

Yoshida, M., Kizaki, K., Kojima, H., Shirahata, H., & Suzuki, M., 1982 — Tectonic and metamorphic history of the crystalline rocks of Lutzow-Holm Bay, East Antarctica. *4th International Symposium on Antarctic Earth Sciences, Adelaide, Abstracts*, 185.