GEOLOGICAL OBSERVATIONS IN THE MORAINE FJORD AREA, SOUTH GEORGIA

By B. F. MAIR

ABSTRACT. A zone of quartz-dioritic and gabbroic rocks crops out within the Cumberland Bay Formation greywackes near Moraine Fjord, South Georgia. They are similar to other, previously described, igneous rocks which intrude both Cumberland Bay and Sandebugten Formation sediments elsewhere on the north-east coast of the island. The intrusions are pre-tectonic and represent the final phases of basic magmatism, within the oceanic floor of the marginal basin upon which the flysch-type sediments were being deposited.

THE Osmic Hill and Dartmouth Point areas, bordering Moraine Fjord, South Georgia (Figs 1 and 2), were mapped by the author during a 5 week period in 1977. The main purpose of the survey was to locate minor igneous intrusions reported by Ferguson and others (1914) to crop out in the area. Plane-table maps of Osmic Hill and Dartmouth Point were drawn at 1 : 20 000 and 1 : 12 500, respectively, using a measured base line and known coordinates of prominent peaks.

The major geological units of South Georgia (Fig. 1) have recently been reviewed by Tanner (in press) and comprise part of an Upper Jurassic–Lower Cretaceous island arc–marginal basin system. The basin floor comprises a sequence of pillow lavas and dykes, the Larsen Harbour Formation, and remnants of continental crust within the gabbroic and granitic rocks of the Drygalski Fjord Complex. A mylonite zone separates the igneous rocks from the Sandebugten and Cumberland Bay Formations, two thick, polyphasally deformed turbidite sequences, which infill the marginal basin. An island-arc assemblage, the Annenkov Island Formation, consists of andesitic breccias and tuffs, and crops out to the west of the mainland of South Georgia (Pettigrew, 1981). The Ducloz Head Formation comprises both continental margin and ocean floor derived rocks deposited during the early stages of marginal basin formation.

The sills intruding black shales of the Cumberland Bay Formation were classified by Ferguson and others (1914) as coarse diabase and quartz-monzonite-porphyry; the latter type was not found *in situ*. The diabase was later described as "comprising plates of augite, decomposed feldspar laths and serpentine in an ophitic texture" and the porphyry as "consisting of orthoclase and oligoclase feldspar, chloritized hornblende and biotite" (Tyrrell, 1915, p. 830). An intrusion at Gold Harbour (Fig. 1) was termed an epidiorite by Tyrrell (1916, p. 437) and was equated with those from Moraine Fjord. Trendall (1959) attempted unsuccessfully to locate the sills reported in 1914 but he did discover sheared dolerites in Wirik Bay (Fig. 1). Members of the Combined Services Expedition, 1964–65, noted igneous intrusions adjacent to Nordenskjöld Glacier and at Lönnberg Valley, inland from Hound Bay (Fig. 1), but no precise localities or descriptions were given (Burley, 1966). Stone (1980) has recently presented a detailed account of minor quartz-diorite intrusions within the Cumberland Bay and Sandebugten Formations, which crop out at Lönnberg Valley, Will Point, Gold Harbour and Iris Bay, and of equivalent epidiorites from Cooper Bay and Wirik Bay (Stone, in press; Fig. 1). The intrusions were thought to be pre-F2 in age but their relationship to F1 was uncertain (Stone, in press).

An outcrop of gabbroic intrusions and well-cleaved slates which occurs at lat. 54°32′S, long. 36°21′W, near the head of Brögger Glacier (Fig. 1; personal communication from B. C. Storey), was also visited by the author. The rock types present and their field relationships are not unlike those of the intrusions near Moraine Fjord.

FIELD RELATIONS

The intrusions are of variable size, up to 0.7 km in length, and traceable discontinuously in the field for up to 1.2 km on Osmic Hill and Dartmouth Point, respectively (Fig. 3). They occur as narrow bands 2–20 m wide, truncated and displaced laterally by small faults within a zone

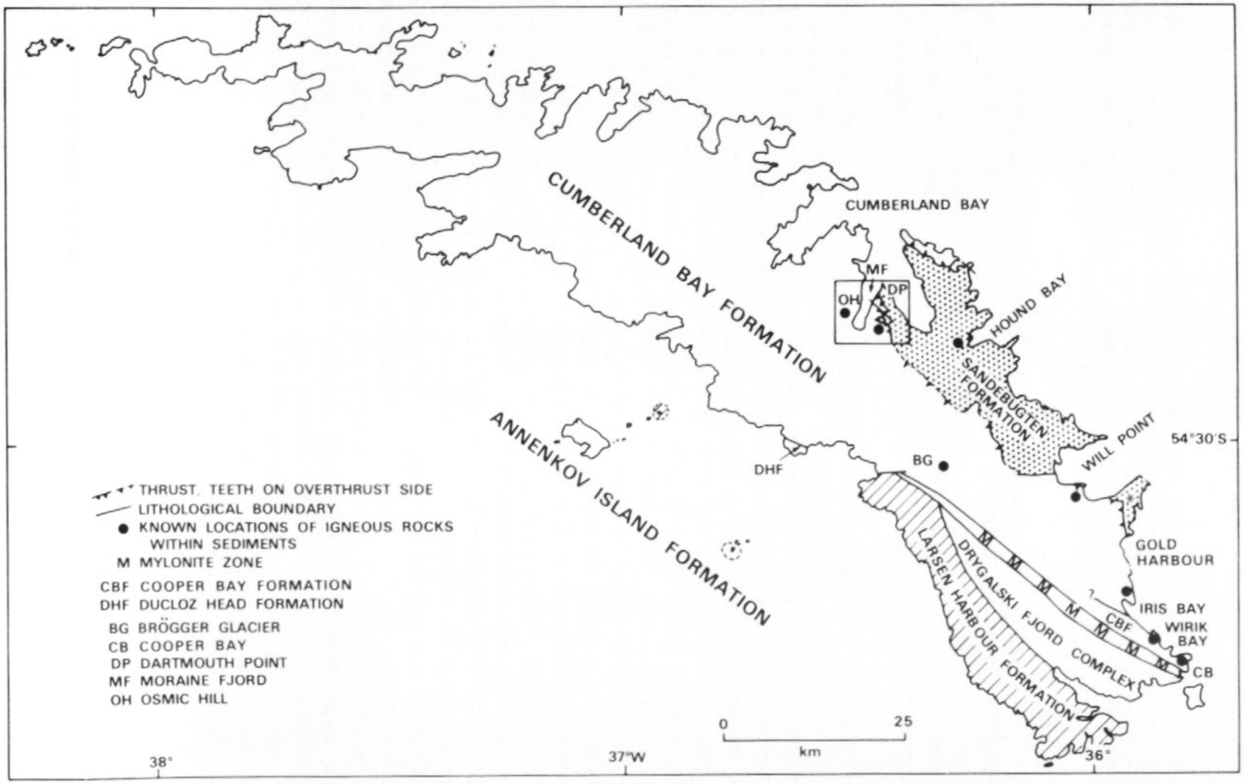

Fig. 1. Map of South Georgia showing the location of the area discussed (outlined), the main geological units and known localities of igneous intrusions in the Cumberland Bay and Sandebugten Formations greywackes (after Stone, 1980).

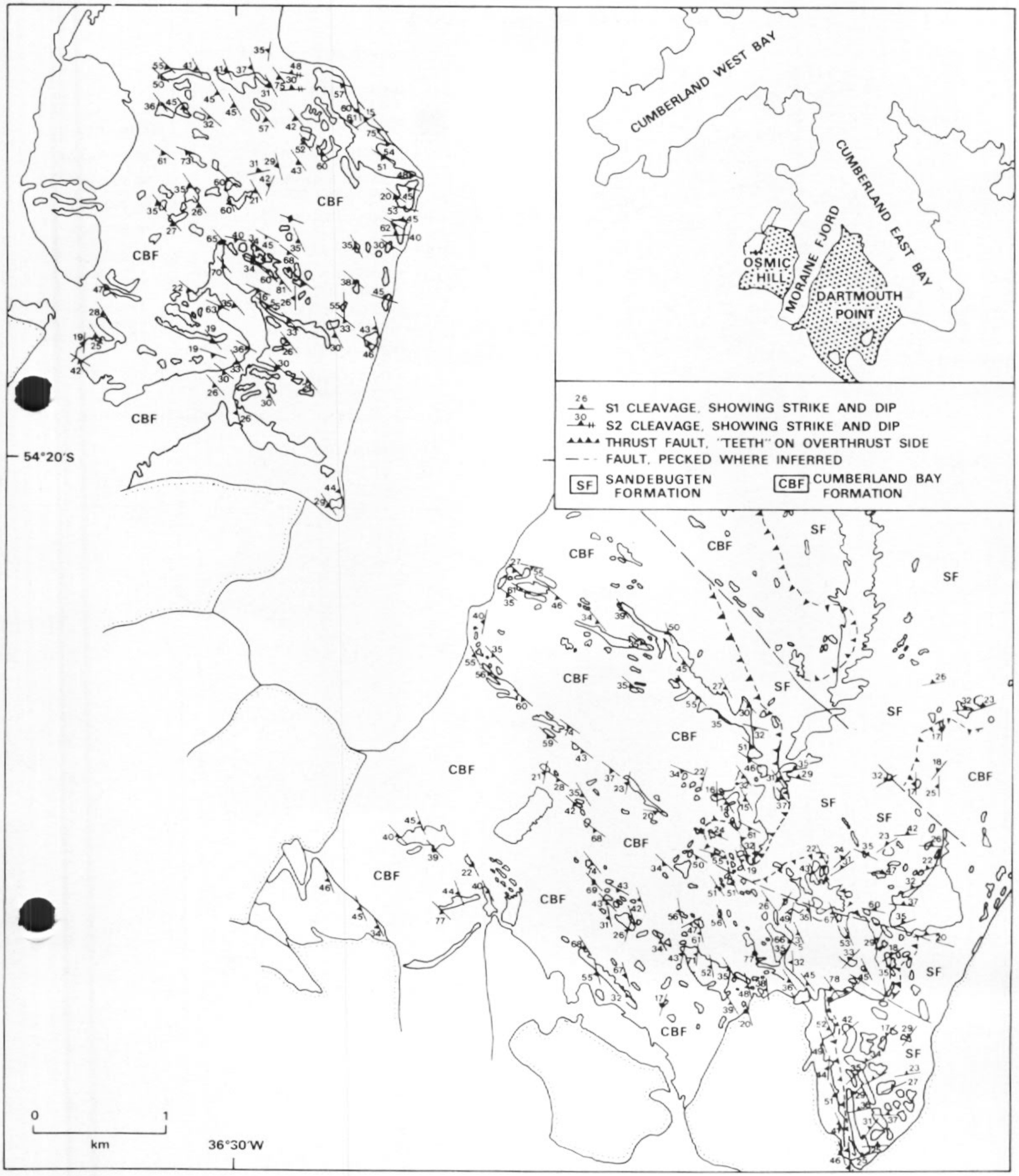

Fig. 2. Geological map of the Moraine Fjord area, showing cleavage observations. The inset shows the location of Osmic Hill and Dartmouth Point in Cumberland Bay, South Georgia.

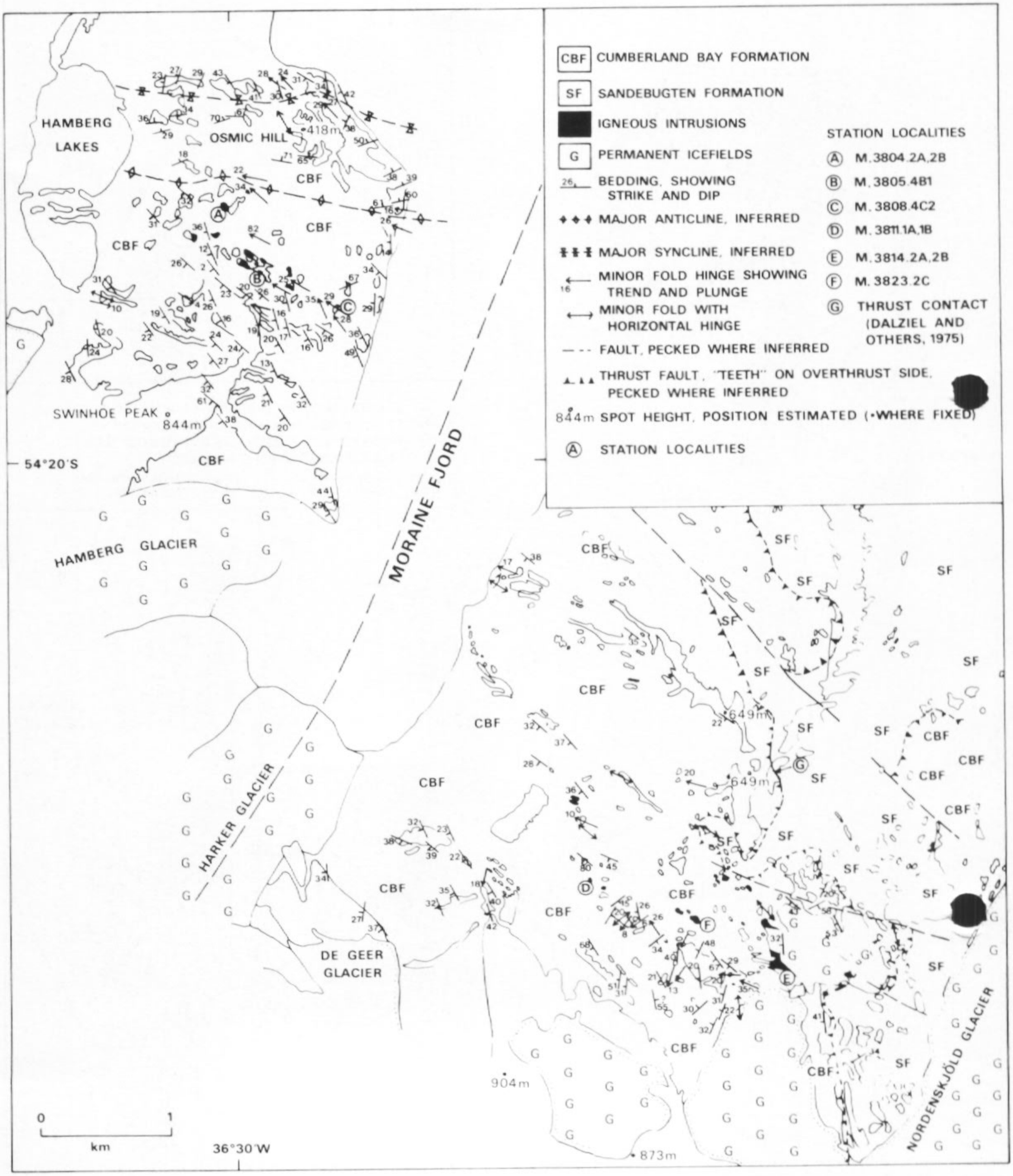

Fig. 3. Geological map of the Moraine Fjord area, showing the outcrops of igneous rocks and the spatial orientation of bedding, fold hinges, faults and thrust contacts.

200 m across which trends north-west to south-east, parallel to the main regional structure. Their light, pale green or white colour contrasts markedly with the adjacent dark slates (cf. black shales of Ferguson and others (1914; Fig. 4)). The relationship between the intrusions and the sediments is unclear, but, in general, the igneous contacts dip more steeply than the local bedding planes. The slates have a prominent cleavage which is often deformed by minor folds and is parallel to the intrusion contacts. The margins are often intensely deformed, whereas the centres of the thicker intrusions appear little deformed; quartz veins are common throughout.

Petrology

Two distinct igneous types have been identified from Osmic Hill and Dartmouth Point. A greater amount of quartz and recognizable andesine defines one type as a quartz-diorite (cf. the porphyry of Tyrrell (1915, 1916)), whereas the other is of gabbroic aspect (cf. diabase of Tyrrell (1915, 1916); dolerite or microgabbro of Stone (1980)) having a well-developed ophitic texture. The gabbros retain fresh clinopyroxene, although all plagioclase laths have been saussuritized completely. The quartz-diorites have been variably deformed and often only traces of the former igneous texture remain.

Gabbro

The gabbros from both areas are medium-grained, consisting of 1.5–2.0 mm clinopyroxene crystals in an ophitic texture with laths of turbid plagioclase (up to 2.5 mm long), 0.8–2.5 mm ilmenite and leucoxene intergrowths and interstitial alteration patches. Late quartz veins traverse many of the thin sections (M.3808.4C2).

Pale-coloured augite is the only pyroxene present, as subhedral to anhedral crystals often traversed by cracks, infilled by chlorite, colourless amphibole or both (M.3803.4C2). A colourless acicular amphibole, probably actinolite, may pseudomorph the augite completely or form alteration fringes around it, and also occurs as randomly orientated laths in interstitial areas. Hornblende (α = pale green; β = yellow-brown; γ = brown) replaces augite in a gabbro from Dartmouth Point (M.3811.1A).

Plagioclase laths have retained their form in spite of complete saussuritization but their anorthite content cannot be determined optically. Each lath has a dusty brown interior, within which chlorite, clinozoisite and quartz are present (M.3811.1A). The granophyric texture noted by Stone (1980) from another intrusion also occurs (M.3804.2B). No potash feldspar was detected by staining methods.

Interstitial areas consist of amphibole, chlorite, clinozoisite, calcite and opaque minerals. Pale green almost colourless zones with a low birefringence may comprise serpentine intergrown with chlorite showing anomalous brown or blue interference colours. Colourless, euhedral and anhedral clinozoisite occurs, usually in association with chlorite. Minor biotite with chlorite is present in a gabbro from Osmic Hill (M.3805.4B1). Calcite is ubiquitous and forms ragged alteration patches on plagioclase and in the matrix. Granules of secondary magnetite occur infrequently, as does red-brown haematite staining.

An example of a well-cleaved gabbro (M.3823.2C) from the deformed margin of one of the intrusions has a granular rather than ophitic texture. Elongated crystals of colourless amphibole define an S1 fabric within it, enclosing relict plagioclase laths and pyroxene pseudomorphs. Leucoxene, sphene and magnetite are also present.

Quartz-diorite

Although similar to the gabbro in the hand specimen, the quartz-diorites differ from it in containing less mafic minerals and relatively fresh plagioclase crystals in which twinning is still recognizable. Quartz is more common and is thought to have been a primary constituent. Only

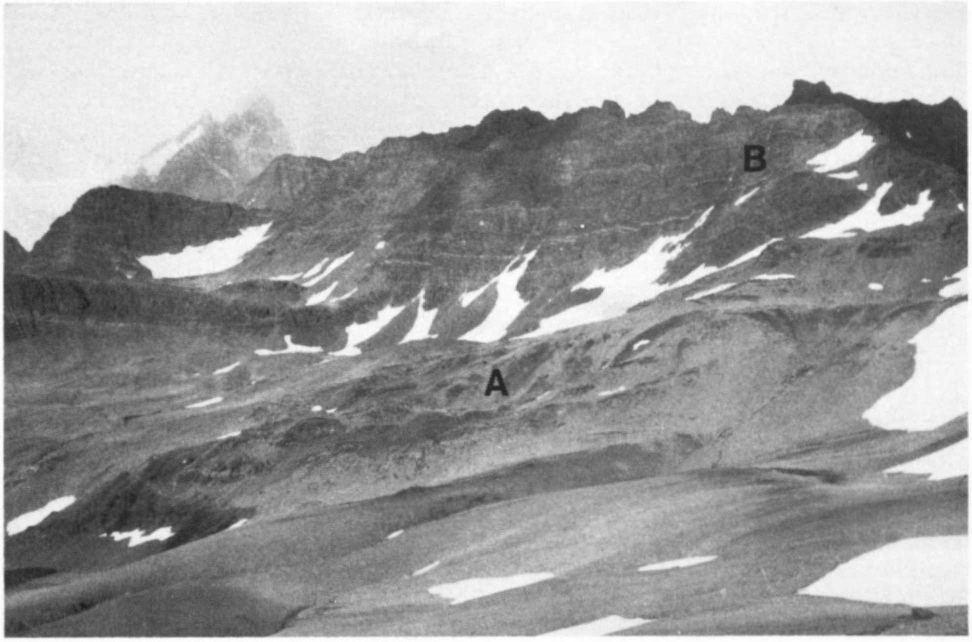

Fig. 4. Light-coloured intrusions into slates within the low knolls in the foreground (A), with gently dipping, well-bedded Cumberland Bay greywackes in the cliffs behind (B). The cliffs are approximately 160 m high; view from Osmic Hill looking south.

in the less deformed quartz-diorites is any igneous texture present. They are medium-grained, porphyritic and leucocratic rocks (M.3814.2A).

Although heavily altered, twinned plagioclase phenocrysts up to 3 mm long give consistent compositions of An_{30-35} in four thin sections, by optical determination. Deformation has resulted in fracturing of the laths and kinking of the twin planes (M.3811.1B). Perthitic intergrowths persist along the fringes of some plagioclase crystals (M.3823.5B).

No fresh mafic minerals were noted, all having been replaced by amphibole which has retained the ophitic texture in places (M.3804.2A). Pale green pleochroic hornblende with actinolitic margins is present (M.3811.1B) and the latter mineral outlines a fabric in the more deformed quartz-diorites (M.3814.2B). Chlorite and clinozoisite occur in association with the two species of amphibole present. Sphene, replacing former mafic minerals and associated with ilmenite, is also common. As in the gabbros, late quartz veins cut many of the quartz-diorites.

Structure

Cumberland Bay Formation

A prominent slaty cleavage dipping south-west at greater than 30° is well developed in the greywackes on Osmic Hill and Dartmouth Point (Figs 2, 5a and b) especially in the finer-grained shale-like units. The cleavage is more variable in orientation on Dartmouth Point and dips westward in the southern part of the peninsula (Fig. 2). This main cleavage (S1) is often locally sub-parallel to the bedding and is related to the large-scale F1 folds which strike north-west to south-east on Osmic Hill (Figs 2 and 3). Folding adjacent to the intrusions is on a smaller scale and is thought to represent F2 deformation; folds seldom exceed 30 cm in amplitude in both areas. No interference patterns between F1 and F2 were recognized and they are co-axial as in

the Wirik Bay area (Stone, in press). Fold hinges are either horizontal or plunge gently to the north-west or south-east (Fig. 5a and b), although on Dartmouth Point a second set of fold hinges trends consistently north-north-east to south-south-west (Figs 3 and 5b) and may be related to a later fold episode. A fracture cleavage (S2) is present within the slates on Osmic Hill and dips north-north-east (Fig. 5a), producing a lineation on the S1 cleavage.

The bedding on Osmic Hill is folded about a west-north-west to east-south-east axial direction (Fig. 5c); the distribution of poles to bedding reflects the asymmetric nature of the regional F1 folds, having a long, gently dipping south-west limb and a short, steeply dipping north-east limb. Data from Dartmouth Point show a less conclusive distribution, the bedding being folded about two dissimilar fold-hinge directions (Fig. 5b and d). The intersection lineations between bedding and each of the cleavages have been identified on Osmic Hill and show similar trends (Fig. 5c) but only four such lineations were recognized on Dartmouth Point (Fig. 5d).

Structural data measured adjacent to the intrusions are presented separately (Fig. 5e) but no definite relationship between them and the regional deformation is evident. On Osmic Hill, S1 maintains a similar pattern to the overall cleavage distribution (Fig. 5a and e) and lineations on S1 plunge north-westward. F2 folds and S2 on S1 intersection lineations are often developed at the margins of the intrusions. The S1 fabric near the intrusions on Dartmouth Point has a steeper attitude than the regional cleavage and the lineations show a more scattered distribution (Fig. 5e).

Sandebugten Formation

No rocks of Sandebugten type crop out on Osmic Hill but they are exposed on Dartmouth Point below the thrust contact with the Cumberland Bay Formation (Figs 2 and 3). Both formations can be distinguished in this area by the opposing dip of their cleavages (Trendall, 1959). In the field, overlap occurs between the dominantly south-westerly dipping Cumberland Bay type cleavage and the north-easterly dipping Sandebugten type cleavage in the central zone of Dartmouth Point (Fig. 2). Trendall (1953, p. 23) suggested that a tectonic contact separated the two formations on Dartmouth Point and this was subsequently located by Dalziel and others (1975); see this paper (Fig. 3). The Sandebugten Formation is intensely folded by large, greater than 10 m amplitude, similar-type folds with axial planes dipping at a low angle towards the north-east (Tanner, in press). In the region of the thrust plane, a strong cleavage is developed which is more readily measured than the former bedding planes (Figs 2 and 3). No igneous rocks intrude the Sandebugten Formation on Dartmouth Point.

Discussion

Ferguson and others (1914) and Trendall (1959) stated that the "sills" are pre-tectonic, and Stone (in press), suggests that intrusion of epidiorite sheets occurred pre-F2 in the structural history. At Iris Bay, where igneous rocks intrude the Cumberland Bay Formation, the relationship to bedding is not clearly defined; "it appears to be at least partly conformable with the original bedding" (Stone, 1980) and their connection with F1 folding is uncertain. The lack of sufficient potassium in secondary hornblende from one of the intrusions precludes their dating by K-Ar methods (Tanner and Rex, 1979).

The gabbroic and quartz-dioritic intrusions on Osmic Hill and Dartmouth Point are similar to those reported from elsewhere on South Georgia. They intrude only the Cumberland Bay Formation, near the thrust contact with the underlying Sandebugten Formation, and have been metamorphosed to upper greenschist–lower amphibolite facies during subsequent burial and deformation. The competency of the igneous rocks may have prevented the development of cleavage in their cores but S1 cleavage and later F2 fabrics are developed at their margins.

The basic sills described by Stone (1980, in press), are regarded as evidence of late-stage basic magmatism within the floor of the marginal basin on South Georgia in Lower Cretaceous times

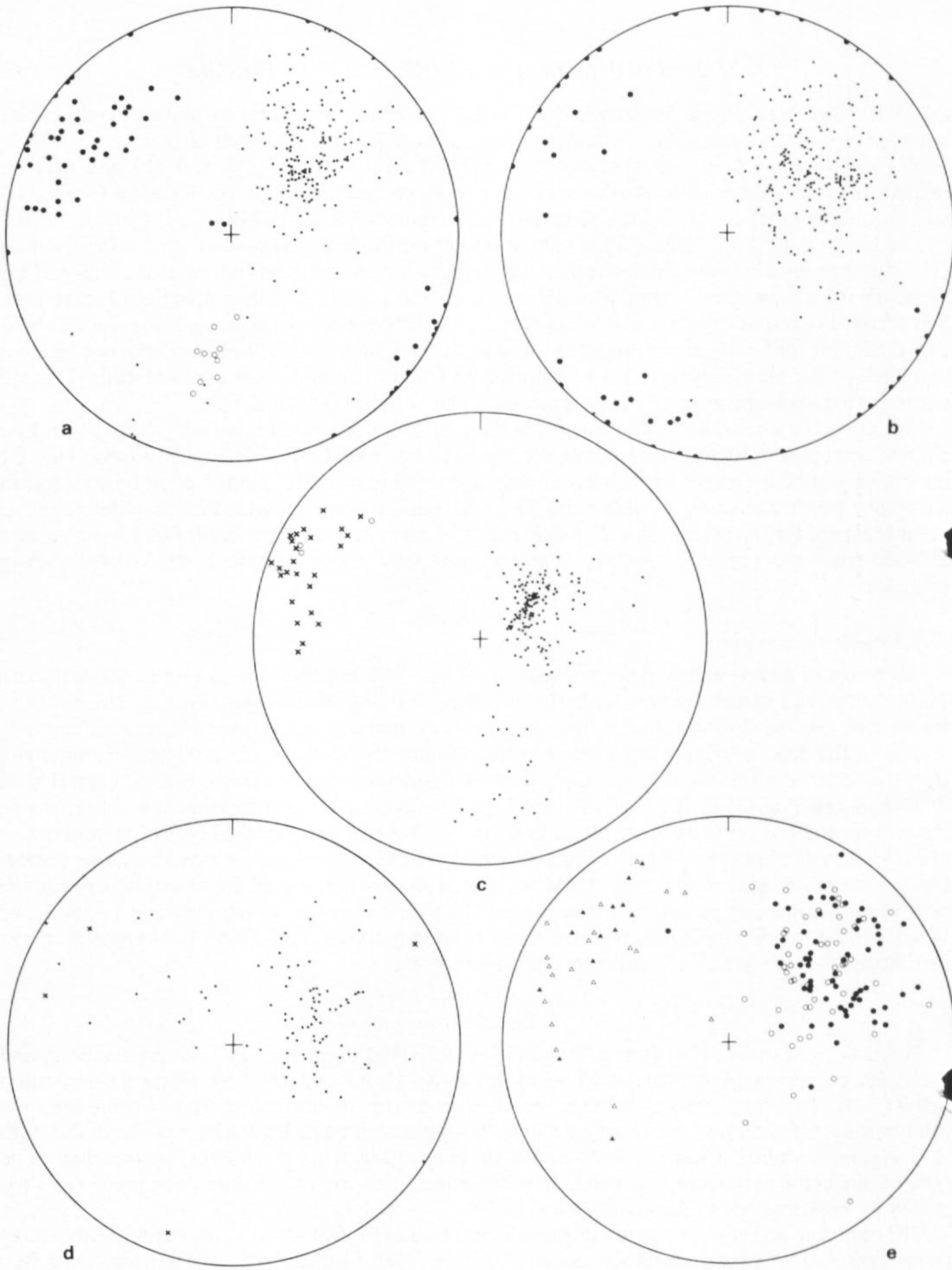

Fig. 5. Stereograms showing structural data from Osmic Hill and Dartmouth Point.

a. Osmic Hill; F1 and F2 fabric data.
- • 170 poles to S1 cleavage.
- ○ 10 poles to S2 cleavage.
- ● 44 F2 minor fold hinges.

b. Dartmouth Point; F1 and F2 fabric data.
- • 254 poles to S1 cleavage.
- ● 30 F2 (?) minor fold hinges.

c. Osmic Hill; bedding data.
- • 157 poles to bedding.
- × 25 bedding/S1 intersection lineations.
- ○ 3 bedding/S2 intersection lineations.

d. Dartmouth Point; bedding data.
- • 90 poles to bedding.
- × 4 bedding/S1 intersection lineations.

e. Fabric data from adjacent to intrusions; Osmic Hill and Dartmouth Point.
- ○ 53 poles to S1 cleavage, Osmic Hill.
- △ 19 S1/S2 intersection lineations, Osmic Hill.
- ● 62 poles to S1 cleavage, Dartmouth Point.
- ▲ 13 S1/S2 intersection lineations, Dartmouth Point.

(Tanner and Rex, 1979). This paper supports this conclusion but it suggests that geochemical investigation is necessary to define the origin of the dissimilar quartz-dioritic and gabbroic rocks described. Their occurrence at Moraine Fjord extends the area over which igneous intrusions are found within the Cumberland Bay Formation, possibly indicating that it is underlain to the north by mafic crust.

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REFERENCES

Burley, M. K. 1966. Combined Services Expedition to South Georgia 1964–5. *Explorers' J.*, **44,** No. 2, 106–18.

Dalziel, I. W. D., Dott, R. H., Winn, R. D. *and* R. L. Bruhn. 1975. Tectonic relations of South Georgia island to the southernmost Andes. *Geol. Soc. Am. Bull.*, **86,** No. 7, 1034–40.

Ferguson, D., Tyrrell, G. W. *and* J. W. Gregory. 1914. The geology of South Georgia. *Geol. Mag.*, Decade 6, **1,** No. 596, 53–64.

Pettigrew, T. H. 1981. The geology of Annenkov Island. *British Antarctic Survey Bulletin,* No. 53, 213–54.

Stone, P. 1980. The geology of South Georgia: IV. Barff Peninsula and Royal Bay areas. *British Antarctic Survey Scientific Reports,* No. 96, 45 pp.

————. In press 1980. Geological observations in the Cooper Bay—Wirik Bay area, South Georgia. *British Antarctic Survey Bulletin,* No. 51.

Tanner, P. W. G. In press. Geological evolution of South Georgia. (*In Third Symposium on Antarctic Geology and Geophysics. Madison, Wisconsin, U.S.A., 22–27 August 1977.*)

————. *and* D. C. Rex. 1979. Timing of events in a Lower Cretaceous island arc–marginal basin system on South Georgia. *Geol. Mag.*, **116,** No. 3, 167–79.

Trendall, A. F. 1953. The geology of South Georgia: I. *Falkland Islands Dependencies Survey Scientific Reports,* No. 7, 26 pp.

————. 1959. The geology of South Georgia: II. *Falkland Islands Dependencies Survey Scientific Reports,* No. 19, 48 pp.

Tyrrell, G. W. 1915. The petrology of South Georgia. *Trans. R. Soc. Edinb.*, **50,** Pt. 4, No. 25, 823–36.

————. 1916. Further notes on the petrography of South Georgia. *Geol. Mag.*, Decade 6, **3,** No. 10, 435–41.