GEOLOGICAL OBSERVATIONS IN THE ROSS GLACIER AREA, SOUTH GEORGIA

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Abstract. Previously unmapped areas in the Ross, Hindle and Weddell glacier regions near Royal Bay, and the Heaney Glacier in the hinterland of St Andrew's Bay, were visited in the 1984–85 field season. These areas are mainly within Cumberland Bay Formation metasediments. Significant observations include: a relatively abundant account of fossil material, including *Inoceramus* and rich *Aucellina* localities; confirmation of a major fault previously postulated to follow the Ross Glacier; the presence of numerous tuff beds, and chert, adjacent to the Ross Glacier, and large and simple but commonly sheared folds around the Hindle Glacier. Chert, marble and igneous rocks were found near the Heaney Glacier in Sandebugten Formation. Metamorphic minerals imply prehnite-pumpellyte facies metamorphism in the Cumberland Bay Formation, and pumpellyite-actinolite or greenschist facies in Sandebugten Formation.

Introduction

The authors visited the Ross, Webb, Hindle, Weddell, Heaney and Spencely glacier regions in southeastern South Georgia (Fig. 1) during the 1984 New Zealand South Georgia Expedition. These areas were chosen on the advice of Drs D. I. M. Macdonald and B. C. Storey of the British Antarctic Survey as representing the largest geologically unmapped areas on the island. The region is adjacent to that mapped by Stone (1980), and the geological work reported here is intended to supplement Stone's (1980) study.

Mapping

The Hindle Glacier has until recently been shown on topographic maps as 'inadequately surveyed' (e.g. Director of Military Survey, 1982). The sketch map (Fig. has been compiled from photographs, field sketches and bearings, and from the margins of areas mapped by Stone (1980, figs. 5 and 6). However, locations of outcrops and glacier margins are still approximate. Photographic coverage of the area is available from the authors.

Sedimentology

Rocks south of the Ross Glacier are mapped as Cumberland Bay Formation (Trendall, 1959; Stone, 1980), and include thick-bedded sandstone, thin-bedded sandstone/mudstone, and mudstone sequences, corresponding to the S, T and Sh facies of Macdonald and Tanner (1983), and the first two to the sandy and normal subfacies described by Stone (1980). Southwest of a large anticline through the head of the Weddell and Hindle glaciers, the Cumberland Bay Formation forms a simple southwest younging, southwest dipping sequence at least 3500 m thick in which the

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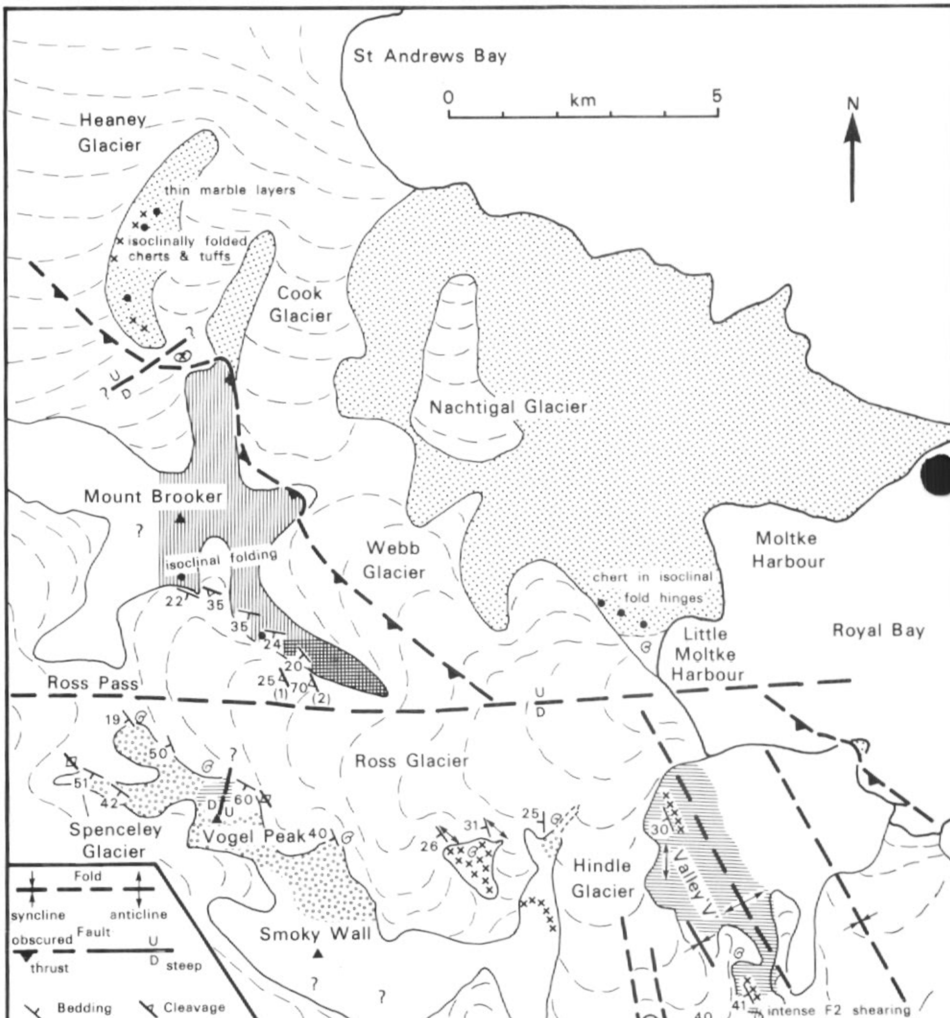

Fig. 1. Sketch map of the Ross and Hindle glacier areas, showing major lithologies, structures, fossil localities, faults and topographic features.

three facies are interbedded in approximately equal amounts. No overall fining- or coarsening-upward trends were noted.

The average grain size of the sandstone (S) facies is greater than reported from this facies elsewhere (e.g. by Macdonald and Tanner, 1983), particularly around the southern side of the Ross Glacier where granule and fine pebble conglomerate with rounded to subangular volcanic and intrabasinal sedimentary clasts averaging 2–3 cm in diameter is exposed. Farther south and stratigraphically higher on spurs running southwest from Vogel Peak, the grain size is only medium to coarse sand. Fossil fragments are common in these coarse sediments.

Pockets of thick-bedded coarse sandstone (S) facies may reach 100 m in thickness, with individual beds averaging 1.5–2 m thick; some beds (probably amalgamated) reach 8 m. The sandstone/mudstone (T) facies is generally thinner (5–10 m) with beds within it ranging from 0.1 to 1 m in thickness (Fig. 2). The cm- to dm-bedded mudstone (Sh) facies (Fig. 3) varies from a few metres to more than 100 m in thickness.

Fig. 2. Thin-bedded sandstone facies interbedded with tuffs (prominent, thick pale beds) on the south side of the Ross Glacier opposite Mt Brooker. Thick-bedded sandstones underlie the main tuff unit, which is overlain by interbedded sandstone and mudstone.

Sedimentary structures and sole marks are as described by previous writers; palaeocurrent data were recorded at a few outcrops (Fig. 1) from grooves and aligned wood fragments, which indicate a SE–NW pattern, as described by Macdonald and Tanner (1983). No unidirectional sole marks were observed. Within the thin-bedded sandstone-mudstone facies, coarsening- and thickening-upward cycles about 15–20 m thick were observed in several places, for example on the west ridge of Peak A (Fig. 1).

Tuff beds are common in two of the areas visited: on the Hindle-Weddell divide, and on the south side of the Ross Glacier below Smoky Wall (Figs. 1 and 2). Individual

Fig. 3. Mudstone facies on the south side of the Ross Glacier below Vogel Peak.

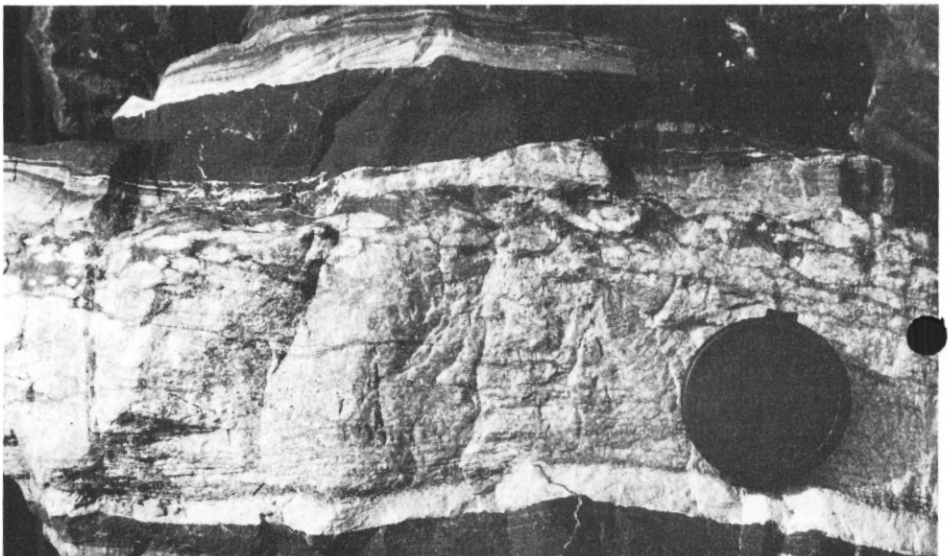

Fig. 4. Tuff beds (white) interbedded with mudstone in a boulder, adjacent to the outcrop in Fig. 2. Ripple cross-lamination is visible in the top tuff; bedding features are largely obscured by prehnitization in the thicker bottom layer. Lens cap 50 mm in diameter.

tuff beds are up to 2 m thick, and some extend for over 1 km. They may be massive, graded, or internally plane-parallel laminated, and ripple cross-lamination occurs in some (Fig. 4). Prehnite alteration obscures many primary features (Fig. 4). The tuffs on the south side of the Ross Glacier occur near an *Aucellina*-rich horizon and could prove useful as a structural marker farther to the south in the Twitcher Glacier area.

Sand dykes are prominent in many areas of thin-bedded sandstone; the top and bottom ends of several were seen, abruptly terminated by shearing off in mudstone beds. Feeder sand beds were never found. In one boulder in the dry valley 'V' (see Fig. 1) a sand dyke has been injected parallel to slaty cleavage. North of the Ross Glacier and above the Cumberland Bay–Sandebugten thrust fault, the Cumberland Bay Formation is relatively fine-grained compared with the sediments south of the glacier and also includes impure chert horizons (Figs. 5 and 6). The chert horizons are 20 cm to 1 m thick, massive to finely mm-laminated, hard and flinty. They are quite distinct from tuff beds.

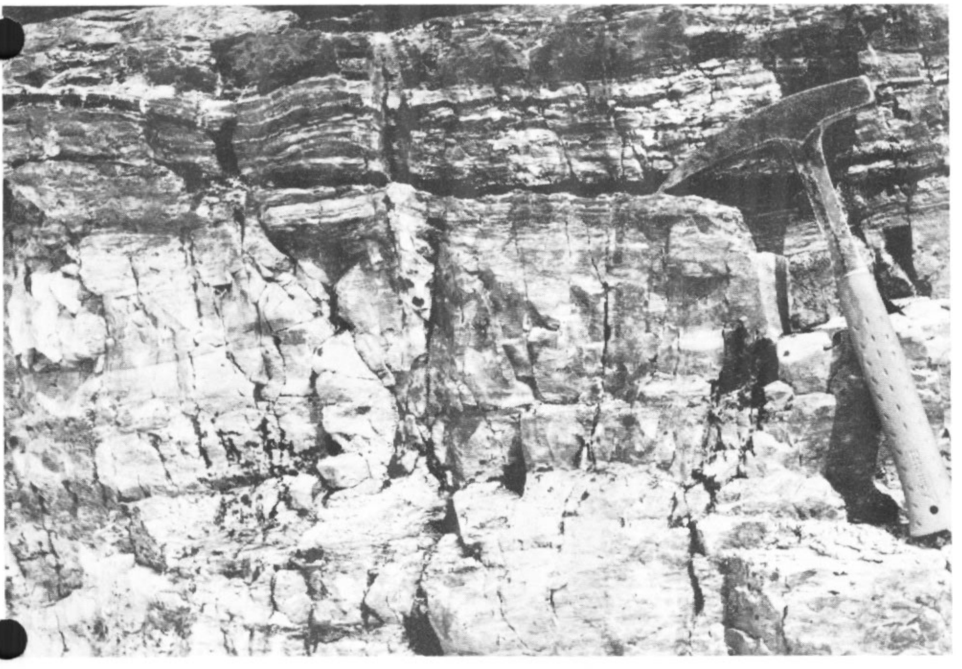

Fig. 5. Chert bed on the southeast ridge of Mt Brooker, interbedded with cleaved mudstone. Hammer 320 mm long.

Sandebugten Formation

We have not mapped this formation in detail and have little to add to earlier descriptions. An isoclinically folded impure chert bed was traced down the north side of the Ross Glacier below the Webb Glacier confluence to Little Moltke Harbour (Figs. 1 and 7). The chert is interbedded with quartzofeldspathic schist.

On the ridge east of the Heaney Glacier, chert, marble, and meta-plutonic rocks (cf. Stone 1980) were found in moraine near the ridge crest (see Fig. 1). Marble is interbedded with tightly folded thin-bedded sandstone and mudstone below the first prominent peak on the ridge, and also interbedded with sandstone on the saddle

(a)

(b)

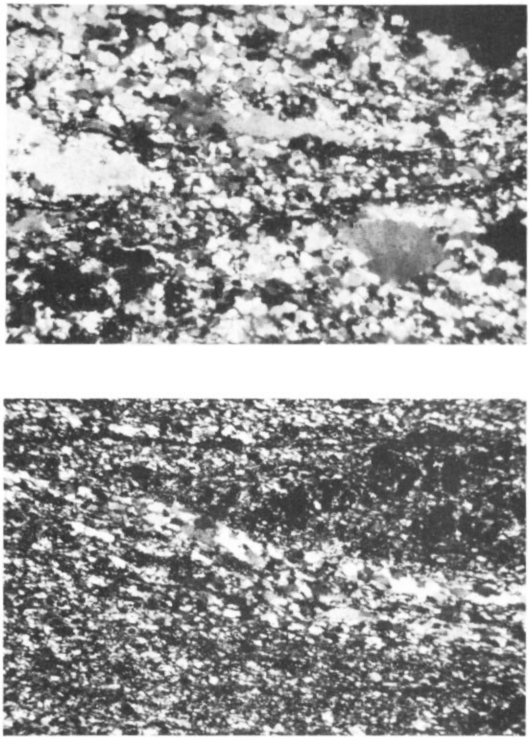

Fig. 6. Photomicrographs of (a) chert from Cumberland Bay Formation, Mt Brooker and (b) chert from Sandebugten Formation, lower Ross Glacier (see Fig. 7). White quartz; dark fine-grained materials is epidote. Crossed polars; field of view 4 mm in both photographs.

between this and the next peak. Tuff beds occur near both outcrops. Chert interbedded with marble was also found in float. Both chert and marble are recrystallized. No fossil material was found in the Sandebugten Formation.

Fossils

Several collections of fossil material were made from two Cumberland Bay lithologies south of the Ross Glacier; granule conglomerate and black mudstone (see Fig. 1). Material in conglomerate is generally fragmented, and original calcite is weathered out on exposed surfaces. Fossil localities in mudstone are more restricted in occurrence. *Inoceramus* is relatively abundant in mudstone clasts in moraine near Ross Pass, and is readily recognizable by its prismatic shell structure. A boulder containing *Inoceramus* fragments was also found at Little Moltke Harbour. *Aucellina* is abundant in mudstone on the south side of the Ross Glacier opposite the southeast ridge of Mt Brooker. Preliminary examination of the material by BAS paleontologists suggests a Early Cretaceous (Kimmeridgian–Albian?) age (Dr J. A. Crame, pers. comm., August 1985).

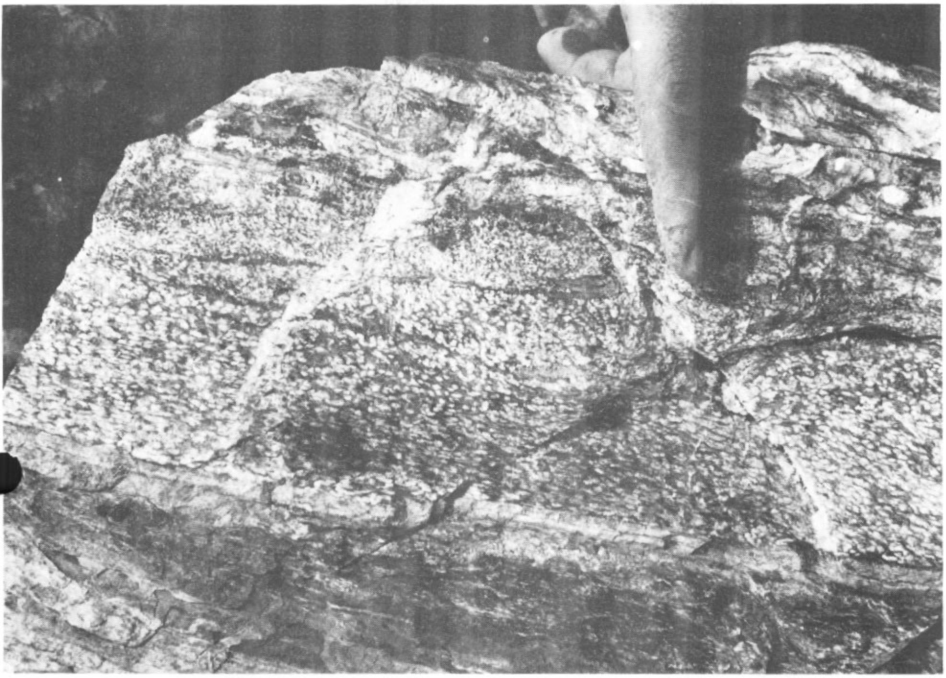

Fig. 7. Impure chert (top), muscovite-rich rock (spotted) and clastic sediment in Sandebugten Formation on north side of the Ross Glacier near Little Moltke Harbour.

STRUCTURE

South of the Ross Glacier, the Cumberland Bay Formation forms the southwest limb of an anticline traced from the snout of the Ross Glacier southeast to beyond the head of the Weddell Glacier. This fold has a sub-vertical axial surface, marked by a zone of shearing and poorly developed slaty cleavage and an interlimb angle of *c.* 90°. Smaller folds with wavelengths of about 100 m, also with sheared-out axial surfaces, occur at the head of the dry valley 'V', and farther south in the Hindle Glacier area (Fig. 8). The shear zones have a variable developed slaty cleavage, and some mesoscopic folds in bedding in mudstone. Sandstones are generally unaffected by shearing, but it was not possible to trace individual sandstone layers across these zones.

Slaty cleavage is patchily developed in areas away from fold hinge zones. *Aucellina* fossils on the south side of the Ross Glacier are slightly distorted, and in one mudstone outcrop below Vogel Peak, possible tectonic ripples are developed. Sandstones are unfoliated, and the area south of the Ross Glacier is within Textural Zone (t.z.) I of Bishop (1972).*

The Cumberland Bay Formation rocks north of the Ross Glacier are more pervasively deformed, with a penetrative schistosity in sandstone (t.z. IIB), and a

* Textural zonations in medium-grained quartzofeldspathic greywackes can be summarized as follows (after Bishop, 1972): textural zone (t.z.) I = non-foliated; t.z. IIA = slightly foliated, bedding still dominating outcrop; t.z. IIB = penetratively foliated, foliation dominates over bedding; t.z. IIIA = strongly foliated, with incipient, discontinuous leucocratic segregations; t.z. IIIB = strongly foliated with continuous segregation laminae < 2 mm thick; t.z. IV = strongly foliated with segregation laminae > 2 mm thick.

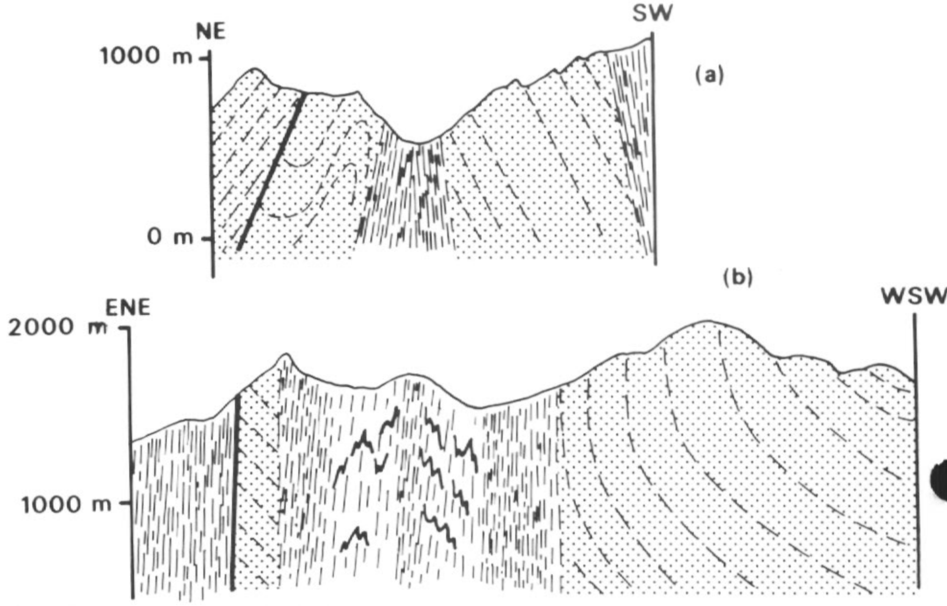

Fig. 8. Sketch cross-sections in the Hindle Glacier area: (a) head of valley V showing detailed structure of the anticline in Fig. 1; (b) head of Hindle Glacier on Hindle–Twitcher Glacier divide, southwest of Peak A. Steeply dipping slaty cleavage (close dashes) in fine-grained rocks has developed parallel to fold axial surfaces of folds in bedding (spaced dashes). Predominantly coarse-grained sections are dotted. Vertical scale = horizontal scale.

well-developed slaty cleavage in mudstone units. This fabric has formed axial planar to tight to isoclinal folds in bedding. On the southeast ridge of Mt Brooker (Fig. 1), a second cleavage in mudstone may be related to the adjacent thrust contact with the Sandebugten Formation (Stone, 1980). Numerous large antiformal folds were observed from a distance in the rocks on the south side of the Allardyce Range north of Ross Pass.

A major fault postulated to follow the Ross and Brøgger glaciers (e.g. Tanner and others 1982) is confirmed. Apart from the offset thrust fault, the textural grade of the Cumberland Bay Formation rocks is quite different across the glacier, structures do not match, and marker horizons (chert and tuff beds) are also offset with no equivalents found on opposite sides. From these differences, we infer that the fault has a predominantly vertical sense of movement, with north side up. Structures in the Sandebugten Formation were not investigated in detail, as they are already adequately described from this area (e.g. Stone, 1980). We had difficulty in differentiating Stone's Phase 1 from Phase 2 structures in the Royal Bay–St Andrew's Bay area, and were unable to locate precisely the thrust fault separating the Cumberland Bay and Sandebugten Formations in the upper Heaney Glacier area. There are no clear differences in structural style or lithology between obviously Sandebugten Formation rocks at the foot of the glacier, and apparently Cumberland Bay Formation rocks in the slopes of Mt Brooker (Fig. 1).

Metamorphism

Clastic rocks of the Cumberland Bay Formation on the south side of the Ross Glacier show only incipient recrystallization. Feldspars have been albitized, and prehnite has replaced some sedimentary textures in many samples (cf. Trendall, 1959). However, original sedimentary texture is preserved throughout most of the sequence. Matrix material has recrystallized to fine-grained chlorite, sericite, epidote, calcite, sphene and possibly some colourless pumpellyite. Tuff horizons are extensively recrystallized, with little primary texture remaining (Fig. 4), although relict feldspar crystal shapes are preserved. Tuffs consist mainly of albitized feldspars, clinozoisitic epidote, chlorite, prehnite and sphene, with minor quartz and calcite. Cumberland Bay Formation clastic rocks around Mt Brooker (Fig. 1) are more thoroughly recrystallized than those across the Ross Glacier. While original clastic grains can be recognized, these grains have been sheared into augen shapes 'floating' in a thoroughly schistose matrix of fine-grained chlorite, sericite, epidote and sphene. Feldspar clasts have been albitized, and partially replaced by prehnite and rare pumpellyite. Chert horizons are completely recrystallized and consist of quartz and fine-grained epidote showing some metamorphic segregation. Cherts are cross-cut by numerous quartz and prehnite veins.

Sandebugten Formation metasedimentary rocks examined are largely recrystallized, with a penetrative schistosity developed axial planar to isoclinal folds in bedding. Relict clastic quartz and feldspar grains lie in a fine-grained matrix of quartz, albite, muscovite, actinolite (microprobe and optical confirmation), chlorite, epidote, calcite and sphene. Tanner (1982) reports pumpellyite elsewhere in the Sandebugten Formation. Stilpnomelane crosscuts foliation (cf. Tanner 1982). Difficulty was experienced in assigning these rocks to either t.z. II B or t.z. III A, because of the common occurrence of metamorphically accentuated cross-lamination in psammitic horizons. We believe the rocks to be in textural zone II B, as are the Cumberland Bay rocks at Mt Brooker, but the Sandebugten Formation rocks are more thoroughly recrystallized and coarser grained than the Cumberland Bay Formation rocks. Sandebugten Formation cherts consist of quartz, epidote and muscovite and are more segregated than their Cumberland Bay equivalents. One chert horizon, above the Heaney Glacier, contains abundant chalcopyrite with minor pyrite, pyrrhotite, and sphalerite, and some superficial malachite staining.

Considerable rusty staining and mineralization was observed from a distance on the west side of a branch of the Nordenskjold glacier adjacent to a ?quartz lode, vertically cross-cutting *c.* 500 m of Cumberland Bay Formation sandstone.

Metamorphosed plutonic rocks found in moraine above the Heaney Glacier consist of epidote, albitized feldspars and partially actinolitized brown hornblende. They are petrographically similar to gabbroic rocks described by Stone (1980) in the Sandebugten Formation southeast of the Weddell Glacier.

Conclusions

The Royal Bay area mapped by the authors consists of three internally coherent structural domains. The largest domain from the Hindle glacier to Ross Pass, consists of relatively little-recrystallized (t.z. I) Cumberland Bay formation volcanogenic sediments including relatively coarse-grained facies, and fossils indicative of a Lower Cretaceous age. The domain has been folded into open upright structures which commonly have sheared-out hinges. The sediments contain mineral assemblages consistent with prehnite-pumpellyite facies metamorphism.

Within the second domain, the volcanogenic Cumberland Bay Formation rocks which underlie Mt Brooker are broadly similar to those of the Hindle–Ross domain, but have undergone two phases of deformation, the first of which produced a penetrative foliation (t.z. II B). Folded chert horizons occur in Mt Brooker, interbedded with the Cumberland Bay sequence. Mineral assemblages in this domain are consistent with prehnite-pumpellyite facies metamorphism and it is separated from the Hindle–Ross domain by the fault beneath the Ross Glacier.

The third structural domain is composed of schists (t.z. IIB) of the relatively quartz-rich Sandebugten Formation which have suffered two phases of tight to isoclinal folding. Metamorphic mineral assemblages are indicative of pumpellyite-actinolite or greenschist facies. Tightly folded chert and marble bands occur within the Sandebugten Formation sequence. The formation is separated from the Cumberland Bay Formation by a southwest-dipping thrust fault (on Mt Brooker; Stone, 1980) but the fault was not precisely located further to the northwest during this study.

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