REPORTS ON ANTARCTIC FIELD WORK

GEOLOGY OF HUGO ISLAND, QUINTANA ISLAND, SOOTY ROCK, BETBEDER ISLANDS AND PARTS OF THE BISCOE AND OUTCAST ISLANDS

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This report describes field work carried out by the authors between 27 November and 22 December, 1983 in the area between Anvers and Adelaide islands (Fig. 1). The work was carried out from RRS *John Biscoe* and it formed the major part of a ship-supported programme of geological landings. The principal objectives of the programme were to visit and map coastal exposures that had been visited only briefly before or not at all, to return to previously visited areas and continue specific aspects of the geology there and to make gravimetric readings on rock at as many localities as possible. As the areas to be visited were also poorly known biologically, the opportunity was taken to make a census of nesting birds and to collect plant samples.

Although rapid-survey tactics were adopted, using spot localities of detailed information to infer the geology over wide areas, they were an effective method of mapping, for two reasons: (i) the rocks are mainly plutonic and largely homogeneous except at their margins; landings, therefore, were concentrated at plutonic contacts; (ii) a tide line some 1–2 m high surrounds most of the islands, providing roughly continuous exposure, which was examined by eye or using binoculars, usually from a distance of about 25 m. This method enabled gradational lithological variations to be assessed, and sampled.

PREVIOUS WORK

With the exception of the Outcast Islands, which were mapped and described in detail by Hooper (1962), all the remaining areas examined were poorly known or unknown geologically. Observations by Goldring (1962) and Curtis (1966) were restricted to the eastern and southern periphery of the Biscoe Islands and the Graham Land mainland. Holtedahl (1929) described gabbro on a small island close to Hugo Island and his samples were later described by Barth and Holmsen (1939).

SEDIMENTARY AND VOLCANIC ROCKS

(*1*) *Biscoe Islands*

Sedimentary and volcanic rocks crop out at several localities (Figs. 2–4). With the exception of a specimen containing microfossils (radiolaria and sponge spicules; JB . 626 . 1) and one exhibiting the trace fossil *Chondrites* (JB . 624 . 6A), the rocks are apparently unfossiliferous. The outcrops are described together here for convenience of description but it is not known whether they are time-equivalent. The volcanic rocks are presumed to be part of the Antarctic Peninsula Volcanic Group of Jurassic–Tertiary age (Thomson and Pankhurst, 1983), whereas the sedimentary sequences indicate the former presence of a widespread fore- or possibly intra-arc basin or series of basins coeval with the volcanism.

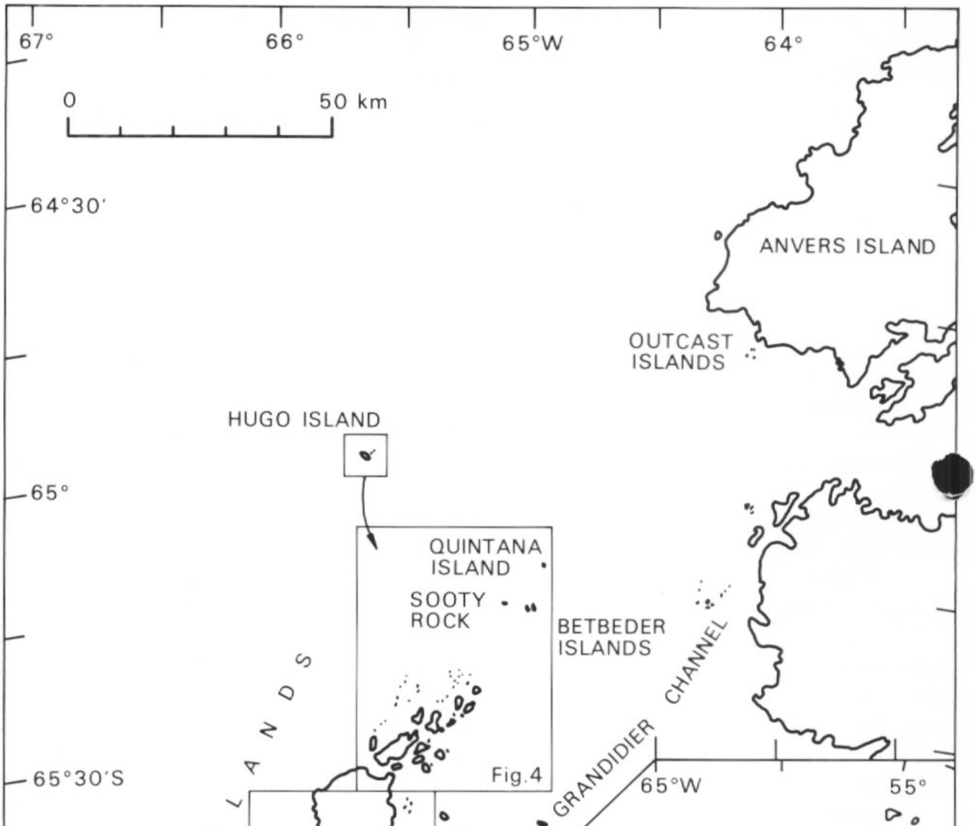

Fig. 1 Sketch map of the Biscoe Islands and their location (inset).

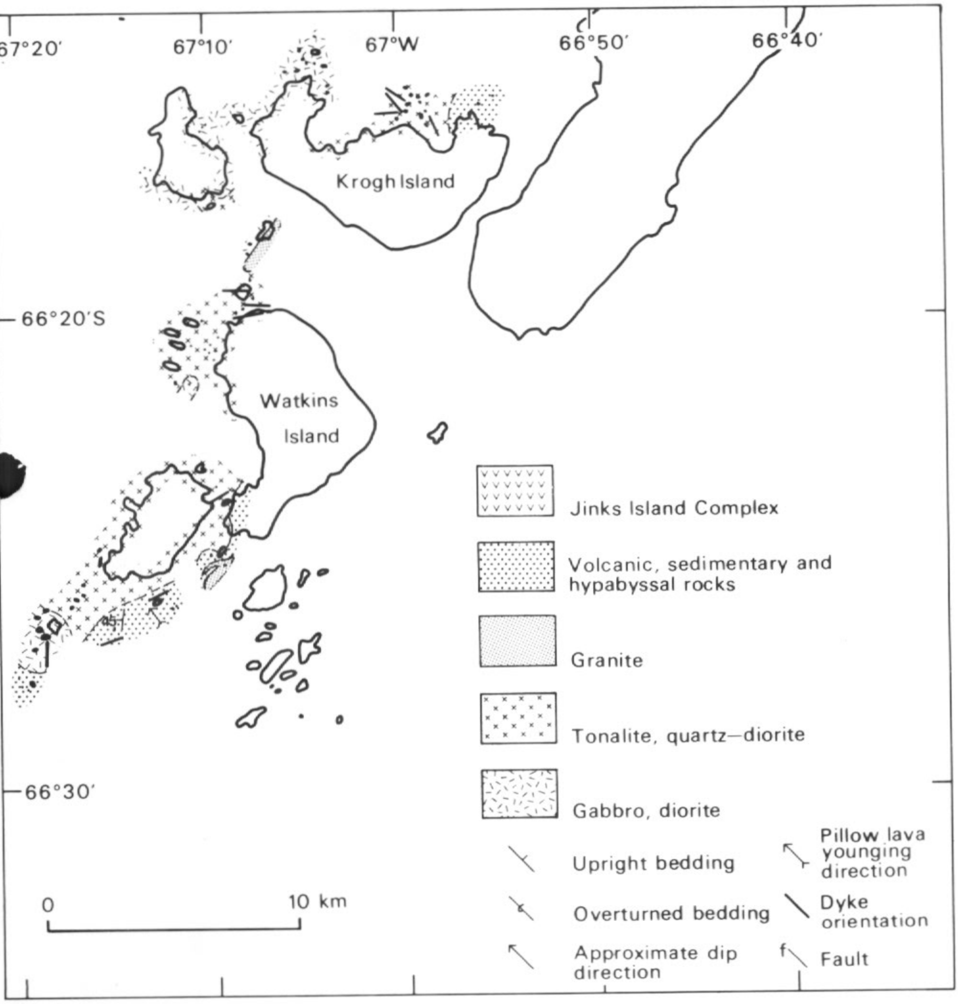

Fig. 2. Geological sketch map of the southern Biscoe Islands; the legend applies to Figs 2–4.

The commonest rocks are massive, disorganized, polymict agglomerates, lapillistones and tuffs that rarely fill shallow channels. Possible accretionary lapilli were recorded at two localities (JB.622, 638). Beds vary in thickness from *c.* 15 cm to a few tens of metres. These rocks are often interbedded with undoubted water-lain sediments and a similar origin for them is likely, possibly by deposition as debris flows although, where they occur in isolation, a subaerial pyroclastic origin cannot be discounted. Cryptically bedded and variably welded to non-welded varieties of (?) dacitic ash-flow tuffs are common in the Pitt Islands (Fig. 4).

Poorly stratified, fine- to very coarse-grained volcanic sandstones and granule conglomerates with a prominent bed-parallel purple, brown and green coloration, are common at several localities. Sedimentary structures other than parallel lamination are rare. The sediments are clearly water-lain and they probably represent traction sedimentation deposits laid down under fluctuating, high-energy conditions, possibly from sandy-gravelly high density turbidity currents. Continuous even-bedded

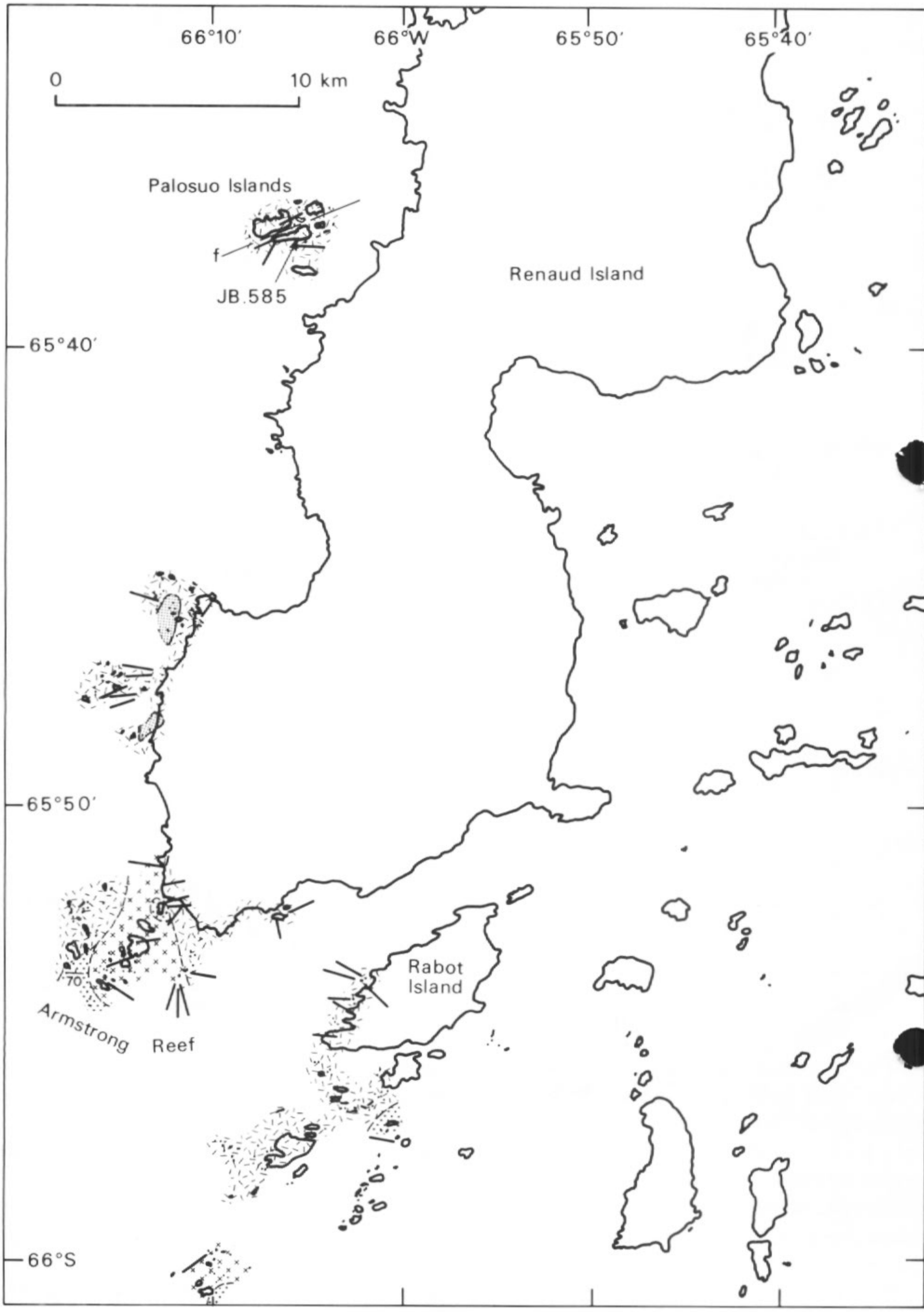

Fig. 3. Geological sketch map of the central Biscoe Islands.

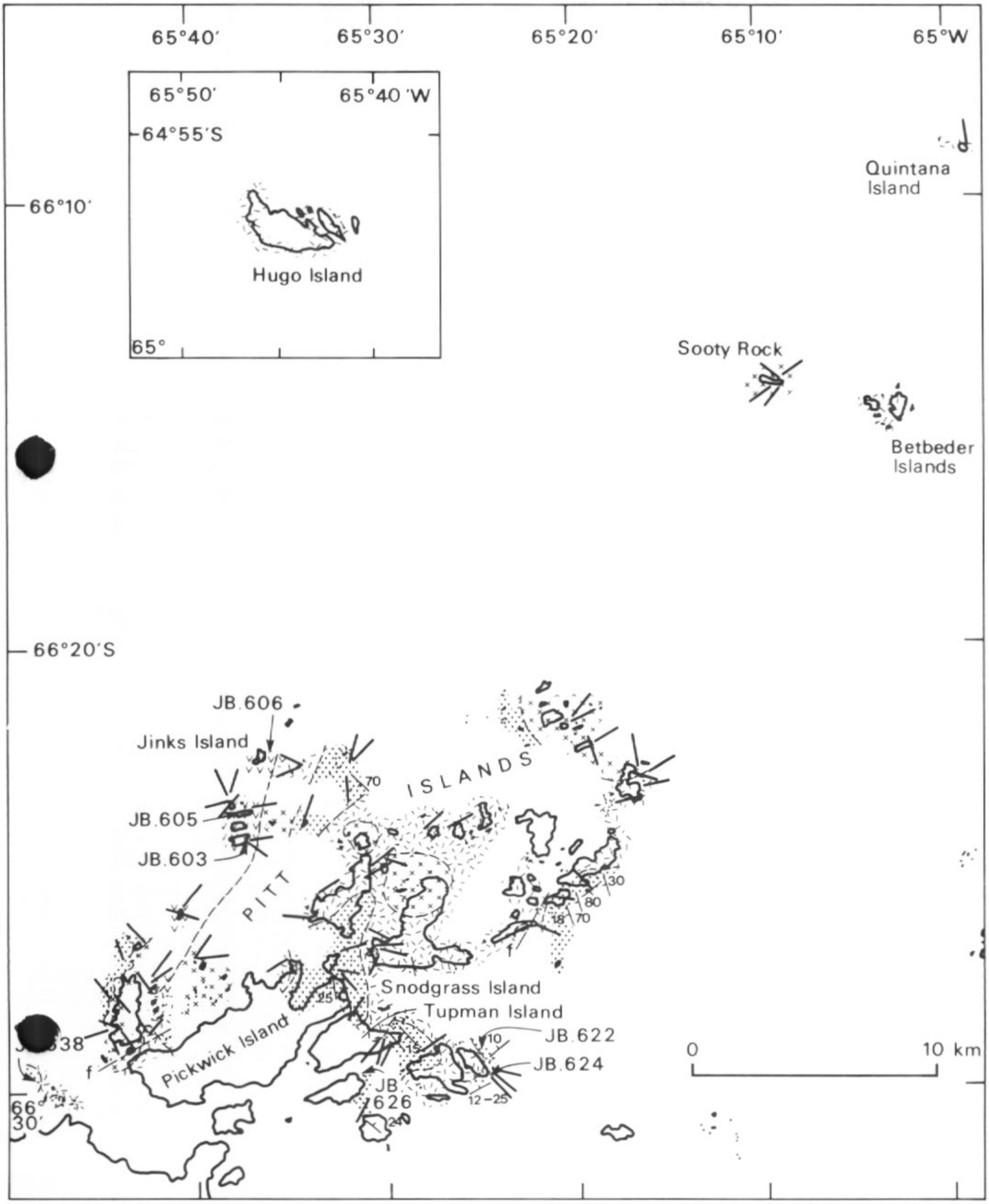

Fig. 4. Geological sketch map of the northern Biscoe Islands, including the Pitt Islands, and outlying islands farther north.

sequences of thin-and thick-bedded sandstone–siltstone–mudstone strata are also present at many localities and these show a variety of sedimentary structures which are consistent with an interpretation as classic proximal turbidities. Unusual red and cream-coloured sediments at station JB . 626 were found to be indistinguishable from the other sediments in thin section.

Massive, brecciated and (rare) pillowed basic lavas and occasional hyaloclastites are interbedded with the sedimentary sequences at many places and the majority were clearly emplaced subaqueously. Hypabyssal intrusions are very common and, in the absence of primary features, are often difficult to distinguish from massive lavas. Some may represent highly eroded volcanic necks. They are predominantly basic to intermediate in composition but rare dacitic porphyries and fine-grained felsites also occur, particularly in the Pitt Islands. Some 200 dyke orientations were measured and these indicate a polymodal distribution with slight to pronounced maxima corresponding to east-north-east, east and south-east directions.

(2) *Outcast Islands*

Brief landings were made at three localities in order to test an hypothesis that the penetrative deformation of volcanic country rocks noted by Hooper (1962) may have formed in a shear zone similar to those affecting granitic intrusions in eastern Palmer Land (Meneilly, 1983). Insufficient time was available to test rigorously this hypothesis but the overall impression gained, supported by a limited number of structural measurements, was that the relationships described by Hooper (1962) are substantially correct. We concur with his interpretation that the forcible intrusion of tonalite was responsible for the progressive increase in metamorphism and intensity of deformation seen in the volcanic country rocks. However, these rocks are water-lain contrary to the impression given by Hooper (1962) of a predominantly pyroclastic sequence.

Plutonic Rocks

Plutonic rocks are volumetrically dominant throughout the area visited and comprise essentially gabbroic or dioritic types with subordinate intermediate and rare acidic varieties. Field terms only have been applied as many outcrops display heterogeneities that defy simple classification. Where contacts are visible, it is common to find the more evolved rock intruding the less evolved. In addition, many outcrops display gradational boundaries, particularly between the more basic varieties. Contacts with volcanic rocks are exposed in the Palosuo Islands and Armstrong Reef (Fig. 3). Extensive hornfelsing is evident and, towards the contact, a migmatitic zone up to 20 m across is developed (Fig. 5). No true contact was observed but a narrow (1–5 m) zone of very fine-grained, possibly mylonitic material marks the transition from country rock to pluton. The migmatite zones are believed to be high level features associated with the intrusion of hot, wet magmas. A similar nebulitic migmatite was observed north of Snodgrass Island (Pitt Islands) but appears to occur between two plutons.

Numerous, diverse textures were observed, many plutons showing a combination of these features, or displaying them only in limited areas or zones. Eight major textural varieties were identified. *Homogeneous rocks* include those showing no evidence of variation, and those with a crude or faint mineral alignment. *Dispersed microgranular enclaves* are very common in most outcrops, usually dispersed randomly and with no discernible indication of origin; they may represent either cognate enclaves or xenoliths. *Abundant microgranular enclaves* are distinguished by their restriction to narrow zones or areas within plutons, but are otherwise comparable to the dispersed microgranular enclaves. *Disrupted syn-plutonic dykes* are represented by narrow linear zones of abundant microgranular enclaves; typical and distinctive features include lobate margins to the enclaves, often with re-entrant angles, and inclusions of host rock indicating that the host was incompletely crystallized at the time of dyke

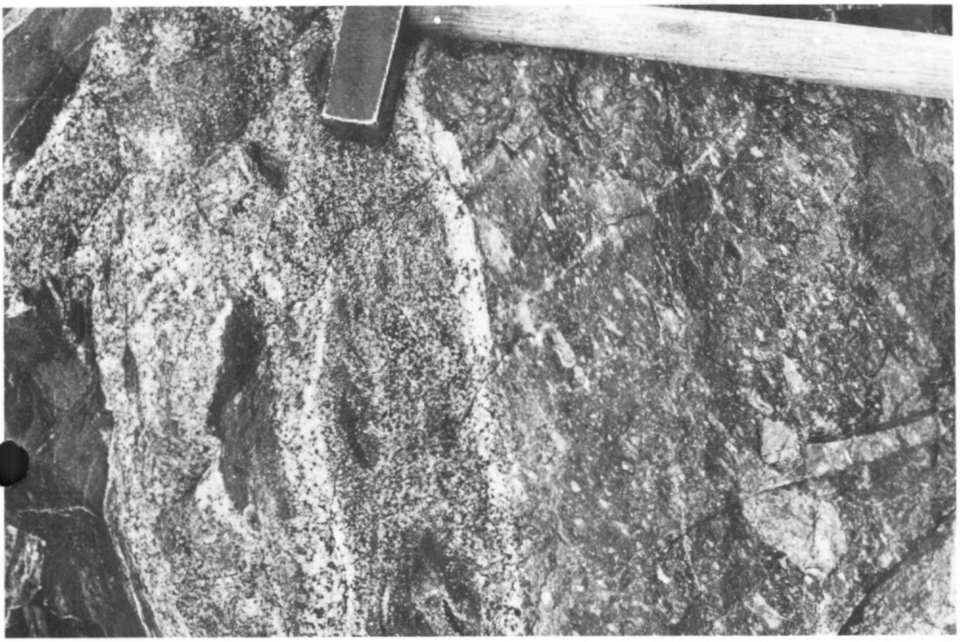

Fig. 5. Locality JB.585, Palosuo Islands. A block of sheared volcaniclastic agglomerate (right) with neosome material (left) in a migmatitic zone at the contact between a gabbronorite and volcanic rocks. Hammer head is approximately 15 cm long.

intrusion. *Grain size or modal variation* occurs typically in the more basic rocks with cumulate texture and varies from diffuse to well-defined layering in many gabbro outcrops. Although cross-lamination and channel-like features were observed, these are at high angle and are evidently contact effects related to the margins of intrusions. *Breccias* occur in zones usually less than 10 m wide. They contain angular blocks of coarser and/or more basic material set in a fine felsic matrix suggestive of auto-brecciation; some breccia blocks are layered. *Schlieren* are indistinct, wispy curvilinear inclusions that may occur isolated or in well-defined zones up to 10 m across; they are generally more mafic and/or fine-grained than the host and appear to represent a more ductile deformation than do the breccia zones. *Orbicules* up to 20 cm across are developed only locally within gabbroic rocks, occurring singly or in zones. The orbicules probably resulted from localized diffusion gradients within a slowly cooling pluton.

At two localities (north of Tupman Island and north-west of Pickwick Island, Pitt Islands), gabbros show a cyclic repetition of many of the textural features described above.

Jinks Island Complex

The informally named Jinks Island complex occupies a linear zone at least 1 km wide extending some 10 km in a north-north-east direction on the west side of the Pitt Islands (Fig. 4). Outcrops characteristically comprise a pale-coloured tonalitic or granodioritic host with abundant large (up to 3 m) rounded enclaves of finer-grained basic rock (Fig. 6). The enclaves form up to 40% of the outcrop and show superbly displayed pillow structures with lobate and crenulated margins indicative of magma mixing; some basic dykes were demonstrably disrupted *in situ* to produce enclave

Fig. 6. Locality JB.606, Jinks Island, showing the characteristic appearance of the 'Jinks Island complex' in outcrop. Note the large enclave (centre) with lobate margins suggestive of liquid–liquid contact, and the variation in size and shape of the basic enclaves and the degree of interaction with the host. Hammer shaft is approximately 25 cm long.

zones. The majority of enclaves do not appear to be compositionally distinct from the host rock, representing finer-grained equivalents of it with a higher modal content of mafic minerals; they often retain an acicular texture despite recrystallization (stations JB.603 and 605). The generally fine to medium grain-size suggests a high level of mixing, possibly in a subvolcanic magma chamber.

Gas Pneumatolysis Structures

At many localities, particularly in the Pitt Islands, the plutonic rocks are cut by dark-coloured anastomosing fractures which locally coalesce to form cataclasite zones a few millimetres in width. As the intensity of fracturing increases, the rocks become brecciated with minor relative displacement. Associated phenomena that also affect the volcanic country rocks are dyke-like intrusions, up to 0.2 m wide, that contain cataclasite and rounded to angular polymict rock fragments. In none of these areas is there any sign of shearing or penetrative deformation of the host rocks or fragments and it is likely that the fracturing and transport of material is due to pneumatolysis associated with volcanic activity.

Discussion

The islands along the western seaboard of the Antarctic Peninsula between Anvers and Adelaide islands, are composed of a number of igneous rock types believed to be the equivalents of the Antarctic Peninsula Volcanic Group and the Andean Intrusive Suite of the Antarctic Peninsula itself. The area contains a number of unusual relationships between these two groups of rocks that are not commonly observed. For example, the intrusion of gabbroic and dioritic rocks into a volcanic envelope, with localized migmatization of the latter, has not been described previously in any part of the peninsula, and it indicates that the plutons were intruded to a very high structural level within the crust. This is corroborated by the high proportion of hypabyssal rocks at some outcrops, representing perhaps the eroded roots of volcanic necks. In addition, magma mixing in a subvolcanic magma chamber is represented by the Jinks Island complex, and may be the triggering mechanism for volcanic eruptions. The abundant pneumatolysis of many rocks may result from degassing of crystallizing magma chambers at a high level.

The volcano-sedimentary sequences are evidence for an extensive fore- or possibly intra-arc basin (or series of basins) that has likely correlatives in the South Shetland Islands (Smellie, 1980), the Davis Coast (BAS unpublished data), Adelaide Island (Dewar, 1970) and Alexander Island (Taylor and others, 1979; Butterworth, 1985) although the relative ages and relationships of these different sequences are largely unknown. Unlike these areas, however, the rocks exposed in the Biscoe Islands have preserved evidence of their relationship with associated volcanic and plutonic arc products.

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References

Barth, T. F. W. *and* Holmsen, P. 1939. Rocks from the Antarctandes and the Southern Antilles. Being a description of rock samples collected by Olaf Holtedahl 1927–1928, and a discussion of their mode of origin. *Scientific Results of the Norwegian Antarctic Expeditions 1927–1928 and 1928–1929*, No. 18, 64 pp.

Butterworth, P. J. 1985. Report on Antarctic field work. Sedimentology of Ablation Valley, Alexander Island. *British Antarctic Survey Bulletin*, No. 66, 73–82.

Curtis, R. 1966. The petrology of the Graham Coast, Graham Land. *British Antarctic Survey Scientific Reports*, No. 50, 51 pp.

Dewar, G. J. 1970. The geology of Adelaide Island. *British Antarctic Survey Scientific Reports*, No. 57, 66 pp.

Goldring, D. C. 1962. The geology of the Loubet Coast, Graham Land. *British Antarctic Survey Scientific Reports*, No. 36, 50 pp.

Holtedahl, O. 1929. On the geology and physiography of some Antarctic and sub-Antarctic islands. *Scientific Results of the Norwegian Antarctic Expeditions 1927–1928 and 1928–1929*, No. 3, 172 pp.

Hooper, P. R. 1962. The petrology of Anvers Island and adjacent islands. *Falkland Islands Dependencies Survey Scientific Reports*, No. 34, 69 pp.

Meneilly, A. W. 1983. Report on Antarctic field work. Deformation of granitic plutons in eastern Palmer Land. *British Antarctic Survey Bulletin*, No. 61, 75–9.

Smellie, J. L. 1980. The geology of Low Island, South Shetland Islands, and Austin Rocks. *British Antarctic Survey Bulletin*, No. 49 (for 1979), 239–57.

Taylor, B. J., Thomson, M. R. A. *and* Willey, L. E. 1979. The geology of the Ablation Point–Keystone Cliffs area, Alexander Island. *British Antarctic Survey Scientific Reports*, No. 82, 65 pp.

THOMSON, M. R. A. *and* PANKHURST, R. J. 1983. Age of post-Gondwanian calc–alkaline volcanism in the Antarctic Peninsula region. (*In* OLIVER, R. L., JAMES, P. R. *and* JAGO, J. B. *eds. Antarctic earth science.* Canberra, Australian Academy of Sciences and Cambridge, Cambridge University Press, 328–33.)

GEOLOGICAL OBSERVATIONS ON RUGGED ISLAND, SOUTH SHETLAND ISLANDS

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Although Rugged Island, situated about 3 km west of Livingston Island, South Shetland Islands (Fig. 1), was undoubtedly well known to the numerous sealers who visited the islands in large numbers between 1820 and 1822, there is no published record of geological or other scientific investigations of the island. Araya and Hervé (1966) suggested that an extension of the fossiliferous marine clastic sequence (sandstones, conglomerates and volcanic breccias) exposed on Byers Peninsula nearby may crop out on Rugged Island. However, the striking topographical similarity between this island (Fig. 2) and north-western Ray Promontory (Byers Peninsula), which is formed of early Cretaceous, thick-bedded (?) vent agglomerates, led Smellie and others (1980) to suggest a lithological correlation with the agglomerates.

Rugged Island was visited briefly on 24 December 1983, during a ship-supported programme of geological landings from RRS *John Biscoe* (Smellie and others, in press). The island was circumnavigated by small boat at an average distance from the shore of a few hundred metres; visibility was good but there was a heavy swell. Opportunistic landings were made at two localities on the north and east coasts in order to confirm observations made from the boats and to collect more detailed information. The general description that follows is based on these field observations and also a petrographical examination of representative rock specimens.

General Description

The dominant rock type appears to be olive-green to khaki-brown monomict agglomerate (Fig. 1) formed of feldspar-phyric lava clasts with prominent large pyroxene and olivine phenocrysts (JB . 642 . 2). The agglomerates form massive, unsorted beds up to 35 m thick dipping gently ($\leqslant 10°$) in a variety of directions. Substantial homoclinal units of agglomerate strata are frequently separated, by planar bedding-parallel surfaces, from superseding agglomerate beds that dip in a markedly different direction, lending the appearance of an angular unconformity (cf. Smellie and others, 1980, fig. 4). These unconformities, which are particularly well seen along the south coast, are probably non-erosional in origin and can be attributed to changes in the location of the contemporaneous eruptive centres. Quaquaversal bedding orientations at the south-western tip of the island suggested the former presence of a minor vent there. The rocks have a massive, almost lava-like appearance but clastic textures can usually be discerned when the rocks are examined closely and there is often faint to pronounced stratification caused by variations in the dominant clast-size; clasts range up to 30 cm in diameter. A 17-m-thick sequence of thin-bedded (1–3 m) feldspar–phyric lavas containing numerous tiny olivine and pyroxene phenocrysts (JB . 642 . 1) crops out near station JB . 642. Each lava consists of a massive, greenish-grey centre flanked on either side by thick piles of scoriaceous debris which are reddened but have not developed true boles; the vesicles are infilled by white, fibrous zeolite. All the rocks are cross-cut by a few khaki-brown, fine-grained feldspar–pyroxene–phyric dykes (JB . 642 . 3), which are lithologically very similar to the

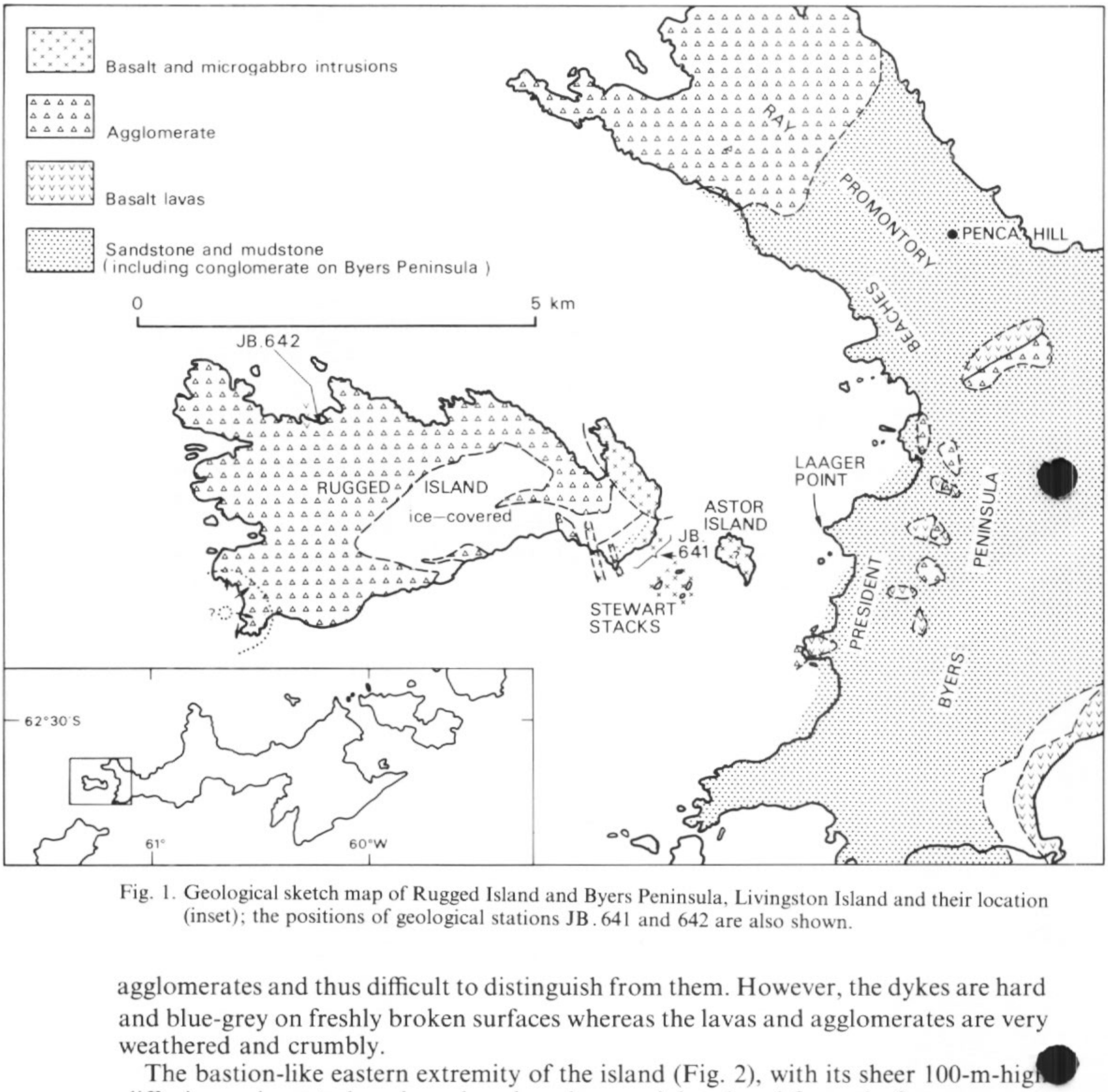

Fig. 1. Geological sketch map of Rugged Island and Byers Peninsula, Livingston Island and their location (inset); the positions of geological stations JB . 641 and 642 are also shown.

agglomerates and thus difficult to distinguish from them. However, the dykes are hard and blue-grey on freshly broken surfaces whereas the lavas and agglomerates are very weathered and crumbly.

The bastion-like eastern extremity of the island (Fig. 2), with its sheer 100-m-high cliffs, is an elongate hypabyssal neck, columnar-jointed and formed of one or more intrusions of grey microgabbro (JB . 641 . 17). Two large north-north-west-trending dyke-like masses of porphyritic basalt (JB . 641 . 1, 2) were also mapped at this end of the island, whereas the prominent bluffs and stacks (including Stewart Stacks) around station JB . 641, composed of highly porphyritic (plagioclase, pyroxene, minor olivine) basalt (JB . 641 . 14, 15), may be sill remnants, perhaps relicts of the extensive sill that appears to form nearby Astor Island.

The 150–200-m-long beach by station JB . 641 (Fig. 3) is about 5 m wide and consists of flattened pebbles of buff and pink fine-grained sandstone and buff siltstone intermixed with some grey (?) microgabbro. The abundance of these rock types suggests that there is an outcrop of sedimentary rocks nearby at sea-level but one was not found, nor could it be seen beneath the scree-covered slope at the back of the beach. Loose blocks of a variety of other sedimentary rocks were found on this scree slope

Fig. 2. The southern coast of Rugged Island, viewed from President Beaches, Livingston Island. The sedimentary rocks at station JB . 641 form the low cliffs behind Stewart Stacks.

Fig. 3. Station JB . 641, looking towards the dyke-like masses of porphyritic basalt at the south-west end of the beach. The sedimentary rocks occur beneath the scree-covered slope (at right). (Photograph: S. Fraser).

during a traverse of it at a height of 10 to 15 m above sea-level. These include buff-coloured sandstone, siltstone with abundant plant remains, buff-coloured siltstone in graded contact with carbonate-cemented coarse sandstone and granule-conglomerate, green siltstone and coarse agglomerates (JB . 641 . 7, 8, 9, 13). Because of limited time at the locality, it was not possible to determine whether these blocks had fallen from higher up the scree slope, or whether they were derived from outcrops beneath the scree at about the same height. A blocky outcrop of grey flinty, fine-grained (?) microgabbro (JB . 641 . 3), occurring about 2 m above the beach, represents the lowest rocks seen *in situ*. A sequence of gently dipping (*c*. 10° to the north-west) fine-grained sediments protrude through the scree above this, but only at heights of 15 to 20 m above sea-level (Fig. 3). The lowest sediment observed in this sequence is at least 1 m of pale green tuffaceous sandstone (JB . 641 . 4). Above it there is a 20-cm-thick brown-weathering basalt sill (JB . 641 . 5) overlain by a purple-black muddy sandstone (essentially a greywacke: JB . 641 . 6). The highest strata in the section are poorly indurated and highly shattered chocolate-brown mudstones, with abundant loose fragments of cone-in-cone calcite ('beef': JB . 641 . 12). Fine-grained tuff and microgabbro (JB . 641 . 10, 11) were collected from outcrops above the scree-covered slope, at about 20 m above sea-level. All the sandstones examined have a volcanic provenance and consist of abundant lithic clasts (mainly fragments of polymict dense lavas, but including a few clay-altered vitric clasts, some with relict bubble structure, and a small proportion of brownish silty mudstone) together with crystals of plagioclase, quartz and minor opaque ore. Most clasts are angular to sub-angular but some are moderate to well-rounded, and sorting varies from moderate to very poor.

No macrofossils were seen *in situ* but a worn *Spiticeras*-like ammonite was found in a pebble of buff sandstone from the beach (JB . 641 . 16) and plant-bearing siltstones were common in the float on the scree (JB . 641 . 8).

Discussion

All the rocks exposed on Rugged Island can be matched lithologically with those comprising the Upper Jurassic–Lower Cretaceous Byers Formation, which crops out 3 to 5 km to the east on President Beaches and Ray Promontory, Byers Peninsula. Specifically, the Rugged Island agglomerates correspond to an extension of the agglomerate member of the Byers Formation (cf. Smellie and others, 1980). Considered together, these outcrops clearly represent a major volcanic centre active during the early Cretaceous and, with the exception of recently active Deception Island, it is the largest coherent vent complex identified in the South Shetland Islands so far. Correlation of the Rugged Island sedimentary rocks is slightly more ambiguous, however, although they almost certainly correspond to the mixed marine or, possibly, mudstone members of the Byers Formation. In particular, the *in situ* rocks are closely comparable to sequences of shattered dark-coloured mudstones, with calcite 'beef', and a few interbedded sandstones, which crop out around Penca Hill on Ray Promontory and in coastal scarps east of Laager Point (part of the mixed-marine member: Smellie and others, 1980; Crame and Farquharson, 1982, p. 12). The ammonite-bearing pebble may have been derived locally on Rugged Island or it could have been glacially transported from outcrops on President Beaches since the ammonite genus *Spiticeras* is characteristic of the mixed marine member on Byers Peninsula (Tavera, 1970; Smellie and others, 1980).

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REFERENCES

ARAYA, R. *and* HERVÉ, F. 1966. Estudio geomorfológico y geológico en las Islas Shetland del Sur, Antártica. *Publicaciones del Instituto Antártico Chileno*, No. 8, 76 pp.

CRAME, J. A. *and* FARQUHARSON, G. W. 1984. Stratigraphical and sedimentological studies on Byers Peninsula, western Livingston Island (South Shetland Islands). *British Antarctic Survey Geological Field Report R/83-84/G9*, 21 pp. [Unpublished.]

SMELLIE, J. L., DAVIES, R. E. S. *and* THOMSON, M. R. A. 1980. Geology of a Mesozoic intra-arc sequence on Byers Peninsula, Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 50, 55–76.

SMELLIE, J. L., MOYES, A. B., MARSH, P. D. *and* THOMSON, J. W. 1985 Report on Antarctic field work. Geology of Hugo Island, Quintana Island, Sooty Rock, Betbeder Islands and parts of the Biscoe and Outcast islands. *British Antarctic Survey Bulletin*, No. 68, 91–100.

TAVERA, J. J. 1970. Fauna Titoniana-Neocomiana de la Isla Livingston, Islas Shetland del Sur, Antártica. *Serie Científica. Instituto Antártico Chileno*, 1, No. 2, 175–86. [*Contribuciones del Instituto Antártico Chileno*, No. 23.]