Chapter 6 Metamorphic and intrusive rocks of Foula

Introduction

The island of Foula is situated in the Atlantic Ocean, 14 miles (22 km) WSW of Wats Ness. It consists mainly of sedimentary rocks of Old Red Sandstone age (Chapter 12) but contains a 0.5 mile (800-m) wide strip of metamorphic rocks along its east coast ((Figure 21), p. 173). The metamorphic rocks are separated from the sedimentary rocks to the west by a fault and they give rise to relatively flat ground at roughly 100 ft (30 m) OD bounded by low sea cliffs. They consist mainly of metasediments and are cut by a network of microgranite dykes and sills.

The metasediments are made up of alternating bands of garnetiferous quartz' feldspar-granulite (psammite) and garnetiferous mica-schist (semi-pelite and pelite). They contain lenses and layers of amphibolite and hornblende-schist with bands and patches of epidosite. The amphibolites probably originated as basic and ultrabasic sills and dykes. Several bands of crystalline limestone with calc-silicate minerals have been recorded. All the metamorphic rocks contain feldspathic lits and porphyroblasts; they are also cut by two sets of syntectonic granite and pegmatite intrusions. There is a marked similarity between the Foula metamorphic rocks and parts of the Neeans Feldspathic Group of the Walls peninsula (pp. 43–44).

The characteristic mineral associations of the Foula metamorphic rocks are given on pp. 66–68 and these show that the rocks belong to the transition between the greenschist and amphibolite facies of metamorphism (Turner 1968, pp. 302–20). The only aluminium-silicate mineral in Foula which is diagnostic of the amphibolite facies is staurolite and this has been recognized in only one band (p. 67).

The sequence of events in the structural and metamorphic development of these rocks appears to be similar to that of the metamorphic rocks of the Walls Peninsula (pp. 48–57), though not all stages recorded there can be recognized. The following events can be recognized in Foula:

1. Deposition of sediments, emplacement of basic intrusions. (No evidence for a pre-Main Phase period of folding.)
2. Beginning of emplacement of 'pre-tectonic' granite and pegmatite veins, and development of feldspar lits and porphyroblasts. This phase probably continued throughout period (3).
3. 'Main phase' folding, producing tectonite fabric, followed by mimetic coarsening and porphyroblast metamorphism.
4. Late 'brittle' folding with production of kink bands and conjugate folds.
5. Emplacement of network of sills and dykes of porphyritic microgranite (pp. 67–70).
6. Development of N10°–20°E and N10°–20°W–trending faults and some near-horizontal thrusts.

Metamorphic rocks

Field relationships

Metasediments

Though the metamorphic rocks are composed of roughly alternating bands of feldspathized garnetiferous mica-schist and flaggy quartz-feldspar-granulite, major groups in which psammite or pelite bands predominate can be recognized. Many of the mica-schists have been converted into banded gneisses or augen-gneisses by feldspar 'permeation'. In the banded psammite the most common products of feldspathization are lits of feldspar 1 to 8 in (2.5–20 cm) thick, which are concordant with the foliation and are generally rodded. These rods are oval in cross section, up to 1 ft (30 cm) wide and 6 in (15 cm) high. Discrete feldspar porphyroblasts are more common in the amphibolites and mica-schists. The intensity of feldspar permeation is variable within the sequence, and certain parts of the coast section, such as that between Swaa Head and Kinglia [HT 977 397], are virtually unaffected.

Two beds of crystalline limestone, respectively 15 ft (4.6 in) and 41 ft (1.4 m) thick, are present on the north shore of Little Ham, 300 yd (275 m) S of Ham Voe and at Strem Ness]972 413], in the north-east corner of the island. Other bands appear to crop out on the inaccessible cliffs of Durga Ness [HT 976 383].

Amphibolites

Concordant bands, lenses and pods of coarse-grained amphibolite, amphibole-epidote-rock and epidosite are present throughout the metamorphic rocks. They range in thickness from less than 1 ft (30 cm) to 20 ft (6 m). They are most commonly 4 to 6 ft (1.2–1.8 m) thick and can be traced laterally for several metres. Though a number of ultrabasic bodies appear in the field to be virtually monomineralic, many consist of irregularly interbanded streaks and lenticles of amphibolite and epidosite. Within the larger lenticular masses these bands, which range in thickness from 0.5 to 0.75 in (12–19 mm), are folded, with the individual fold axes parallel to the lineation, but with axial planes randomly orientated and curved when seen in sections normal to the lineation. Close to the margins of the larger bodies the amphibole-epidote-rock is in places inter-banded with quartz-feldspar-granulite and both rock types are folded together. The folds in these marginal zones are more regular, and their axial planes are roughly parallel to the regional foliation (p. 49). Many of the smaller amphibolite masses contain roughly equidimensional porphyroblasts of feldspar.

Early (pre- and syn-kinematic) granites and pegmatites

The metamorphic rocks of Foula are cut by both concordant and cross-cutting veins of:

1. Yellowish pegmatite devoid of dark minerals with large white quartz crystals.
2. Pink medium-grained granite with some schistose partings.

The concordant intrusions are folded with the country rock and the crosscutting veins show typical ptygmatic folds. It is possible that many of the veins were intruded along foliation planes which were already folded and therefore the period of vein formation may have extended to the post-kinematic phase.

Fold styles in metamorphic rocks

Minor folds of two periods are recognized (p. 40). The early folds ascribed to the main phase of deformation are isoclinal or near isoclinal with axes parallel to the rodding of the feldspar lits and the mineral lineation of the gneiss. The axial planes of the folds are sub-parallel to the regional foliation within the metasediments but irregularly curved in the amphibolites and amphibole-epidote-rocks (p. 68). All these folds are small with wave lengths generally less than 2 ft (0.6 m). The area is too small for major structures, which could be ascribed to the folding of this period, to be recognized.

The second set of folds consists of brittle-style kink folds (pp. 51–52) with a regional plunge of 30 degrees to S5°–10°E. These folds are best seen at Baa Head and between Skarf Skerry [HT 978 396] and The Taing where they affect the platy mica-schists. Locally the axial planes of these brittle folds are fractured and pass into small faults.

Petrography

Granulites

The characteristic mineral assemblage of the Foula granulites is: quartz, albite-oligoclase with subordinate interstitial potash feldspar, subordinate muscovite and biotite. Epidote and almandine-garnet are present in some specimens. Accessory minerals are zircon, apatite and sphene.

Quartz forms up to 70 per cent of the total volume and occurs in discrete, somewhat lenticular bands, 0.3 mm to several millimetres thick. These are composed of interlocking grains elongated in a ratio of 3 to 1 parallel to the foliation, together with subordinate patches of albite-oligoclase and interstitial microcline which appears in some cases to be replaced by myrmekite (S29889) [HT 976 390]. Albite-oligoclase, usually kaolinized in the centre or patchily throughout, also forms irregular blebs or porphyroblasts. In the coarsely banded granulites khaki-brown biotite and muscovite form scattered small curved flakes, but in the more finely banded rocks they form folia, up to 0.3 mm thick, which contain thin lenticles of cloudy plagioclase.

Epidote, which in some cases forms 20 per cent of the total volume, appears as :

1. Large grains (up to 0.8 mm in diameter) which are usually slightly elongated parallel to the foliation, but in some cases (S50823) [HT 973 388] cut across it. Elsewhere they are bent or fractured.
2. Indistinct aggregates within or associated with feldspars and probably alteration products of feldspar.

Zircon is the most consistently present accessory mineral. It forms euhedral crystals scattered throughout the quartzose and feldspathic bands. Apatite and sphene are abundant in certain bands.

Garnetiferous mica-schist and gneiss

The following mineral assemblage is present in most of the Foula mica-schists : muscovite, biotite, almandine, epidote, quartz, calcic albite or oligoclase. Accessory minerals are apatite, zircon and sphene. Only one highly aluminous band which contains kyanite, staurolite, biotite, muscovite, quartz and oligoclase has been recorded.

Most of the mica-schists are strongly foliated and consist of:

1. Micaceous folia composed of thick plates of muscovite, which are in many instances mantled by smaller, thinner flakes of biotite which is pleochroic from yellowish-green to khaki-brown.
2. Folia made up of an aggregate of irregular interlocking granulitized crystals of albite-oligoclase and quartz. The quartz grains are generally elongated parallel to the foliation.
3. Feldspar lits consisting of very large (up to 1.5 mm diameter) irregular plates of oligoclase.

The garnets are generally slightly elongated parallel to the foliation, and the larger porphyroblasts contain inclusions of quartz and muscovite. Epidote, as in the granulites (p. 66), occurs both as large crystals and as diffuse aggregates in saussuritized feldspars.

The band of garnet-kyanite-staurolite-schist on Swaa Head (S29898) [HT 975 401], (Plate 8), fig. 3) contains garnet poikiloblasts up to 5 mm in diameter, large subhedral crystals of kyanite which form 20 per cent of the total volume, and smaller subhedral crystals of staurolite. Muscovite, in thick plates, forms distinct folia, while biotite is scattered in small plates throughout. Quartz and feldspar (oligoclase) form irregular aggregates of small grains which make up less than 50 per cent of the total volume.

There are also bands of poorly foliated calc-schist which consist of very irregular lenses and folia of:

1. Fine-grained interlocking feldspar-quartz aggregates.
2. Epidote-calcite aggregates with abundant large sphenes, and
3. Poikilitic feldspar full of small grains of amphibole.

Small laths of amphibole and flakes of chlorite are scattered throughout.

Crystalline limestones

The limestones (S50843) [HT 970 413] are composed of calcite with varying amounts of epidote, clinozoisite and hornblende. In the Strem Ness peninsula tremolite is associated with calcite.

Amphibolites and epidosites

The metamorphosed basic rocks are composed of hornblende, epidote, clinozoisite and almandine with subordinate oligoclase or albite-oligoclase. Accessory minerals are sphene, apatite and biotite.

The amphibolites (S29883) [HT 974 384], (S29886) [HT 972 389], (S29893) [HT 976 390] are composed of large anhedral stumpy crystals of hornblende which range in diameter up to 2 mm and make up between 70 per cent and 90 per cent of the volume of the rock. In the hornblende-rich bands the crystals show little or no orientation but in the more feldspathic layers and, particularly in the banded hornblende-epidote-rocks (S50838) [HT 975 402], hornblende crystals are strongly elongated and aligned. Apart from almandine the remainder consists largely of interstitial anhedral plates of extensively altered oligoclase together with very small interstitial patches of quartz. Sphenes are abundant, both as large euhedral crystals and as clusters of small rounded grains. Apatite normally forms clusters of subrounded crystals. The amphibolites are commonly cut by thin veinlets of epidote and potash-feldspar, locally with penninite.

The epidote-rich bands are weakly foliated and consist of up to 90 per cent epidote which forms large subhedral to euhedral crystals, averaging 0.8 to 1.2 mm in length but reaching 6 mm, with less than 10 per cent interstitial oligoclase together with rare interstitial quartz. Sphene and apatite are both abundant accessory minerals.

Banded epidote-amphibole-quartz rocks (S29891) [HT 976 390] are common. These consist of alternate laminae of:

1. Calc-silicate, composed of up to 60 per cent of epidote and interstitial patches of amphibole (?actinolite), which is pleochroic from straw-yellow to bluish green, and
2. a coarse-grained quartz aggregate with individual crystals up to 2 mm across.

Syn-tectonic pegmatites and granites

The syn-tectonic granites have a banded texture both on the macroscopic and microscopic scale. Though in the porphyritic granites (S29892) [HT 976 390] the feldspar phenocrysts and the feldspar (untwinned potash feldspar and albite-oligoclase) of the groundmass are relatively undeformed, the quartz occurs as elongated interlocking grains. Biotite and muscovite form small crystals which are in most cases orientated parallel to the foliation, but which in one thin section (S50825) [HT 973 388] give rise to radiating aggregates.

Microgranite minor intrusions

The metamorphic rocks of Foula are cut by a network of sills and dykes of pink porphyritic microgranite, which, in the field, show no evidence of deformation by either of the two sets of folds described above (p. 65), but which in thin section contain irregular planes and patches of sheared and granulitized granite.

Field relationships

Ruscar Head Microgranite

By far the most extensive outcrop of pink micro-granite is that exposed along a 700-yd (640-m) stretch of the shore at Ruscar Head, near the north-east corner of Foula. This outcrop appears to be part of a large sill which splits both northwards and southwards into a network of sills and dykes. Though in the Ruscar Head exposure neither top nor base of the sill is seen, metamorphic rocks apparently underlying this sill appear to be present in the faulted exposures at the head of the geo just south of Ruscar Head. In the northern half of the Ruscar Head peninsula a number of small masses of intensely granite-veined granulite and gneiss project through the granite. Though it is possible that these are detached enclaves within the granite it is more likely that they are projecting portions of the country rock underlying the sill.

The Ruscar Head microgranite is intensely jointed and in the southern half of its outcrop the following sets of joints are most prominent:

1. Closely set joints trending S10–20°E and inclined at 70° to WSW.
2. Two sets of joints, both trending N10–20°E inclined at 70° to WNW and 50–60° to ESE. The trend of the latter joints swings to NNW in northern part of outcrop, and
3. Near horizontal, gently curving joints inclined eastward at a low angle.

The microgranite is cut by swarms of thin chlorite-bearing quartz veins emplaced mainly, but not invariably, along the S10–20°E trending joints. The swarms are up to 6 yd (6 m) wide and individual veins are 1 to 2 in (2.5–5 cm) (exceptionally up to 5 in. (12.5 cm)) thick and 6 in to 1 ft (15–30 cm) apart. The microgranite also contains a number of lenticular kaolinitized zones of up to 21 ft (0.8 m) wide and 15 yd (14 m) long, in which the granite is completely white. The orientation of these zones is parallel to the S10°E joints.

Sills and dykes

Both north and south of Ruscar Head, porphyritic microgranite forms a network of sills and dykes cutting the metamorphic rocks. These are most closely spaced in the immediate vicinity of Ruyhedlar Head [HT 975 402] and Swaa Head where individual sills range in thickness from 2 to 5 ft (0.6–1.5 m) and are 6 to 10 ft (1.8–3 m) apart. Though roughly concordant, they tend to transgress the foliation by a series of small steps. The dykes are more widely spaced and generally thinner than the sills. They have a north-easterly trend and a steep inclination to the south-east. There are instances of dykes cutting sills and *vice versa,* but in most cases the microgranite of the intersecting dykes and sills is continuous in all directions, indicating that the network of microgranite was formed in a single intrusive pulse.

South of Swaa Head microgranite sills are less closely spaced, and dykes are very rare. Sills range in thickness from 1 to 7 ft (30 cm-2.1 m) and easily accessible examples occur on both shores of Ham Voe.

Intrusion-breccia

An irregular sill of microgranite with three roughly lenticular masses of intrusion-breccia close to its lower (north-eastern) margin, is exposed on the shore just south-west of The Taing, 670 yd (610 m) NE of Ham Pier. Two of the breccia masses contain subangular clasts of all the types of metamorphic rocks encountered in Foula. The clasts range in size from 4 in to 2 ft (10–60 cm) and are set in a matrix of microgranite. Though the orientation of many clasts is parallel to that of the foliation of the adjoining county rock, a certain proportion of clasts, particularly those composed of amphibolite, are randomly orientated. The most southerly lens of breccia which is up to 5 ft (1.5 m) thick and is closest to the sill consists of subrounded fragments of amphibolite and gneiss, up to 2 in (5 cm) long, normally orientated parallel to the sill margins, set in granulitized granite. The junctions between the lenses of breccia and between breccia and granite are gradational. It is thought that the brecciation of the country rock is the result of gas-streaming ahead of the rising granitic magma. This produced a breccia approximately *in situ,* leaving the orientation of the country rock, which forms most of the clasts, unchanged. Subsequently the intruding magma engulfed the clasts and carried with it and rotated many of the less platy fragments, particularly the amphibolites. It is presumed that within a lens of breccia containing many small ovoid clasts the velocity of the gas-charged magma was sufficient to move and round the clasts.

Petrography

The Ruscar Head microgranite is composed of plagioclase phenocrysts set in a granular groundmass rich in quartz, and poor in mafic minerals. The phenocrysts form from 20 to 70 per cent of the total volume of the rock, range in diameter from 3 to 0.6 mm and consist entirely of oligoclase (An > 20) which is occasionally zoned, and is in many cases turbid particularly in the centre. The phenocrysts in places form clusters and they always have irregular or serrate margins with embayments suggesting partial resorption by the matrix. The latter consists of a fine-grained mosaic of equidimensional grains of quartz with intersertal patches of potash-feldspar. The ratio of quartz to feldspar in the groundmass ranges from 40:60 to 75:25 and in some areas within the Ruscar Head Sill there are large irregular patches composed entirely of a coarse quartz mosaic. In some sections (S29900) [HT 975 401] there is an increase in the grain size of the matrix in the immediate vicinity of the oligoclase phenocrysts. In a number of sections ferromagnesian minerals are completely absent, in others the only dark minerals are small plates of muscovite and biotite, or, more commonly, irregular patches of penninite or diffuse chloritic material.

Though some hand specimens of the microgranite show foliation, this is less obvious in thin section. All thin sections, however, show varying degrees of granulation of the groundmass ((Plate 8), fig. 5), which may be due to shearing before the granite was completely consolidated. The granular texture which is reminiscent of the texture of many coarse-grained felsites may, however, be an original feature due to the high percentage of quartz in the matrix.

Faults and crush belts

Both the metamorphic rocks and microgranite intrusions are cut by two suites of closely-spaced sub-parallel, somewhat curving faults with displacements not exceeding 10 ft (3 m) as well as a number of low-angle thrusts. In the area extending from Ruscar Head to Shoabill the trend of the majority of the faults ranges from due north-south to N20°W, and their inclination ranges from 60° to the west to 50° to the east. At Baa Head, just south of Ham Voe, the country rock is intensely shattered close to these faults and the foliation is locally buckled into open conjugate folds similar to those associated with faults in West Mainland (p. 53).

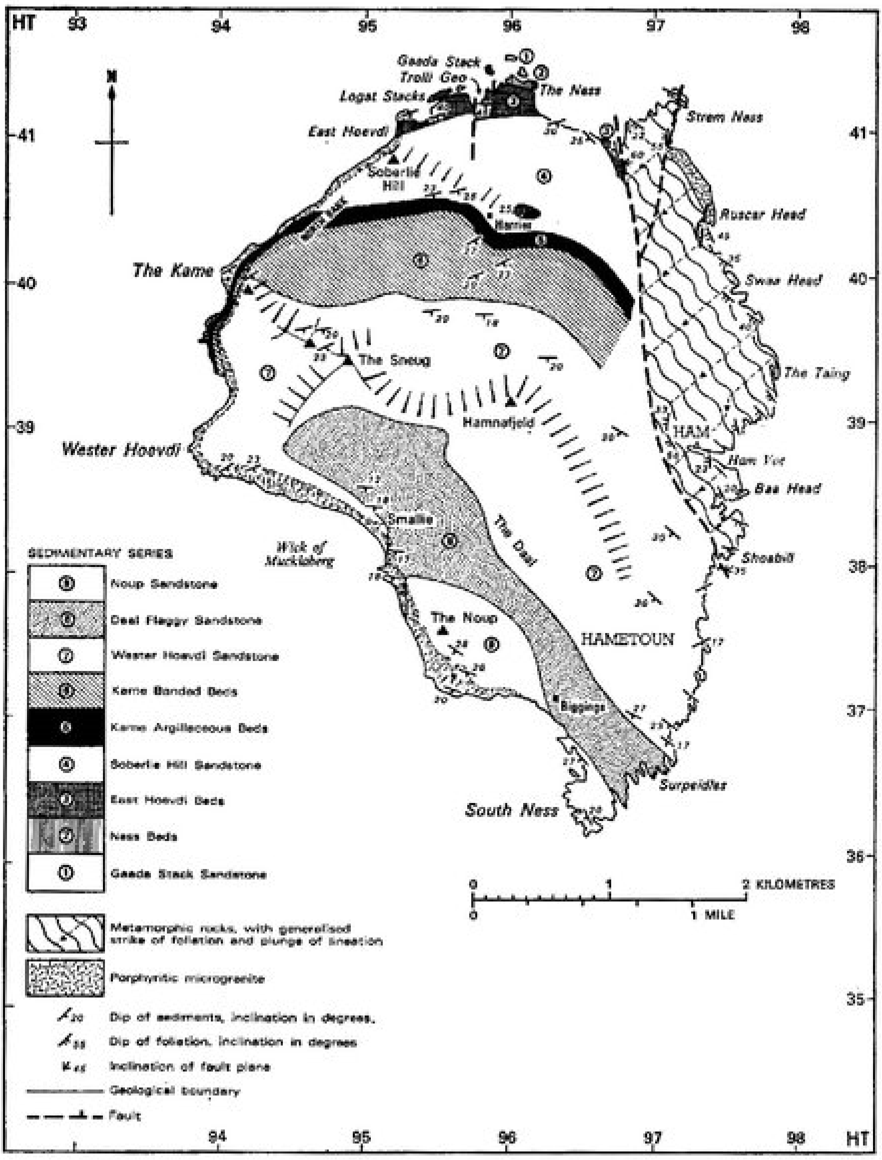
At Strem Ness and Ruscar Head the following two intersecting sets of faults are developed:

1. Trend N10–20°E with steep inclination to both east and west.
2. Trend N20–40°W with inclinations ranging from 55° to the south-west to 65° to the north-east.

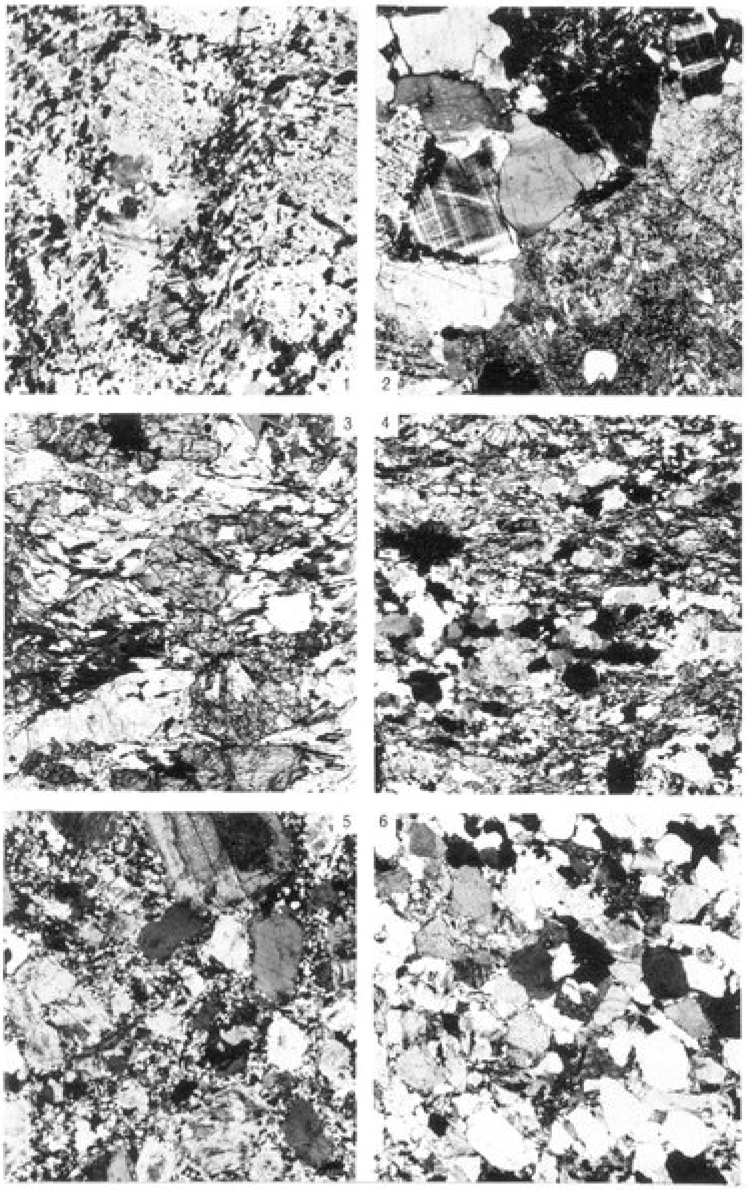
Thrust planes accompanied by considerable zones of shattered rock crop out on the west side of Strem Ness (trend north–south, inclination 25° to the west), on the shore between Ruscar Head and Ruyhedlar Head [HT 974 403] (trend south-south-east, inclination to the east-north-east), at Swaa Head (trend east to east-south-east, inclination to the south), and between The Taing and Sloag Burn [HT 977 391] (trend north–south, near horizontal). The extreme variation in the direction of inclination of the exposed sections of thrusts over the whole area would suggest that the thrusts are highly undulating planes, whose regional disposition is near horizontal.

Reference

TURNER, F. J. 1968. *Metamorphic Petrology.* New York: McGraw-Hill.



(Figure 21) Geological sketch-map of Foula.



(Plate 8) Photomicrographs of metamorphic rocks, microgranite and sandstone of Ve Skerries and Foula Fig. 1. Slice No. (S29982) [HU 103 658]. Magnification × 16.8. Crossed polarisers. Granulitized granite with large crystals of albite-oligoclase, sieved with muscovite. Adjacent feldspar crystals are in optical continuity and separated by streaked out mozaic-quartz. Small near-euhedral crystals of epidote are abundant in the quartz network. Ve Skerries, North Skerry, west coast [HU 103 658]. Fig. 2. Slice No. (S29989) [HU 104 656]. Magnification × 31. Crossed polarisers. Coarse poorly-foliated granite-gneiss composed of quartz, large clear plates of potash-feldspar and albite-oligoclase full of inclusions of white mica, and small grains of epidote. Ve Skerries, Ormal, north coast [HU 105 656]. Fig. 3. Slice No. (S29898) [HT 975 401]. Magnification × 8. Plane polarized light. Garnet-kyanite-staurolite-gneiss, with muscovite and quartz. Large stumpy plates of kyanite with close parallel cleavage (bottom and top centre), smaller plates of golden-yellow staurolite, and subrounded garnets are set in a base of biotite, muscovite, quartz and andesine. Foula, Swaa Head, 860 yd (790 m) NNE of Sloag. [HU 976 401]. Fig. 4. Slice No. (S50823) [HT 973 388]. Magnification × 20. Plane polarized light. Strongly foliated and sheared quartz-biotite-schist composed of lenses of quartz with mortar texture alternating with streaks composed of feldspar, muscovite and reddish brown biotite. Scattered porphyroblasts of oligoclase (left-centre). Foula, south shore of Ham Voe, 110 yd (100 m) E5°N of Brae [HU 974 387]. Fig. 5. Slice No. (S29900) [HT 975 401]. Magnification × 16. Crossed polarisers. Dyke of porphyritic microgranite, with granulitized matrix between phenocrysts of albite-oligoclase. Foula, Swaa Head, 880 yd (800 m) NNE of Sloag [HU 976 401]. Fig. 6. Slice No. (S50829) [HT 963 407]. Magnification × 16. Crossed polarisers. Coarse-grained arkose with subrounded to subangular grains. Ratio of quartz to feldspar grains is 50:50. Some interstitial flakes of muscovite. Matrix forms 15 per cent of total volume, composed mainly of carbonate. Foula, shore of Whiora Wick, 520 yd (470 m) E20°S of Freyars [HU 966 412].