GEOLOGY OF SHAG ROCKS, PART OF A CONTINENTAL BLOCK ON THE NORTH SCOTIA RIDGE, AND POSSIBLE REGIONAL CORRELATIONS

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ABSTRACT. Shag Rocks are the only sizeable outcrops on a large continental block on the north Scotia Ridge. They are situated 250 km west-north-west of South Georgia and this is the first description of their geology based upon *in situ* material. The rocks consist of finely banded epidote-tremolite/actinolite-stilpnomelane-albite-bearing greenschists cut by quartz veins containing ferroactionolite and stilpnomelane. Foliation strikes east–west and dips steeply to the south, and the rocks have been affected by at least two episodes of deformation. Directly comparable rock types are absent from the adjacent South Georgia block (although the Sandebugten Formation does contain stilpnomelane) and the petrography of the greenschists can be most closely matched with that of members of the pre-Jurassic metamorphic complex in the South Orkney and South Shetland Islands. Both the greenschists and the metamorphic complex have assemblages characteristic of transitional medium- to high-pressure (Sanbagawa) type metamorphism.

SHAG ROCKS and Black Rock are the only exposed parts of a large continental block about 11 500 km^2 in area which lies west of South Georgia in the Scotia arc (Fig. 1). Knowledge of the geology of this block and how it may be correlated with rock units in the southern Andes, southern Scotia Ridge and Antarctic Peninsula is of value in guiding a detailed pre-Tertiary reconstruction of the Scotia arc.

Evidence for the probable metamorphic nature of the rocks comprising this block was given by stones dredged from the vicinity of Shag Rocks by RRS *Discovery* II in 1930 and described by Tyrrell (1945). The first recorded landing was by M. B. Giovinetto, by helicopter from the Argentine vessel ARA *Bahía Esperanza* on 6 March 1956; a rock sample was collected but no description of it has been published. Marine geophysical study of the Shag Rocks continental block suggests that it consists of essentially non-magnetic metamorphic rocks, possibly with younger overlying sediments in places (Barker and Griffiths, 1972).

This account is based mainly on rock specimens collected by two parties of naval personnel who were landed on Shag Rocks by helicopter from HMS *Endurance* on 4 December 1974, and on oblique and vertical air photographs flown at the time. Observations and photographs of Shag Rocks were also made by the author during a close circumnavigation by RRS *John Biscoe* in November 1973. No samples have yet been obtained from Black Rock which lies 16 km south-east of Shag Rocks and only rises about 3 m above sea-level.

FIELD RELATIONSHIPS

Shag Rocks consist of two groups of islets about 200 m apart (Fig. 2, inset). They are sharply pointed and have an asymmetric profile: sheer north-facing sides and less steep foliation-controlled south sides (Figs 3 and 4). The highest rock is about 71 m high and lies in lat. 53°32.5′S, long. 42°01.7′W as fixed by navigation satellite from HMS *Endurance* in 1972.

All the islets appear to consist of regularly banded grey-green rock which strikes approximately east–west and dips to the south at 40–60°. Vertical air photographs show that open warps affect the main foliation trend, particularly in the northern group. Samples were collected from the largest islet in each group and their location is shown on Fig. 2.

PETROGRAPHY

In the hand specimen the rocks are uniform in appearance, being mainly iron-stained, fine-grained grey-green schist, with slight colour banding (2–5 mm) due to varying proportions of tremolite, epidote, stilpnomelane and chlorite. Quartz veins up to a few millimetres thick

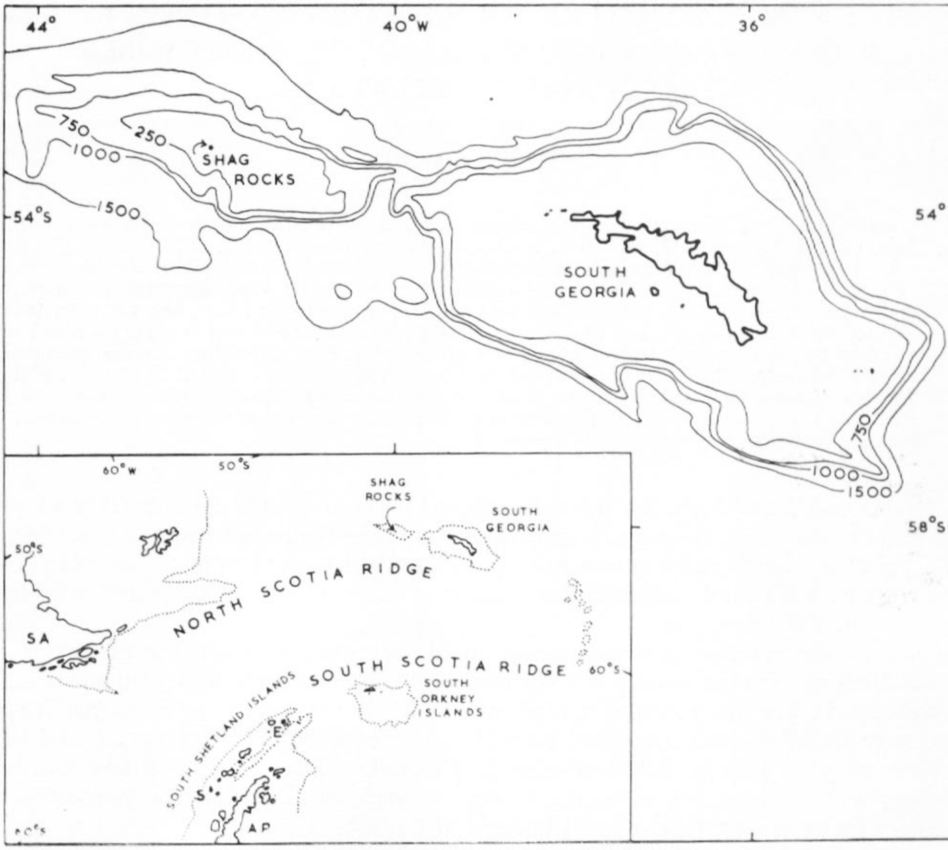

Fig. 1. The location of the Shag Rocks continental block with respect to South Georgia; bathymetry taken from Barker and Griffiths (1972, fig. 1); contours are in fathoms. The inset shows the position of Shag Rocks on the north Scotia Ridge. AP, Antarctic Peninsula; SA, South America; E, Elephant and Clarence Islands group; S, Smith Island.

occur parallel to the foliation together with less common pale green epidote-rich bands showing tremolite cross-fibre growth. Thicker (1–3 cm) quartz veins, which were sampled individually, contain albite, stilpnomelane, actinolite and epidote.

The main schistosity is parallel to lithological banding and is affected by a later crenulation cleavage in a number of specimens. A new streaky looking fabric is developed parallel to the axial traces of crenulations where they affect concordant quartz veins. In specimen M.1536.4, a crenulation lineation is superimposed upon an earlier ribbon lineation. It is inferred that the crenulation cleavage is steeply dipping and that the associated lineation plunges steeply down the dip of the foliation. The crenulation event is probably responsible for a large-scale warping of the foliation seen in the northern group of islets.

In thin section, the main schistosity in these rocks is defined by small (0.1–0.2 mm) tremolite-actinolite needles, epidote and clinozoisite granules, quartz-feldspar lenses and dusty sphene- and leucoxene-rich streaks. Foliation is marked by horizons of small opaque granules, sphene and zircon. The tremolite-actinolite is colourless to pale green, length slow and has $\gamma{:}c$ (max.) = 17–20°. Clinozoisite shows typical anomalous interference colours, is colourless or very pale greenish brown and sometimes has a dark brownish core (? allanite) or is clouded with fine brown dust. Epidote is less common, shows pale yellowish green pleochroism and higher birefringence. Chlorite forms pale green sheaves or patches with a dark blue-brown interference colour.

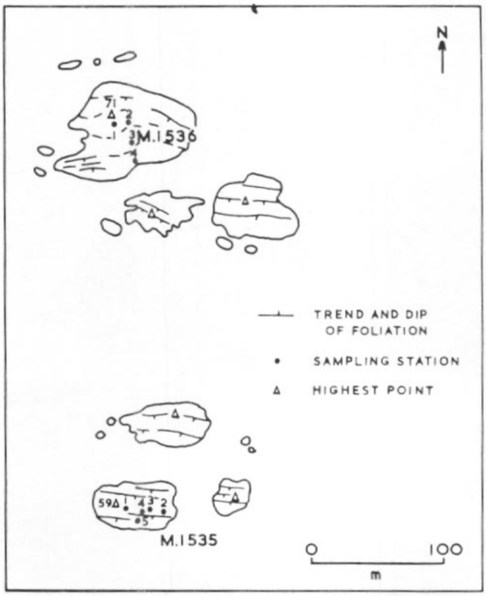

Fig. 2. Outline of the geology of Shag Rocks with sample locations, compiled from low-level air photographs. The map was prepared by the hydrographer, HMS *Endurance*, in June 1973 and subsequently modified by the author using vertical air photographs.

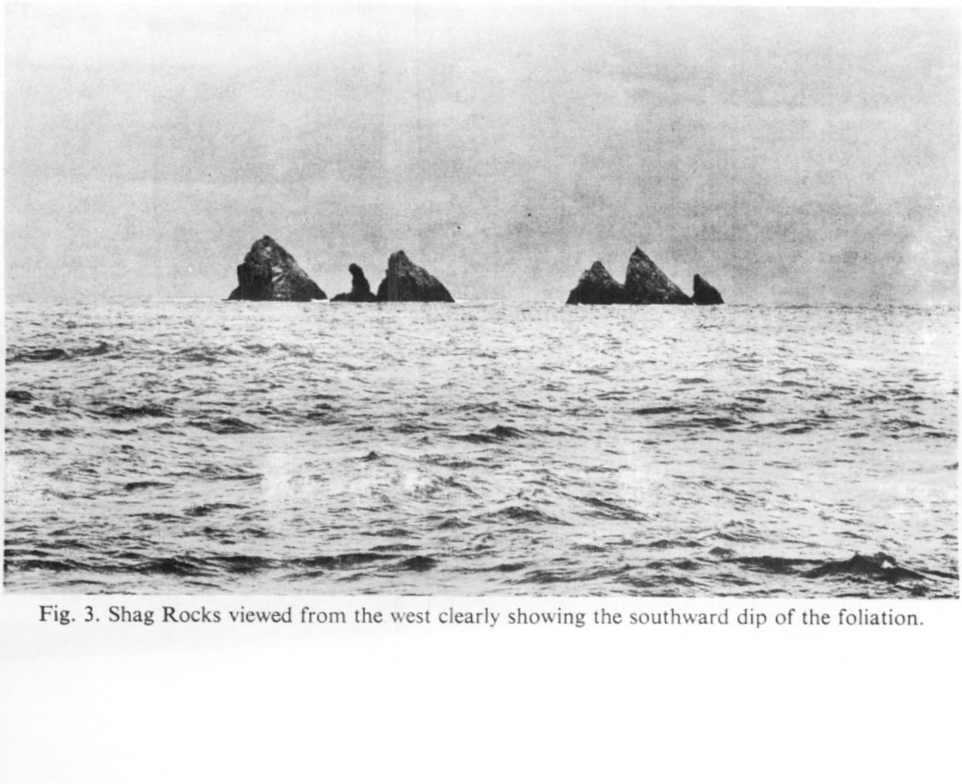

Fig. 3. Shag Rocks viewed from the west clearly showing the southward dip of the foliation.

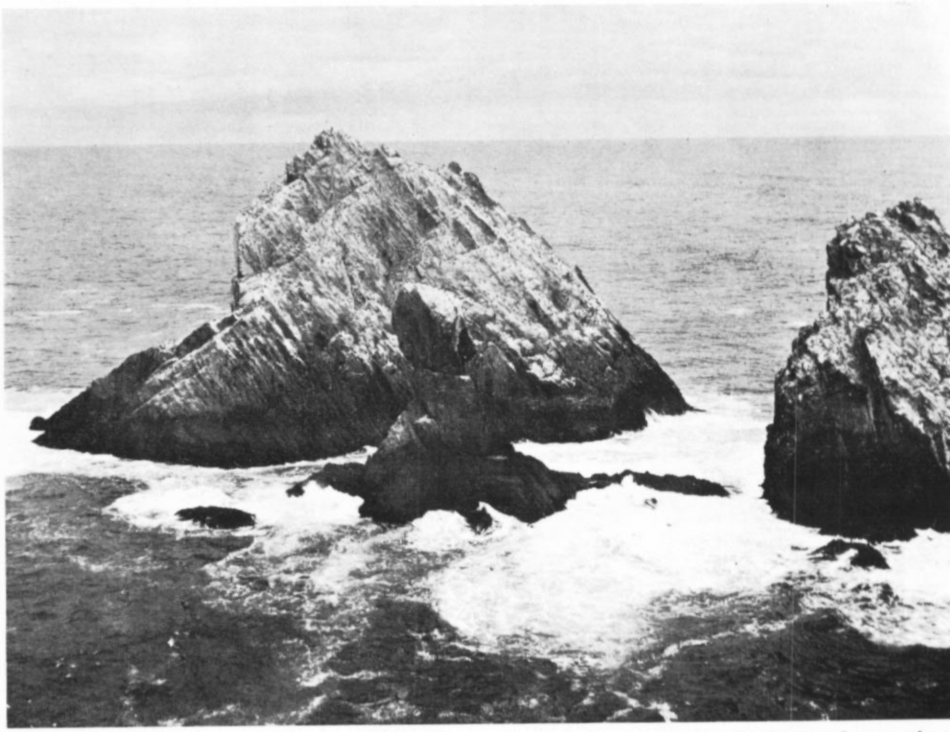

Fig. 4. The northern group of islets viewed from the south-west; the one in the background was selected for sampling (Fig. 2, M.1536) and clearly shows the fine lithological banding. The higher parts of all the islets are encrusted with bird excrement and thus appear pale-coloured.

Stilpnomelane occurs as small isolated clusters (0.2–0.3 mm across) or as sheaf-like or radiating groups along the margins of quartz-plagioclase lenses in tremolite-clinozoisite-schist; it also forms alternating lamellae with tremolite-actinolite in specimen M.1535.2. It has predominantly green pleochroism in some rocks (ferrostilpnomelane) and is olive-brown or yellowish brown (ferristilpnomelane) in others. Clinozoisite also forms small aggregates (0.3–0.5 mm) or porphyroblasts; the schistosity has been slightly flattened around these and the same effect is seen around some of the stilpnomelane clusters.

Plagioclase is generally poorly twinned, has a refractive index consistently lower than that of quartz, positive 2V and is An_{0-5} in composition. It is rare in some specimens but forms small porphyroblasts ($\leqslant$ 0.2 mm) in specimen M.1535.2. Quartz is uncommon, shows strain extinction and occurs largely in lenses and patches, in places intergrown with albite. Both the lenses and the concordant quartz veins consist of a mosaic of minute quartz crystals and appear to be recrystallized cataclasites. The other constituents of the rock have been completely recrystallized and only the quartz-rich parts retain evidence of an early cataclastic deformation.

The thicker quartz-rich veins found in these rocks contain varying amounts of albite, stilpnomelane, actinolite, chlorite, carbonate and epidote. Quartz forms crystals up to 2–3 cm across and invariably shows strained extinction, whilst tabular albite crystals are crossed by fractures and also have strained extinction. In specimens M.1535.3 and 5, dark orange-brown plates of stilpnomelane are partially altered to pale green, almost colourless actinolite. Stilpnomelane is locally bleached of pleochroism and is replaced by felted aggregates of actinolite crystals which also occur as separate needles in adjacent plagioclase and quartz crystals (Fig. 5a and b). In detail this relationship closely mimics that commonly seen between biotite and

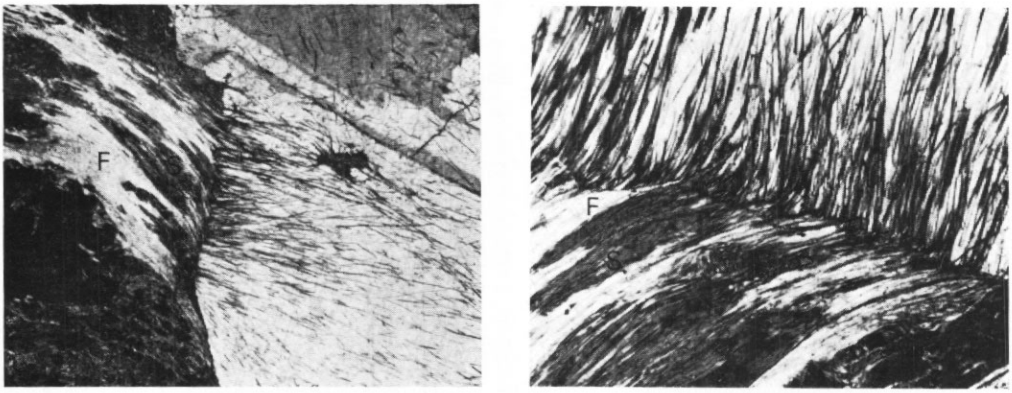

Fig. 5. a. Mats of ferroactinolite (F) with relict patches of stilpnomelane (S); individual needles of ferroactinolite are contained within a large adjoining crystal of plagioclase. The dark area in the middle left of the photomicrograph is of plagioclase in the extinction position and beneath it dark rounded patches of chlorite are seen enclosed in stilpnomelane (analysed specimen M.1535.3B; X-nicols; ×30).
b. Photomicrograph showing the detailed relationship between ferroactinolite mats (F), stilpnomelane (S) and acicular ferroactinolite enclosed in plagioclase (M.1535.3B; X-nicols; ×110).

fibrolite in rocks of the amphibolite facies. Stilpnomelane is partially altered to pale green to colourless chlorite in some sections; elsewhere it is completely replaced by lozenge-shaped bodies of chlorite. Carbonate occurs in patches and along quartz–quartz boundaries.

The main schistosity, defined by dimensional orientation of tremolite-actinolite, epidote minerals and quartz-albite lenses, is strongly affected by a crenulation cleavage in a number of sections. Development of this later cleavage caused folding and rupture of muscovite and tremolite laths with some subsequent recrystallization. Main chlorite growth appears to post-date this event with the mineral developing mainly from tremolite-actinolite and stilpnomelane.

Assemblages:

Schists: epidote–clinozoisite–tremolite-actinolite–stilpnomelane–(muscovite)–chlorite–quartz–albite–sphene–(zircon).

Quartz veins: quartz–stilpnomelane–chlorite–carbonate.
quartz–epidote–tremolite-actinolite.
quartz–stilpnomelane–chlorite–(actinolite)–albite–zircon.

The dredged stones described by Tyrrell (1945) were collected from two sites 2 km and 45 km west of Shag Rocks and they differ in one important respect from the samples collected *in situ* from Shag Rocks: they do not contain stilpnomelane. The 19 thin sections described by Tyrrell have been examined and, with one exception, can otherwise be approximately matched in petrography and grain-size with greenschists from the new collection. Epidote is more common than clinozoisite, whereas the reverse is true for the rocks collected *in situ*. Finely disseminated graphite is common in some thin sections.

Assemblages:

Schists: epidote–clinozoisite–tremolite-actinolite–chlorite–quartz–albite–(muscovite)–graphite–(carbonate).

Veins: quartz–(epidote)–(chlorite)–(carbonate).

Quartzitic arkose: quartz–(epidote)–albite–orthoclase–(sphene).

The quartzitic arkose is probably an erratic, as it cannot be matched in the rock collection from Shag Rocks nor does it resemble rock types so far described from the Sandebugten Formation on South Georgia, as suggested by Barker and Griffiths (1972, p. 158).

Mineral chemistry

The mineral assemblage in specimen M.1535.3B was analysed by electron microprobe by the writer. Each analysis is the mean of several determinations on individual grains. Albite (to 2 cm) is unzoned and five crystals analysed from core to margin showed an overall range in anorthite content from An_0 to $An_{0\cdot74}$ with K_2O = 0–0.13% and FeO (total Fe) = 0–0.14%.

Ferristilpnomelane (Table I, 1 and 2) has a composition similar to ferristilpnomelane occurring in the Haast Schist Group (Otago schists) of New Zealand (Table I, 3 and 4)

TABLE I. ANALYSES OF STILPNOMELANES FROM SHAG ROCKS AND THE HAAST SCHIST GROUP, NEW ZEALAND

	1		2		3		4	
SiO_2	47·0		47·4		45·24		46·3	
TiO_2	0·0		0·0		0·33		0·0	
Al_2O_3	5·64		5·84		6·73		6·38	
FeO	27·9*		27·5*		3·45		29·6*	
CoO	0·28		0·50		n.d.		n.d.	
Fe_2O_3	–		–		25·3		–	
MnO	0·85		0·78		0·60		0·62	
MgO	6·21		6·20		7·67		8·23	
CaO	0·96		0·60		1·91		0·28	
Na_2O	0·0		0·0		0·03		0·01	
K_2O	1·23		1·46		1·67		0·69	
	NUMBER OF IONS ON THE BASIS OF 8 SILICON ATOMS							
Si	8·00		8·00		8·00		8·00	
Al	–		–		–		–	
Al	1·13		1·16		1·40		1·30	
Ti	0·0		0·0		0·05		0·0	
Fe	3·98		3·89		3·89		3·85	
Co	0·04		0·07		–		–	
Mn	0·12	7·30	0·11	7·21	0·09	8·20	0·09	7·35
Mg	1·58		1·56		2·02		2·11	
Ca	0·18		0·11		0·36		0·05	
Na	0·0		0·0		0·01		0·0	
K	0·27		0·31		0·38		0·15	

* Total Fe as FeO.
n.d. Not determined.

1 and 2. Ferristilpnomelane from Shag Rocks (M.1535.3B).
3. Ferristilpnomelane from an albite-stilpnomelane-actinolite-schist (No. 2646), Haast Schist Group, New Zealand (Hutton, 1938, table 3).
4. Stilpnomelane from zone IIIb, Haast Schist Group, New Zealand (Kawachi, 1975, table 2).

(Hutton, 1938; Kawachi, 1975) and in low-grade metagabbros described by Graham (1976) from the Dalradian rocks of Islay, north-west Scotland.

Analysis of the fibrous amphibole associated with, and contained in, stilpnomelane shows that it is ferroactinolite (Table II, 1–3) with very low Al_2O_3 content (< 0.9%) and unusually high Fe content (Deer and others, 1963, p. 250) with 57% replacement of Mg by Fe^{2+}. These features are emphasized by comparison with actinolite from stilpnomelane-albite-actinolite-schists of the Haast Schist Group (Table II, 4 and 5).

Stilpnomelane from Shag Rocks is partially chloritized and altered to pycnochlorite-brunsvigite, an aluminous iron-rich chlorite (Hey, 1954) (Table III, 1–3). Chlorites from co-existing stilpnomelane–chlorite assemblages in the Haast Schist Group are similar in composition, especially that analysed by Kawachi (1975) (Table III, 4 and 5).

The apparent break-down of stilpnomelane to form ferroactinolite involves loss of K, a small reduction in Fe/Mg ratio and considerable gain of Ca. No other K- or Ca-bearing

TABLE II. ANALYSES OF ACTINOLITES FROM SHAG ROCKS AND THE HAAST SCHIST GROUP, NEW ZEALAND

	1	2	3	4	5
SiO_2	53·4	53·9	52·6	51·40	52·3
TiO_2	0·0	0·0	0·0	0·74	0·0
Al_2O_3	0·84	0·65	0·72	3·88	1·67
FeO	21·1*	21·7*	22·2*	14·91	17·0*
CoO	0·33	0·40	0·15	n.d.	n.d.
Fe_2O_3	–	–	–	3·90	–
MnO	0·31	0·45	0·42	0·33	0·25
MgO	10·2	9·41	9·18	11·22	13·9
CaO	12·4	12·0	12·0	10·17	11·6
Na_2O	0·0	0·0	0·0	1·67	0·77
K_2O	0·09	0·0	0·0	0·09	0·14

NUMBER OF IONS ON THE BASIS OF 23 OXYGEN ATOMS

	1	Σ	2	Σ	3	Σ	4	Σ	5	Σ
Si	7·90	8·00	7·99	8·00	7·90	8·00	7·54	8·00	7·71	8·00
Al	0·10		0·01		0·10		0·46		0·29	
Al	0·05		0·10		0·03		0·21		0·0	
Ti	0·0		0·0		0·0		0·08		0·0	
Fe	2·61	4·99	2·69	4·98	2·78	4·93	2·25	5·05	2·10	5·18
Co	0·04		0·05		0·02		–		–	
Mn	0·04		0·06		0·05		0·04		0·03	
Mg	2·25		2·08		2·05		2·47		3·05	
Ca	1·96		1·90		1·93		1·60		1·83	
Na	0·0	1·98	0·0	1·90	0·0	1·93	0·44	2·06	0·22	2·08
K	0·02		0·0		0·0		0·02		0·03	

* Total Fe as FeO.
n.d. Not determined.

1–3. Ferroactinolite from Shag Rocks (M.1535.3B).
4. Actinolite from albite-stilpnomelane-actinolite-schist (No. 2646), Haast Schist Group, New Zealand (Hutton, 1940, table 2). Anal. C. O. Hutton.
5. Actinolite from greenschist facies zone IV, Haast Schist Group, New Zealand (Kawachi, 1975, table 4).

mineral phases are present in the assemblage and a balanced equation can only be written for this reaction if addition and subtraction of elements through a possibly mobile pore fluid is assumed. In very low-grade iron-ore deposits a texturally similar replacement of stilpnomelane by minnesotaite has been described (Gruner, 1944; Klein, 1974). Minnesotaite is a talc in which Fe^{2+} has almost completely replaced Mg and which contains no Ca. The major chemical difference between minnesotaite and ferroactinolite is that the latter contains about 12% CaO and development of ferroactinolite in preference to minnesotaite is probably a function of higher temperature and pressure during the replacement reaction rather than bulk rock composition.

CORRELATION WITH THE SCOTIA ARC AND ANTARCTIC PENINSULA

South Georgia

The specimens from Shag Rocks described above cannot be matched petrographically with any of the rock units on the South Georgia block.

Correlation with metasediments found within the "south-eastern Igneous Complex" (Adie, 1962, table 4) is unlikely, as these consist of a fairly uniform sequence of quartz-biotite-plagioclase-*para*gneisses (Trendall, 1959; Storey and others, 1977). There is a closer similarity with the Sandebugten Formation, as recent work has shown that stilpnomelane is developed throughout the sequence (Tanner, in press). However, these rocks are siliceous sandstones and slates of turbidite facies, are well banded in units up to 50–100 cm thick and contain abundant quartz grains and clasts of acid igneous rocks. No rock type has been reported from the

Sandebugten or Cumberland Bay Formations of South Georgia which is either as finely banded throughout as the Shag Rocks greenschist or has the same high Ca content in addition to moderate amounts of Fe and Mg. In Table IV, an analysis of a typical dredged suite from

TABLE III. COMPOSITION OF CHLORITES FROM SHAG ROCKS AND THE HAAST SCHIST GROUP, NEW ZEALAND

	1		2		3		4		5	
SiO_2	26·7		28·5		26·4		26·69		25·4	
TiO_2	0·0		0·0		0·0		0·30		0·0	
Al_2O_3	17·7		18·3		18·4		19·57		20·0	
FeO	30·7*		29·6*		31·4*		21·80		30·5*	
CoO	0·42		0·33		0·34		n.d.		n.d.	
NiO	n.d.		n.d.		n.d.		3·13		n.d.	
Fe_2O_3	–		–		–		3·49		–	
MnO	0·33		0·33		0·31		0·30		0·38	
MgO	12·0		11·32		11·5		16·23		13·00	
CaO	0·0		0·09		0·0		0·0		0·01	
Na_2O	0·0		0·0		0·0		0·0		0·03	
K_2O	0·09		0·33		0·0		0·0		0·05	
	NUMBER OF IONS ON THE BASIS OF 28 OXYGEN ATOMS									
Si	5·80	8·00	6·03	8·00	5·72	8·00	5·58	8·00	5·41	8·00
Al	2·20		1·97		2·28		2·42		2·59	
Al	2·33		2·60		2·42		2·36		2·43	
Ti	0·0		0·0		0·0		0·05		0·0	
Fe	5·57		5·24		5·69		4·33		5·44	
Co	0·07		0·06		0·06		–		–	
Ni	–		–		–		0·03		–	
Mn	0·06	11·95	0·06	11·63	0·06	11·93	0·05	11·90	0·07	12·08
Mg	3·90		3·57		3·70		5·08		4·12	
Ca	0·0		0·02		0·0		0·0		0·0	
Na	0·0		0·0		0·0		0·0		0·01	
K	0·02		0·08		0·0		0·0		0·01	

* Total Fe as FeO.
n.d. Not determined.

1–3. Pycnochlorite-brunsvigite from Shag Rocks (M.1535.3B).
4. Ripidolite from albite-epidote-chlorite-amphibole-calcite-schist (No. 2718), Haast Schist Group, New Zealand (Hutton, 1940, tables 7 and 8). Anal. C. O. Hutton.
5. Ripidolite from mafic rocks in zone IV, Haast Schist Group, New Zealand (Kawachi, 1975, table 6).

TABLE IV. CHEMICAL ANALYSES OF ROCKS FROM THE SCOTIA ARC

	1	2	3	4
SiO_2	51·56	47·37	58·04	69·58
TiO_2	0·56	1·20	1·13	0·61
Al_2O_3	17·54	16·46	14·42	13·25
Fe_2O_3	1·80	1·92	6·38	3·09
FeO	8·28	7·41	3·60	1·80
MnO	0·36	0·15	0·17	0·09
MgO	5·23	8·64	3·32	1·22
CaO	11·42	10·19	3·64	1·48
Na_2O	2·18	2·74	3·35	4·16
K_2O	0·33	0·06	1·45	1·86
P_2O_5	tr	0·14	0·17	0·18

tr Trace.

1. Tremolite-epidote-albite-greenstone; stones dredged near Shag Rocks (Tyrrell, 1945, p. 91).
2. Actinolite-clinozoisite-albite-chlorite-schist; Clarence Island (Barth and Holmsen, 1939, p. 59).
3. Mean of 78 analyses of sandstones from the Cumberland Bay Formation; South Georgia (Clayton, 1981).
4. Mean of 29 analyses of sandstones from the Sandebugten Formation; South Georgia (Clayton, 1981).

Shag Rocks (Tyrrell, 1945) is contrasted with mean analyses for the Sandebugten and Cumberland Bay Formations (Clayton, 1981).

Correlation between the greenschists from Shag Rocks and the Sandebugten Formation is unlikely but cannot be entirely excluded.

South Orkney and South Shetland Islands

Part of a pre-Jurassic metamorphic complex recognized along the south Scotia Ridge and in the South Shetland Islands (Adie, 1964; Dalziel and Elliot, 1971, 1973) has features in common with the greenschists from Shag Rocks. Lithological and petrographical similarities between members of this complex in the South Orkney Islands and in the Elephant and Clarence Islands group (Fig. 1, inset) were first noted by Holtedahl (1929, p. 108), Tilley (1935) and Tyrrell (1945). Work by Dalziel (1971) and unpublished observations by the author in 1973–74 have established that the metamorphic complex in the South Orkney Islands has been affected by three or possibly four episodes of deformation; comparable rocks in the Elephant and Clarence Islands group have also been affected by at least three such episodes (Dalziel, 1971, 1976). The pre-Jurassic metamorphic complex in these areas consists largely of greenschist, mica-schist and amphibolite. It is characterized by:

i. Albite-bearing assemblages, locally porphyroblastic.
ii. Distinctive thin pink garnet–quartz bands.
iii. Coarse-grained garnet-hornblende rocks and thin bands of marble.
iv. Graphitic schists and graphite-bearing pelites.
v. Polyphase (> 3) deformation.

Specimens from Shag Rocks clearly show the effects of at least two phases of deformation and in thin section they are petrographically very similar to rocks described from Clarence Island (Tyrrell, 1945); they are also chemically alike (Table IV). The closest comparison may be drawn with actinolite-, albite- and epidote-bearing greenschists from Signy Island (Thomson, 1968, p. 12) and similar greenschists and some hornblende-schists from Coronation Island (Thomson, 1974, p. 13 and 14). The notable difference is that these rocks contain biotite instead of stilpnomelane and the significance of this is discussed later.

It is concluded that, although some of the diagnostic features of the pre-Jurassic metamorphic rocks are absent from the Shag Rocks collection, petrographical similarities are sufficiently strong for the two suites to be correlated with reasonable certainty.

Southern Andes

A pre-Middle Jurassic metamorphic complex was identified in the southern Andes by Kranck (1932). However, in many areas both Kranck and later workers (Katz, 1964, 1973; Dalziel and Cortés, 1972) have found it difficult to separate polyphasally deformed metamorphic rocks of the older complex from those of late Mesozoic age. Little detailed petrographical work has been published on the older metamorphic rocks from this region since the work of Kranck (1932) and available data do not permit a meaningful comparison with the assemblages described here from Shag Rocks. The older suite includes greenschist to low amphibolite-facies rocks with abundant quartz veins (Kranck, 1932; Dalziel and Cortés, 1972; Dalziel and Elliot, 1973); stilpnomelane has not been reported.

Metamorphic Facies

Shag Rocks

The stilpnomelane-bearing albite-epidote-actinolite-chlorite assemblages described above are identical to those reported from the Haast Schist Group (Otago schist belt) on South Island, New Zealand, by Turner and Hutton (1935), Hutton (1940), Turner (1968) and Kawachi

(1975). In New Zealand they belong to the Chlorite 4 sub-zone of the greenschist facies in the Wakatipu metamorphic belt.

Similar assemblages have also been described by Seki and others (1971) from the central Kii Peninsula in the Sanbagawa belt of Japan, where actinolite-epidote-albite-chlorite-schists with white mica, quartz, calcite and stilpnomelane occur in the "actinolitic greenschist" facies (zone IV). The Shag Rocks assemblages may therefore be correlated with those found in the upper greenschist facies in parts of New Zealand and Japan. In both areas the metamorphism is of medium- to high-pressure type and the greenschists are associated with rocks of the glaucophane-schist facies.

South Orkney Islands

As mentioned earlier, stilpnomelane has not been reported from the metamorphic complex in the South Orkney Islands and biotite occurs in actinolite-epidote-albite/oligoclase assemblages (Thomson, 1968, 1974). Glaucophane is also apparently absent. Parageneses for the metamorphic rocks have not been listed but the following appear typical:

quartz–albite/oligoclase–muscovite–biotite–epidote–chlorite $\pm$garnet	greenschist
albite/oligoclase–actinolite–epidote $\pm$biotite, muscovite	
hornblende–albite/oligoclase–epidote $\pm$garnet, biotite, quartz	amphibolite
hornblende–albite/oligoclase–biotite–garnet	
calcite–muscovite–biotite–actinolite	marble and calc-schist
tremolite–garnet	

The garnet is almandine-rich (Thomson, 1974, table IV) and the hornblende is either a pale green-blue actinolitic hornblende or deeper green common hornblende. Plagioclase is An_{5-13} in the above assemblages but it reaches An_{28-36} in muscovite-biotite-epidote-garnet-schists from Mansfield Point (Thomson, 1974, p. 16). Sillimanite (fibrolite) was reported from the latter area by Thomson but electron-microprobe examination by the author of three "fibrolite-bearing" specimens, including that figured by Thomson (1974, pl. Vf) has not confirmed the presence of that mineral. Thomson (1968) concluded that the metamorphism was of Barrovian type but Smellie and Clarkson (1975) have recently suggested that, in both the South Orkney and South Shetland Islands, it was more similar to the high P/T metamorphism found in the Sanbagawa belt of Japan.

The above assemblages resemble those found at the greenschist-amphibolite facies transition in the Haast Schist Group (Otago schists) of New Zealand (Turner, 1968). Similarly, in the Bessi-Ino area of the Sanbagawa belt of Japan, Banno (1964) has described an epidote-amphibolite zone transitional between the greenschist and amphibolite facies, in which an albite-epidote-hornblende zone (D) passes to an oligoclase (An_{15})-epidote-hornblende zone (E) with increasing grade. Both sub-calcic and common hornblende occur and almandine garnet and biotite are stable. Most of the mineral assemblages in the metamorphic complex of the South Orkney Islands are identical or closely similar to those reported by Banno. Together with close similarities to the metamorphism of the Haast Schist Group and the presence of muscovite in the epidote-amphibole rocks (Miyashiro, 1973, p. 309), this suggests that the regional metamorphism in the South Orkney Islands was of medium-high pressure type and mainly transitional between the greenschist and amphibolite facies.

South Shetland Islands

On Smith Island (Fig. 1, inset), glaucophane associated with lawsonite (Rivano and Cortés, 1976) and stilpnomelane (Smellie and Clarkson, 1975) in albite-epidote-bearing assemblages is clear evidence, as recognized by these workers, of metamorphism of high-pressure low-temperature type (Miyashiro, 1973). Smellie and Clarkson (1975) concluded that the assemblages are typical of the transition between the glaucophane-schist and greenschist facies.

Farther north, in the Elephant and Clarence Islands group, the presence of glaucophane (Dalziel, 1976) and of chloritoid (Tyrrell, 1945, p. 84) suggests that rocks of the metamorphic complex may also belong to the glaucophane-schist facies. However, other rocks contain the assemblage hornblende-epidote-albite (Tilley, 1930), similar to that described from the South Orkney Islands, and until further petrographical work is carried out it may be inferred that rocks of more than one metamorphic facies are present. It is important to note that albite porphyroblasts are widely developed in rocks described from the Elephant and Clarence Islands group and the South Orkney Islands, as they are first noted at the glaucophane-schist–epidote-amphibolite facies transition (Banno, 1964) or actinolite-greenschist facies (Seki and others, 1971) in the Sanbagawa belt and are commonly found there in rocks of the epidote-amphibolite facies.

Summary

Although much detailed petrological and geochemical work remains to be done, the present data suggest that the greenschists forming Shag Rocks may be correlated with the pre-Jurassic metamorphic complex farther south and that both have been subject to metamorphism of a transitional medium- to high-pressure type. Grouped within this metamorphic complex are fragments belonging to the glaucophane-schist to greenschist facies (Smith Island), greenschist facies (Shag Rocks) and epidote-amphibolite facies (South Orkney Islands). Parageneses analogous to those found in these areas occur in the Haast Schist Group in New Zealand and they are particularly well developed in the Sanbagawa belt of Japan. Metamorphism took place at a lower P/T than the high-pressure Franciscan type (Miyashiro, 1973) and may have varied somewhat in type from one locality to another, as it does across the breadth of the Sanbagawa belt (Seki and others, 1971).

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