GLACIAL ERRATICS FROM THE BRUNT ICE SHELF, COATS LAND, ANTARCTICA

PETER D. CLARKSON

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

ABSTRACT. The petrography of igneous and metamorphic clasts comprising a collection of erratic rocks from a moraine in the hinge zone of the Brunt Ice Shelf, northern Coats Land is described. The collection is compared with other collections of erratic material from the area and their geological significance is discussed. It is concluded that the subglacial hinterland of the Brunt Ice Shelf is a metamorphic terrain, representing part of the Antarctic craton, but that other parts of Coats Land contain more diverse lithologies and may include remnants of unexposed sedimentary basins.

INTRODUCTION

The Brunt Ice Shelf lies against the Weddell Sea coast of northern Coats Land (Fig. 1). It is fed by north-westerly flow from the inland ice sheet but flow within the western part of the ice shelf swings to a westerly direction (Simmons, 1986) and the direction of movement at the British Antarctic Survey (BAS) scientific station Halley

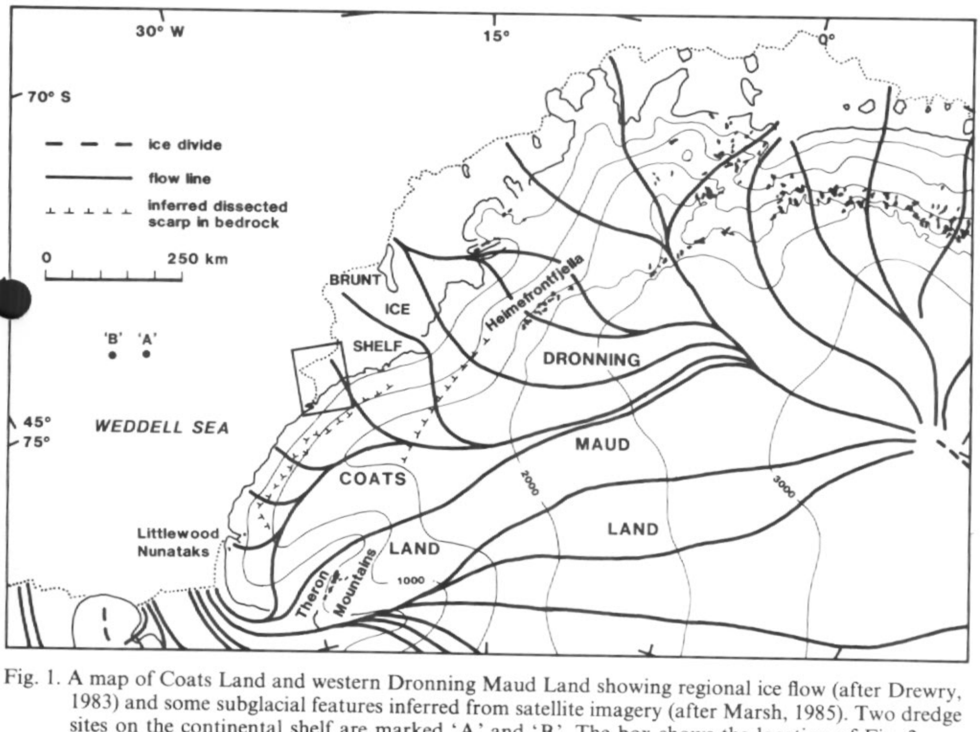

Fig. 1. A map of Coats Land and western Dronning Maud Land showing regional ice flow (after Drewry, 1983) and some subglacial features inferred from satellite imagery (after Marsh, 1985). Two dredge sites on the continental shelf are marked 'A' and 'B'. The box shows the location of Fig. 2.

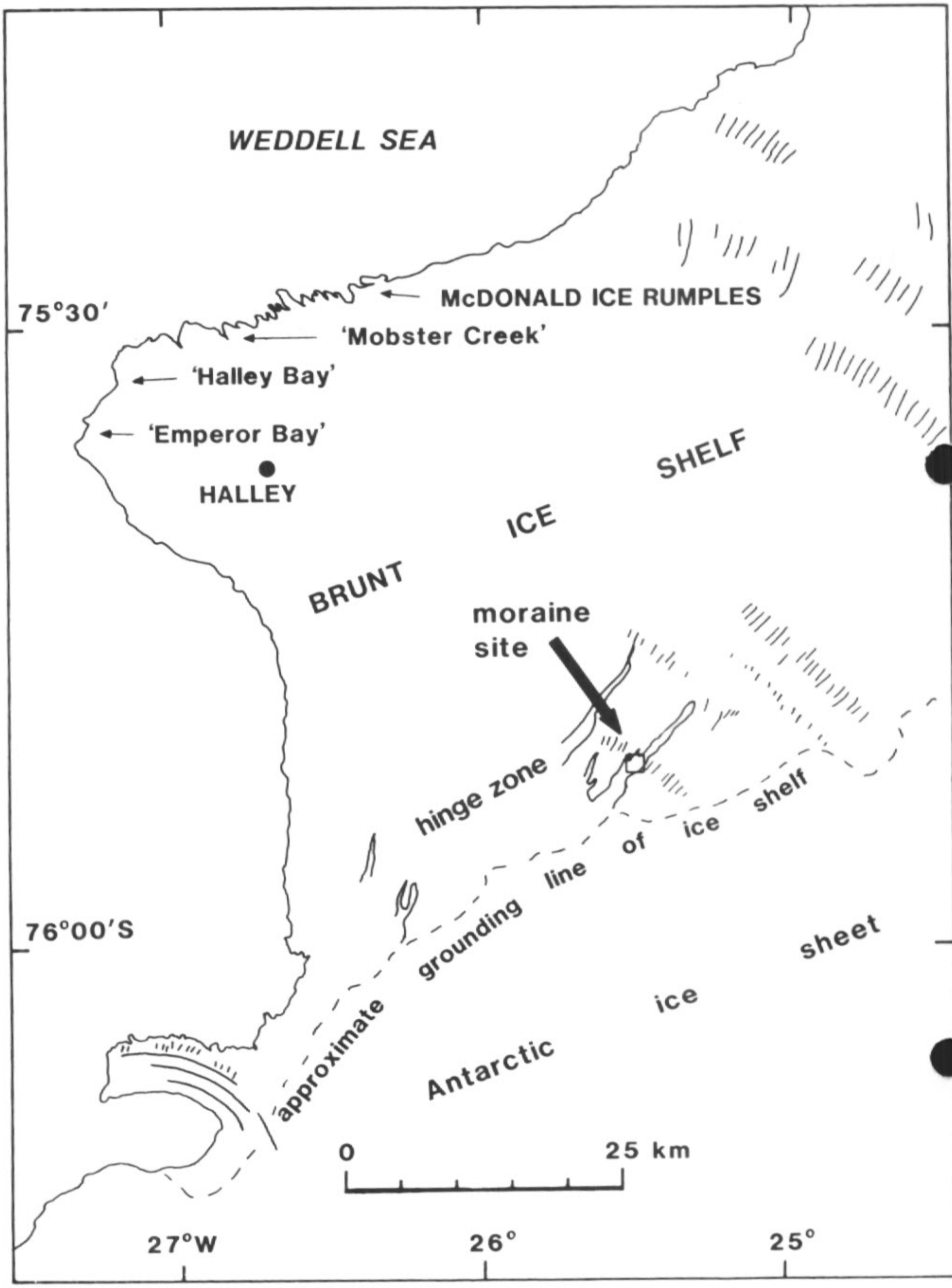

Fig. 2. A map of the western part of the Brunt Ice Shelf, derived from a 1985 satellite image, showing the location of the hinge zone moraine site and of features where other collections of erratics have been made. Unofficial place-names are shown in inverted commas. Note that the original dredge sites at the ice front in 'Halley Bay' and 'Mobster Creek' are now located beneath the ice shelf due to its westward movement.

is currently just south of west at about 742 m per annum (Simmons and Lurcock, 1988). The southern (inland) margin of the ice shelf, a severely crevassed and chaotic region known as the 'hinge zone', corresponds to the grounding line of the ice shelf. The depth of water at the ice front is believed to be about 200 m but the ice shelf is grounded at its south-western corner, where the hinge zone meets the ice front, and at the McDonald Ice Rumples (Fig. 2). The nearest exposed rocks crop out in the Littlewood Nunataks, about 300 km to the south-west, in the Theron Mountains, about 330 km to the south, and in Heimefrontfjella, about 360 km to the east.

In April 1986, a field party (P. M. Aslin and others) from Halley discovered an overturned sérac in a large rift in the hinge zone about 45 km south-east of the station. The sérac had evidently calved from the advancing ice sheet and collapsed into the rift, exposing a patch of moraine debris on an upper surface (Fig. 3). A representative collection was made of the rock types present over an area some tens of metres square. These rocks, together with some smaller collections from other parts of the area, are described here and their significance for the subglacial geology of the hinterland is discussed.

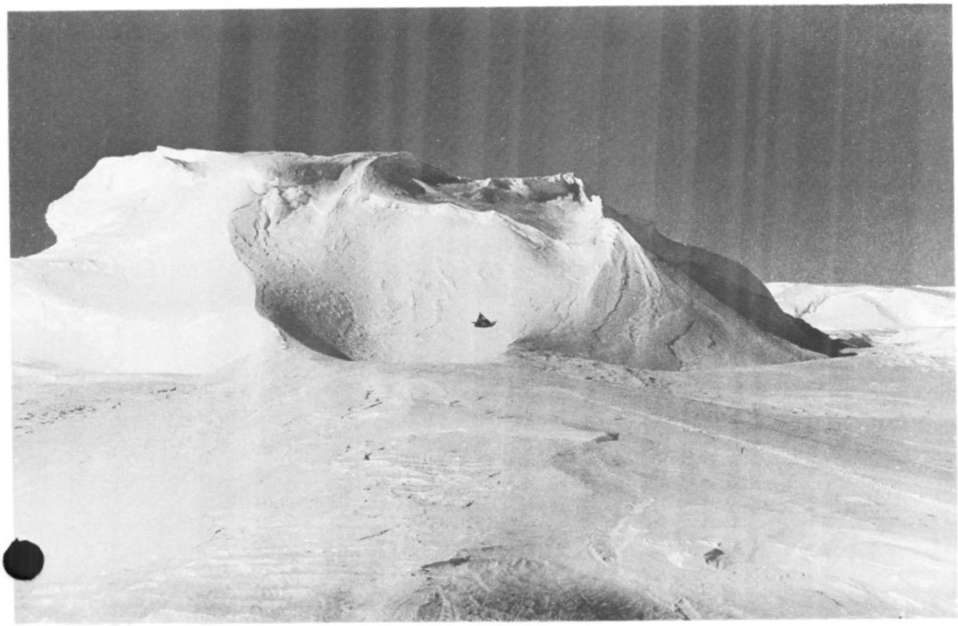

Fig. 3. The moraine site in the hinge zone of the Brunt Ice Shelf seen from the west. The motor toboggan in the ice bowl gives the scale. The main moraine site is at the right-hand end of the ridge. Photograph by P. M. Aslin.

Hinge Zone Collection

The moraine in the hinge zone is exposed along part of the ridge of an overturned sérac (Fig. 3). Several bands of moraine are visible in the ice (Fig. 4) but it appears that the central band or bands contain the largest clasts; the outer bands appear to be very fine-grained dirt bands. The central part of the moraine has melted out to a large extent, concentrating the material and allowing easy collection.

A total of 27 large (> 40 mm ø) rock fragments was extracted from bags of material collected, plus a number of pebbles (< 40 mm ø) and a residue of granules

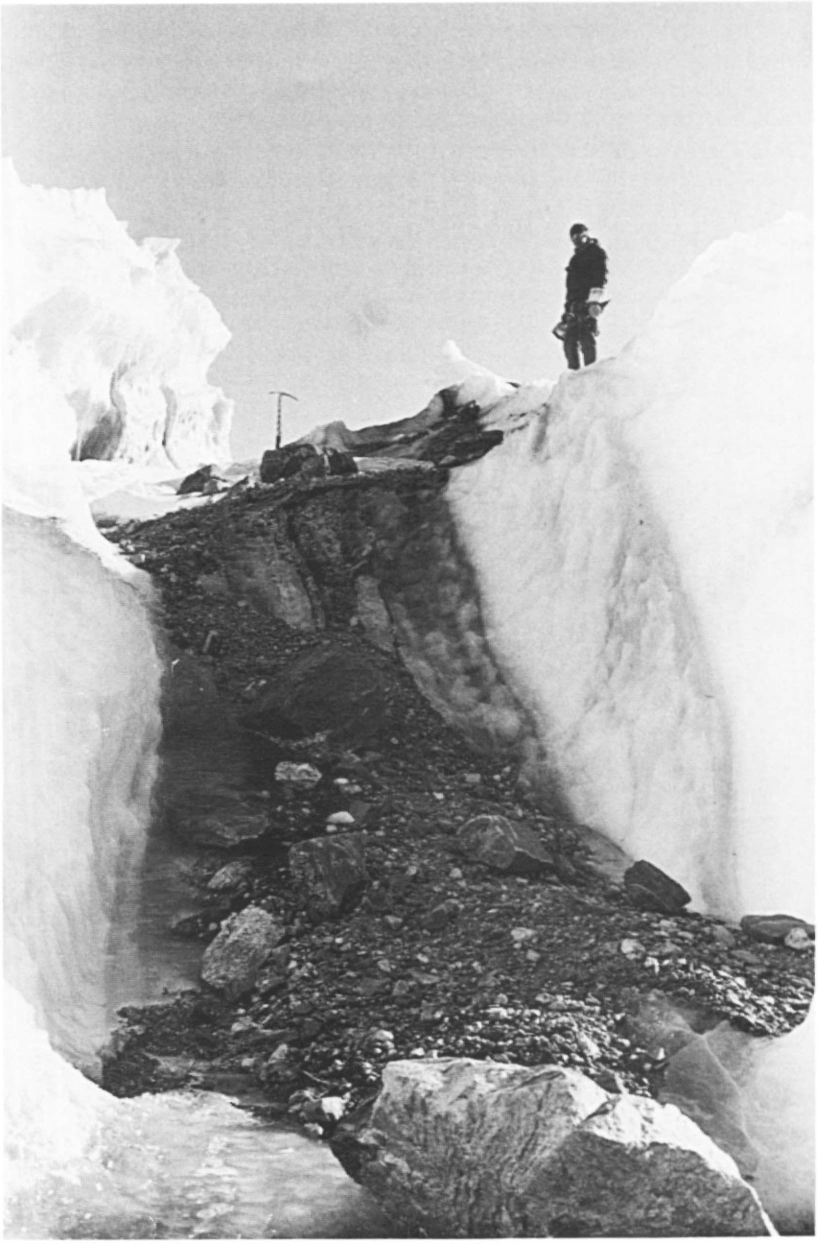

Fig. 4. The moraine site in the hinge zone. The main moraine layers have melted out along the centre of the gully. Stratified bands of moraine are visible to the right and these appear to be vertical. Photograph by P. M. Aslin.

(< 10 mm ø). The pebble lithologies can be matched with those of the rock fragments. The largest clast collected measures approximately 110 × 90 mm but boulders more than 1 m across occurred at the site (Fig. 4). Most of the fragments are angular or sub-angular but some of the smaller ones are partly rounded. One fragment (Z.1301.17) has a tabular shape with one glacially polished and striated surface. The sphericity of the clasts is generally low but shows an inverse relationship to the clast size.

Most of the larger specimens are coarse-grained and may be generally termed *granitoids* although some show a degree of gneissic foliation. Most of the smaller specimens are fine-grained and show a planar fabric.

The granitoid specimens cannot be classified unequivocally because their coarse grain-size, relative to the specimen size, means that the specimen may not necessarily be representative of the parent rock as a whole. Perthite or quartz is generally the dominant mineral phase and in only one specimen does plagioclase content exceed that of perthite. Alteration of feldspar to sericite is common and is severe in some specimens. Plagioclase is generally twinned and lies in the albite-andesine compositional range. Accessory minerals include biotite (frequently altered to chlorite), muscovite, tourmaline and opaque minerals. Quartz is generally strained and garnet is absent. One specimen (Z.1301.6) of pegmatitic appearance contains a tourmaline-bearing quartz vein and tourmaline is also present interstitially in specimen Z.1301.7. None of these rocks shows any preferred orientation of minerals such as mica.

Most other coarse-grained specimens show some degree of foliation, are garnetiferous and may be classified as *gneisses*. They are quartz-rich, potash feldspar-free and contain heavily sericitized plagioclase with muscovite, hornblende, garnet and diopside, minor zircon, tourmaline and calcite, and chlorite and opaque minerals associated with the breakdown of garnet. The mafic mineral content and the absence of potash feldspar distinguish these rocks from the granitoid specimens.

The finer-grained rocks of the collection may all be grouped as quartzo-feldspathic mica *schists*. Plagioclase (albite-oligoclase where this can be determined) is the dominant feldspar and potash feldspar may be absent. Biotite is the principal mica, although muscovite may be common, and phlogopite is dominant in one specimen (Z.1301.13). Hornblende is a major constitutent of some rocks and accessory minerals may include garnet, zircon, tourmaline, calcite and opaque minerals. Chlorite and opaque minerals also occur as alteration products of garnet and mica. Most of these rocks show compositional and textural banding parallel to a micaceous schistosity, indicating a sedimentary origin prior to metamorphism.

A second collection was made from the moraine in an attempt to find any doleritic material. This collection produced a further 29 clasts, ranging in size from 250 to 32 mm maximum dimension, comprising three granitoids, 12 gneisses, 13 schists and one volcanic clast. Except for the volcanic clast, this collection confirms the overall bimodal distribution of clasts noted earlier, bearing in mind that this was a focused collection by non-geologists. Consequently, only the volcanic clast has been included in Table I.

The volcanic clast is a fine-grained, dark grey, sub-rounded pebble 60 mm long. In thin section the rock is a plagioclase-pyroxene-phyric basalt. Plagioclase laths (up to 2 mm long) are about An_{68} and the groundmass plagioclase is rather more acidic. Pyroxene phenocrysts (up to 0.7 mm long) are difficult to determine; pink hypersthene is almost certainly present but it is not clear whether some crystals may be titaniferous augite. The groundmass is relatively fresh plagioclase, biotite, chlorite and opaque oxide. The rock appears to be a tholeiitic basalt but the limited material available precludes a conclusive classification.

Table I. Summary of clast lithologies collected

Lithology	*M*	*P*	*S*	*V*	*Q*	*rQ*	*I*	*Total*
Collection								
Hinge zone	30	29	—	1	—	—	6	66
McDonald Ice Rumples	8	47	50	28	24	18	—	175
'Mobster Creek'	2	9	—	—	2	1	—	14
Weddell Sea	—	1	7	—	2	—	—	10
Penguin crop stones	151	146	152	39	14	71	113	686
Total	191	232	209	67	42	90	119	950

Clast lithologies are indicated: M—metamorphic: P—plutonic; S—sedimentary; V—volcanic; Q—quartzite; rQ—red quartzite; I—indeterminate

These two collections of erratic rocks represent a suite of original sedimentary rocks metamorphosed to amphibolite facies under conditions of load metamorphism with no apparent deformation, a group of gneisses of probably similar metamorphic grade, a group of granitoids and a basalt. The relationships, if any, between these groups are unknown. A common factor between them, however, is the presence of tourmaline which may represent a period of boron metasomatism following metamorphism. If the tourmaline in the schists was originally detrital it is unlikely to have been derived from the tourmaline-bearing veins in the granitoids because the latter show no obvious signs of metamorphic effects, other than sericitization of feldspar and strained quartz crystals, and the lack of potash feldspar in the gneisses excludes the possibility that they are metamorphosed equivalents of the granitoids. Thus, if the first three rock groups are spatially related in the source area, the gneisses may be an equivalent of the schists and the granitoids may have been intruded late in or post-date the metamorphic episode but pre-date the boron metasomatism.

The source of the erratic material is unknown but it must lie along or close to the relevant ice sheet flow line (Fig. 1). This flow line does not pass close to any outcrops today which implies that the rocks forming this collection are most probably representative of the subglacial bedrock somewhere in the region between Heimefrontfjella and the Theron Mountains.

Regional correlation

The Theron Mountains expose a thick sequence of sub-horizontal terrestrial sandstones of the Beacon Supergroup intruded by Jurassic tholeiite sills equivalent to the Ferrar Supergroup (Brook, 1972). The base of the sequence is not exposed. In Heimefrontfjella, equivalent sedimentary rocks and lavas rest uncomformably on a metamorphic complex in the north-east (Juckes, 1972) and this complex constitutes the outcrop throughout the rest of the range (Worsfold, 1967). The lack of outcrop data and the paucity of petrological data for the erratic collection precludes any realistic attempt at regional correlation but, in particular, the apparent lack of deformation in the schists contrasts with the deformed schists known from Heimefrontfjella. The gneisses and granitoids in the erratic collection have no specific diagnostic features which might be used in correlation but similar rocks are known in Heimefrontfjella. The single basalt pebble complicates an otherwise, relatively straightforward conclusion. It is tempting to suggest correlation of the basalt with dolerites and lavas of the Ferrar Supergroup but the petrological data are too few to confirm this and the specimen is too small to allow chemical analysis. At best, it can be said that subglacial occurrences of the Ferrar Supergroup could be expected in the likely source region.

Other Erratic Collections

Other collections of erratic rock specimens from around the Brunt Ice Shelf have been examined by the author. These include glacially entrained material in an overturned 'iceberg' at the McDonald Ice Rumples, two dredge hauls at the ice front, some accidental dredged specimens from the continental shelf and a large number of emperor penguin crop stones gathered from the sea ice and the ice shelf (Table I).

During the 1977–78 summer, K. C. Lax and B. A. Gardiner (BAS) collected some material from the side of an overturned 'iceberg' at the McDonald Ice Rumples (Fig. 5). The pebble content, ranging in size from 5 to 50 mm, includes red- and pale-coloured quartzites, and sedimentary and volcanic clasts, in addition to plutonic and metamorphic clasts similar to those in the hinge zone collection. The opinion of Lax (pers. comm.) was that the 'iceberg' was part of the ice shelf and not a grounded iceberg from farther along the coast. The source of this material is problematical. Original ground moraine from the ice sheet would have been lost by bottom melting of the ice shelf. The ice front is also in a bottom-melting thermal regime so that incorporation of sea-floor sediment, where the ice shelf is grounded at the McDonald Ice Rumples, would be unlikely. In addition, it is likely that the grounded ice shelf will have scoured clear any unconsolidated sea-floor sediment. Furthermore, the diversity of lithologies is probably too great to represent a seabed outcrop where the ice shelf

Fig. 5. A view of the 'iceberg' in the McDonald Ice Rumples showing the site of the erratic material. Photograph by K. C. Lax.

is grounded. The hinge zone collection was made approximately upstream of the McDonald Ice Rumples so that a comparable lithological distribution would be expected if both collections were derived from the same source area. The greater variety of rock types in the McDonald Ice Rumples collection suggests, therefore, a different source area to the hinge zone moraine. It is possible that the material collected in the McDonald Ice Rumples was carried within the ice sheet, well above the basal moraine, possibly having been derived where the ice sheet flowed across a subglacial escarpment (Fig. 1). Exposure near the ice front could then have been achieved either by fracture and overturning or thrusting in the ice shelf as it grounded. It is not possible to discriminate positively between these different hypotheses and the source of the material exposed in the McDonald Ice Rumples must remain conjectural.

Hamilton (1965) described a sample of bottom-sediment collected with a Petersen-type grab through an ice crack in 'Halley Bay' during 1962. No rock fragments were mentioned but an analysis of the heavy mineral grains present indicated derivation of the sediment from a predominantly metamorphic source terrain.

Another dredge haul, made in 1975 at 'Mobster Creek' (Fig. 2), yielded 14 pebbles up to 20 mm in diameter. Several of these pebbles are granitoid in appearance and some show a degree of foliation. Of the remainder, two are quartzites, one is a 'red' quartzite, two are quartz vein material and two small barnacle- and bryozoan-encrusted pebbles are indeterminate. Thus, the collection bears comparison with an assemblage derived from a metamorphic terrain.

In February and March 1978, during the International Weddell Sea Oceanographic Expedition (IWSOE) 1978 (Foster and Middleton, 1978), G. Griffiths of the Institute of Oceanographic Sciences (pers. comm.) collected erratic pebbles caught on drag chains during instrument recovery operations. Four pebbles recovered from each of two sites at the shelf break ('A' and 'B', Fig. 1) were sectioned and are described here for the first time. The pebbles from Site 'A' (74° 37′ S, 35° 52′ W) comprise one quartzite, one granitoid and two quartz sandstones; those from Site 'B' (74° 25′ S, 37° 43′ W) comprise three quartz wackes and one quartzite. None of these pebbles is sufficiently distinctive to permit correlation with any known exposed rocks. The quartz sandstones and quartzite, being coarse-grained and feldspar-free, are distinct from the fine-grained arkosic sandstones of the Beacon Supergroup exposed in the Theron Mountains (Brook, 1972) although the quartz wackes, containing minor feldspar and various heavy minerals, could be comparable. The dominantly sedimentary nature of this collection contrasts with the collection from the Brunt Ice Shelf region. The pebbles almost certainly melted out from the bottom of an iceberg but, as some Weddell Sea icebergs are known to originate far to the east around the continental margin, the source of these pebbles must remain unknown.

The only other evidence of the sea-floor geology in the area comes from crop stones carried by emperor penguins. These were collected between November 1957 and January 1959 by D. G. Ward and other members of the Royal Society IGY (International Geophysical Year) Expedition but they have not been previously described. Data on the collection of these 'stones' are sparse; some were collected on the sea ice in 'Emperor Bay', some on the ice shelf near the expedition base. Some pebbles described as 'chick vomit stones' were presumably seen being regurgitated. The pebbles are all small, generally ranging in size between 5 and 20 mm maximum dimension, the largest measuring 40 mm in its maximum dimension. The majority of the lithologies present are comparable with those recorded in the other local collections but in addition there are some red quartzites and greenish volcanic clasts.

The provenance of all these crop stones is less certain. Emperor penguins are known to dive to depths in excess of 200 m (Kooyman and others, 1971) which places the sea-floor around the Brunt Ice Shelf within their diving range. However, they probably have a considerable foraging range while they are feeding their chicks and, during the winter, the female may walk many kilometres after laying her egg before finding a crack in the sea ice giving access to the water. In late summer, the birds spend their time at sea amid the pack ice, building their food reserves for the winter. During this period they are likely to be in depths of water where the sea-floor is well beyond their diving range. The nearest shoreline, where beach pebbles might be collected, is in the James Ross Island area at the northern end of the Antarctic Peninsula, 1650 km to the north-west. Thus the specimens collected in this way are almost certainly representative of the sea-floor of the continental shelf in the region of the Brunt Ice Shelf although some pebbles could have been collected from farther along the coast and, consequently, could partly reflect a wider source region than the other collections described earlier.

Anderson and others (in press) described piston-cored shelf sediments from close to the coast of Coats Land to north and south of the Brunt Ice Shelf. The pebble content of the core to the north of the ice shelf is entirely igneous, comprising basalt, dolerite and andesite clasts; to the south, the assemblage is similar but it also includes plutonic, sedimentary and metamorphic clasts. Close inshore to the south, near Littlewood Nunataks, pebbles in the core are predominantly igneous with some metaquartzites and amphibolites, whereas the coarse sand fraction comprises approximately equal amounts of igneous, metamorphic and sedimentary rock fragments. Igneous clasts could be expected close to the Littlewood Nunataks where igneous rocks are exposed (Aughenbaugh and others, 1965; Marsh and Thomson, 1984) and also north of the Brunt Ice Shelf where the relevant ice flow will have scoured the known igneous rocks in Heimefrontfjella (Juckes, 1972) but andesite is not known in outcrop. Thus, the pebbles of the cored samples are comparable with the penguin crop stones both in terms of the variety of lithologies represented and the likely areas of collection. Only the distinctive red-coloured quartzites noted in the penguin collections are not specified by Anderson and others, (in press) who gave no detailed descriptions of the lithologies recovered. Anderson and others (in press) concluded that the hinterlands of the southern and eastern Weddell Sea coasts must include some remnants of Mesozoic basins which are nowhere exposed. This conclusion is supported by the penguin collection which was probably made over a similarly wide geographical range to the spread of the piston core sites but, the more localized collection made in the hinge zone indicates only an essentially metamorphic terrain with granitoid intrusions.

Conclusions

The rocks collected in the hinge zone of the Brunt Ice Shelf comprise metamorphic and igneous rocks, suggeting that the subglacial bedrock upstream along the relevant ice flow line in Coats Land is an essentially metamorphic terrain intruded by granitic plutons. As such, it is probably representative of the Antarctic craton but correlation with known exposures is not realistic. Other collections made in the region of the Brunt Ice Shelf show an increasing diversity of lithologies with increasing distance from the grounding line. This diversity of lithologies probably reflects derivation from multiple source regions. These collections may lend support to the suggestion of Anderson and others (in press) that there are unexposed remnants of Mesozoic sedimentary basins beneath the ice sheet in Coats Land.

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