Chapter 13 The Northmaven–Muckle Roe Plutonic Complex

Introduction

Unfoliated igneous rocks occupy most of the area west of the Haggrister and Walls Boundary faults from Muckle Roe to the northern margin of the One-inch Sheet (Figure 5) and (Figure 23). They form the southern part of the intrusive Northmaven–Muckle Roe complex, of presumed Old Red Sandstone age, which extends from Swarbacks Minn to the Beorgs of Uyea near the north coast of Mainland. The total area over which rocks of this complex crop out is at least 50 sq. miles (>130 km^2) and of this total about one-quarter, or 144 sq. miles (37.5 km^2) lies in the Western Shetland One-inch Sheet under description. The rocks occurring in this smaller portion are representative of the whole complex in rock types and probably also in the nature and sequence of the components; however, they include no member of the aegirine-riebeckite minor intrusive group which is a feature of the complex north of Ronas Voe, but on the other hand include two small outcrops of ultrabasic rock which is unrepresented to the north but is similar to material in the Sandsting Complex (p. 216). The descriptions which follow are based almost entirely on the six-inch maps and collections made during the field survey in 1931–33 and can be regarded as no more than preliminary to a more comprehensive study of the whole complex. Unlike the Walls district the Muckle Roe–Northmaven area has not been the subject of revision survey in recent years.

Age and sequence of events

The rocks of the complex comprise a wide range of plutonic types from ultrabasic to aplo-granophyric in composition and a suite of dyke rocks ranging in composition from olivine-dolerite to very acid felsite or rhyolite. They are not foliated but are traversed by many crush zones which are thought to be related to the later movements along the Walls Boundary Fault. They are intrusive into regionally metamorphosed country rock which is largely basic hornblendic gneiss with important mica-schist, quartzo-feldspathic granulite, and siliceous granulite components (Chapter 3). The complex consists essentially of granite, diorite and gabbro and is considered here to belong to one period, probably a prolonged one, of magmatic activity during the Devonian period. It should be recalled however that in the early description by Hibbert (1820; 1822) and the later by Peach and Horne (1879; 1884) the gabbro-diorite portion was considered a pre-Old Red Sandstone intrusion. In the Muckle Roe–Gunnister Voe area there is no geological evidence of an upper limit of age other than that of faulting and shattering along the Haggrister and Walls Boundary faults. In One-inch Geological Sheet Northern Shetland, however, xenoliths of rock which is considered by the writer to be andesitic lava comparable with the Eshaness volcanic rocks are enclosed in the Ronas Hill granite at Colla Firth (Summ. Prog. 1933, p. 78). It is therefore probable, or at least possible, that the complex is later than the Old Red Sandstone volcanic series of Eshaness. The age of rhyolite lava from Eshaness has been given by Flinn and others (1968) as 373 + 2 m.y. from Rb–Sr whole-rock determinations, while the age of the Ronas Hill granite determined by the Rb–Sr method on biotite separated from the rock is reported as 358 ± 8 m.y. (Miller and Flinn 1966), a value practically the same as that determined recently by Snelling for the Sandsting granite (p. 211).

While the age of the granite component of the plutonic part of the complex can thus be regarded as defined within narrow limits by these isotopic determinations on analogous granites there is geological evidence within the area under description that the magmatic activity continued over a long period. From field data the complex can be separated into three major time groups: (i) a stage of early minor intrusion, (ii) a period of plutonic intrusion which can probably be further subdivided into three stages and (iii) a period of late minor intrusion. The plutonic period comprised a stage of basic intrusion, one of acid intrusion and hybridization, and one of late granophyre intrusion; further, at some late stage or stages within the period hydrothermal activity was widespread, and is manifested by retrogressive changes in the thermally altered country rocks (p. 33), uralitization of the basic plutonic rocks (pp. 195–6), and quartzification of retrograde hornfels.

Later in time than the three-stage sequence directly referable to the complex, but perhaps also a final phase of the magmatic activity, there was an episode of mineralization leading to scapolitization and zeolitization. This episode has been shown by Mykura and Young (1969) to be closely associated in time with the crushing and faulting which affect the

Sandsting Granite and adjoining Old Red Sandstone sediments. In the Muckle Roe–Northmaven area the same time association of scapolitization and faulting is observed. Moreover there is evidence that the scapolitization is later than the quartzification of hornfels and that a still later phase of zeolitization resulted in replacement of scapolite by analcime.

Early hypabyssal intrusions

Intrusive rocks earlier than the main gabbro-diorite-granite complex have been identified with certainty in only one case. A specimen collected from the small mass of gneiss enclosed in diorite, in western Egilsay, shows a 2 cm vein of contaminated granodiorite separating country rock which has different aspects on the two walls of the vein. On one side the rock is a foliated banded pelitic gneiss (S44282A) [HU 317 694], on the other the rock is black, fine-grained and structureless (S44282) [HU 317 694]. The black structureless rock is a thermally altered porphyrite which next to the vein also shows accession of quartz. Irregularities of the gneiss and the porphyrite contacts correspond on the opposing sides of the vein as if the latter had made its way along a surface of discontinuity. The conclusion is clear that the porphyrite represents a minor intrusion in the gneiss earlier than the diorite-granite complex in which both are enclosed. Petrographically the porphyrite consists of phenocrysts of zoned plagioclase, centrally ~ An_{55}, varying seriately from 1 mm downwards in length, and microporphyritic pseudomorphs of a ferromagnesian mineral in a base of plagioclase (~ An_{30}), green hornblende, olive-brown biotite, minor ore granules and epidote grains, and interstitial quartz. The mineral constituents of the base are closely intercrystallized and encroach on the faces and along the terminations of the phenocrysts; they have a fresh, recrystallized aspect and their form varies from xenoblastic granular to idioblastic prismatic, up to 0.05 mm long. The ferromagnesian pseudomorphs are composed of microgranular aggregates of green hornblende which may represent pyroxene; larger ragged prisms of hornblende may have a different parent. At the margin against the vein plagioclase and quartz become more coarse and abundant and enclose aggregates and small crystals of the cafemic minerals (S44284), (Plate 22), fig. 1).

On the north face of the Ward of Runafirth [HU 343 676] (Figure 5), a basalt or dolerite, in which the plagioclase prisms range from 0.3 to 3 mm in length, shows some evidence of contact alteration by the gabbro-diorite. It may be an early dyke but its field relations are not known. The pyroxene is ophitic to the plagioclase (~ An_{70}) and though of a faint pink colour is monoclinic (S55658) [HU 343 675]; some small grains of squat octagonal shape may be of orthopyroxene. The mesostasis is a cryptocrystalline green and brown aggregate, with accessory iron ore, which seems to be mainly amphibole but in part is composed of compact clusters of brown microcrystalline scales of biotite which suggest thermal reconstruction.

In the eastern coastal area of Muckle Roe there is some evidence of intrusion of dolerite prior to the emplacement of the granite which forms sheets and veins in the gabbro-diorite but definite conclusions are difficult to reach partly because of the prevalence of mineral change associated with crushing close to the Walls Boundary Fault-zone, and partly because of scapolitization penecontemporaneous with the crushing. The difficulty of distinguishing and classifying basic rocks in exposures along this coast — hornblende-schist, gneiss, or granulite, gabbro-diorite, or doleritic minor intrusion — has already been mentioned (p. 29). The least doubtful field evidence is found in large masses of gneiss enclosed in granite in the Scarfataing Burn [HU 337 639] (p. 30). The mass which is exposed 250 to 300 yd (230–270 m) upstream from the burn mouth shows good foliation in dark grey and green gneiss intruded by thin wedging sheets of granite (Figure 5) which are nearly conformable with the foliation and contain streaks of gneissic rock. The gneiss includes thin bands of dark grey massive structureless basic rock which is ophitic dolerite (S45131) [HU 338 639]. This rock is composed of prismatic labradorite, An_{65} but less calcic in outer zones, colourless augite and less abundant green hornblende, both ophitically related to the plagioclase; plates of leucoxenized ilmenite are abundant and microcrystalline to cryptocrystalline pale green aggregate, locally associated with epidote, is interstitial and occupies areas 2 to 3 mm across resembling irregular vesicles. Both augite and green hornblende are extensively replaced by turbid brownish or greenish grey streaky uralite. Neither quartz nor apatite is seen. The rock shows no textural recrystallization other than that usual in uralitization, but the finely divided green interstitial material, and similar aggregate occupying narrow, impersistent shear fractures, appear to consist entirely of amphibole; this occurrence of amphibole instead of chlorite is taken to indicate low temperature hydrous recrystallization and may be connected with the intrusion of the granite sheets. Similar relations of metadolerite and hornblende-rich gneiss xenolithic in granite were observed in outcrops between the road and the coast about 250 yd (230 m) N of Scarfataing crofts [HU 342 642] (Figure 5).

A dark grey, fine-grained rock sprinkled with white phenocrysts, up to 3 mm in length, collected from the north-east corner of Roedale Water [HU 315 736], 0.5 mile (800 m) SW of Gunnister Voe, is doubtfully included among the early hypabyssal intrusions; its field relations are uncertain. The rock is composed essentially of particoloured brown and green hornblende intersertal or subophitic to calcic labradorite ($An_{65–70}$) prisms 0.1 mm long; fibrous or short acicular green amphibole of lower refractive index than the hornblende, scarce chlorite, and granules of epidote and sphene are interstitial; there is no iron ore (S55269) [HU 329 736]. The phenocrysts are idiomorphic but are very thoroughly altered to saussuritic epidote and white mica; relics of fresh feldspar indicate the original composition as $>An_{75}$. The crystallization of the white mica is unusually coarse, and some plates run the length of the phenocryst and enclose the epidotic aggregates. The alteration of the porphyritic feldspar occurred prior to inclusion in the magma which the groundmass represents since the latter locally invades the phenocrysts and incorporates the mica and epidote alteration products. The rock is unlike any other collected from the complex. From the mineral composition it can be classified as a hornblende-basalt; in the complete absence of pyroxene and iron ore it is a very unusual petrographical type and no corresponding rock is described by Johannsen (1937) under his families 2312 and 3312.

Other early igneous rocks which occur in the main gabbro-diorite area north of Mavis Grind (Figure 5) but are not separable in the field as geological units are described in the section dealing with the plutonic complex (see pp. 184–5).

The plutonic complex field relations

Ultrabasic rocks

Ultrabasic members of the plutonic complex have been found in only two localities, at the south-east corner of Glussdale Water [HU 333 732] and on the east bank of the northern of the Moora Waters [HU 328 729]. Both localities are close to the junction of the Gunnister road with the main road and are easily accessible. The outcrop at Glussdale Water shows black ultrabasic rock while that at Moora Waters is represented by large boulders, the nearest rock in place at both localities being diorite. Both outcrops are in drift and the nature of the contact of the dioritic and ultrabasic rock is not known. The rock at Glussdale Water has a greenish black aphanitic base in which glisten ophimottled cleavage surfaces up to 0.5 cm across. The Moora Waters rock is similar but blacker; it has been chemically analysed and described briefly by P. A. Sabine who has classed it as an enstatite-harrisite (Guppy and Sabine 1956, p. 35). The petrography of rocks from the two exposures is described on pp. 193–4; they are composed of orthopyroxene, clinopyroxene, calcic plagioclase, olivine, and minor hornblende and biotite.

Diorite and gabbro

The basic and intermediate rocks of the complex can be considered only together since it is impossible to separate them in the field. On the published one-inch Geological Sheet areas in which the rock has been noted as gabbroic or doleritic have been outlined and are coloured as gabbro. The outlines on the map are however only lines necessary in the production of a colour-printed sheet and do not indicate bodies possessing a definite form within or showing contact relations to the dioritic portion of the complex. No contact relations between gabbroic and dioritic rocks have in fact been noted during the survey, and as recorded by Finlay (1930, p. 685) in the more basic modifications, rocks of different composition are often confusedly intermingled, gabbros passing upwards or laterally within a small area into dioritic or even more acid types'. He stated also that gabbro is more common in the south of the Northmaven area and along the eastern margin from Mavis Grind northwards (op. cit., p. 690) and that 'in a north-west direction one finds a gradual increase in acidity and occasionally the rock is a granodiorite'. Finlay regarded the gabbrodiorite-granite as an intrusion of sheet form inclining gently westwards, showing a transition from granite above to gabbro at the base of the sheet and extending from near the north coast to Muckle Roe, the granite reappearing again in Sandsting from beneath the Walls Syncline. In the Muckle Roe–southern Northmaven area, however, mapping has shown that areas of gabbro are distributed through the diorite as far west as the entrances to Gunnister and Mangaster voes, Turvalds Head (Figure 5) and the western end of Roe Sound. In contrast to Finlay's observation that there is a gradual increase of acidity westwards it will be seen from the geological map that granite veining and acidification of the diorite is as common in the east as in the west. A phenomenon unremarked hitherto is the presence of areas where inclusions of black basaltic rock are numerous in the diorite and in places give the rock the aspect of a breccia (Plate 21A), (Plate 21B). The petrography of these rocks (pp. 198–9) suggests that some represent early volcanic or sub-volcanic rocks which have been thermally altered by the diorite. Unfortunately only a few specimens were collected during the field survey and it is not possible to make a statement of the dominant rock-type. They are mentioned in this section dealing with the gabbro-diorite rather than in the previous section on early intrusions because there is no evidence that they were intruded into gneiss country rock as minor intrusions. Detailed study of the breccia-like areas and of the xenoliths is necessary to show whether gneiss enters into or is absent from their composition. In the latter event the xenolithic material must represent early volcanic or sub-volcanic material which has been disrupted prior to or concurrently with intrusion of the plutonic rock.

In the following paragraphs the distribution of the basic rocks and their associations is dealt with by areas.

Gunnister Voe–Mangaster Voe

In this district low rocky hills and knobs separated by peat-filled hollows are composed mainly of dioritic rocks. A speckled medium-grained type, ranging in general colour from grey to dark grey as the proportion of mafic minerals—mainly hornblende—to feldspar increases, is dominant but wide variation in grain and texture and of composition occurs. Thus the rock may possess a homogeneous aspect corresponding with uniform distribution of dark and pale minerals or may show regular mottling by feldspathic clusters or irregular, impersistent feldspathic veining. Homogeneous members differ in aspect owing to difference in nature or morphology of the dark mineral; the presence of much augite is associated with a more sparkling appearance and a cuboidal fracture while the occurrence of hornblende in longer prisms, usually in the more feldspathic varieties, produces a felted as distinct from the usual granular texture. Variations from diorite to more basic and more acid types are common, and are found in any part of the district. Along the eastern limit of the diorite dark greenish grey, medium to coarse-grained gabbroic rocks are common south of Glussdale Water to the head of the Mangaster Voe, plagioclase-phyric types being frequent in the complex of granitic and basic rock between Innbanks [HU 337 700] and Scora Water [HU 337 717]. In the central area coarse gabbro occurs around the Gill of Mangaster [HU 323 708] and medium-grained feldspathic gabbro at intervals northwards to Gunnister Voe [HU 315 473], for example on the north-east of Brei Water [HU 320 713], on the south-west of Brei Water of Nibon [HU 315 713] and east of the southern loch of Moora Waters. Along the west coast coarse gabbroic types appear south of Lang Head [HU 305 703], on the east side of the Isle of Nibon and astride North Sound [HU 306 743] at the mouth of Gunnister Voe.

Varieties of granodioritic composition occur throughout the diorite. Locally, as at Noons Vird [HU 317 739] south-west of Gunnister, such rocks occupy outcrops large enough to be mapped as bodies of granodiorite which, however, have no well-defined demarcation from the diorite; in places they are contiguous with red granite of the type which forms most of the larger acid masses shown within the diorite on the One-inch Geological Map. They show irregular variation in mineral composition and contain basic xenoliths more or less digested. As well as in these larger occurrences variably acid types are numerous as bodies of small extent and irregular form, and occur also as networks of veins. These appear at intervals throughout the diorite outcrop and are particularly well exposed on Wilson's Noup [HU 301 718], on the west coast (Figure 23), where their wide variation in mineral composition from aplite to granodiorite coupled with varying degrees of assimilation of fine-grained basic material is clearly seen.

In addition to this range of varieties, which because of their continuous transition from ultrabasic to acid exemplify a serial type of variation, another type of variation which may be referred to as hiatal is found. The hiatal type is characterized in this area by an abundance of xenoliths of a very fine-grained basic igneous rock in a matrix of diorite or granodiorite of normal medium grain. On the evidence of the specimens collected during the survey of the area most of the xenoliths make sharp contact with the enclosing rock and generally no change in either rock is visible across the contact. There is usually, however, some small part of the contact along which reaction occurs involving feldspathization and coarsening of the xenolith though its original margin remains visible; from these parts feldspathic material may penetrate into the xenolith as irregular, impersistent apophyses with diffuse margins. The hiatal xenoliths are in places so numerous, as at Wilson's Noup [HU 301 718] (Plate 21A) and south of Nibon between Middis Vird and the coast [HU 305 728], that the rock has the appearance of a breccia and the sharp margins of the fine-grained basic individuals, in some cases separated by only a few millimetres of acid material, confirm the appropriateness of the designation. To the eye the xenoliths look like basic microdiorite or feldspathic basalt and some are aphanitic. Usually they contain microporphyritic thin laths of feldspar up to 2 mm in length. Petrographical examination of a number of xenoliths shows that some have been thermally recrystallized but that most retain their original, in some cases fluidal, igneous texture. The matrix to the xenoliths may be diorite or granodiorite and usually contains ghosts of fine-grained basic and even ultrabasic material or shows diffuse variation in proportion of dark to light-coloured minerals. These characteristics indicate assimilative rather than hybridization activity. The narrow veins and strings separating parts of xenoliths or penetrating into them are generally of feldspathic or quartzo-feldspathic composition and their composition and manner of occurrence suggest that fluids rich in silica and alkali have been active over a long period and represent also the final stages of magmatic action. An unusual kind of xenolith occurs a short distance north-east of Roedale Water [HU 315 736]. Described from its field relations as diorite marginal to the granite, it is a hornblende-porphyrite showing opaque white tables of altered calcic labradorite up to 4 mm long, and is perhaps an early dyke rock (p. 181).

The 'serial' and 'hiatal' styles of variation appear to reflect two geological processes. The serial is essentially a magmatic process of differentiation leading to the formation of ultrabasic, basic and intermediate rocks and late quartzofeldspathic residuals while the hiatal represents an early though cognate hypabyssal or volcanic phase perhaps representative of the undifferentiated magma. There is no evidence in this area of the structural relations of the ultrabasic, basic, and intermediate components of the complex and no directional structure has been noted. The more acid components are clearly of later formation whether their formation has been by the action of alkali-silica liquors on rocks consolidated in place or by the consolidation of intrusive granitic magma.

Mangaster Voe–Roe Sound

This area comprises the Islesburgh peninsula, lying north-west of Mavis Grind, the islands of Egilsay, The Hogg [HU 313 697], and Black Skerry [HU 319 692], and the Busta peninsula between Mavis Grind and Roe Sound (Figure 5). The same irregular distribution of patches of gabbroic rock in medium-grained speckled and fine-grained grey diorite is found as in the country north of Mangaster Voe but the gabbroic patches seem more numerous; this, however, may be occasioned by better exposure in the hilly topography of this area, which is almost free of peat cover. Here also as in the northern district, ground composed of basic and intermediate rock, in places cut by individual dykes or sheets of granite or aplite, alternates with ground in which a network of acid veins penetrates the diorite with local production of variable granodioritic material.

The most common rock of the area is diorite of medium grain which shows an equal and homogeneous distribution of pale and dark minerals, but variation to dark rocks speckled, or occasionally clotted by feldspar and to more feldspar-rich types speckled by black mineral is usual. Variation in grain appears to be less common but fine-grained varieties occur, in some cases feldspar-phyric, which on their macroscopic appearance could be classed as fine-grained dolerite or basic microdiorite. The relation of these finer-grained members to the medium-grained diorite is not known, but in one case, on the shore 300 yd (274 m) NW of Mavis Grind, the fine-grained rock is noted as forming a basic band in diorite. Breccia-type concentration of very fine-grained inclusions in diorite or granodiorite, such as have been described above from Wilson's Noup, occurs only rarely in this area, for example on the western coast south of Turvalds Head, but the basic inclusions there are, in some cases at least, of metamorphic rock (pp. 27–28). The most common type of gabbroic rock is a medium-grained, greenish grey, homogeneous gabbro, but varieties with specks of pale feldspar and scattered scales of biotite are almost as plentiful. Varieties with poikilitic feldspars up to fully 1 cm across are found, for example, on the knoll 500 yd (450 m) NW of Busta House and on the summit of Cliva Hill [HU 341 682] above Mavis Grind. The most accessible localities for examination of the gabbro and diorite, and their variation lie along the coast east and west of Mavis Grind, along the rocky ascent of the main road north from the Grind, and in the quarry bordering a stretch of this road on the Ell Wick coast. Coarse, greenish grey gabbro with plates of augite up to 0.5 cm across, ophitically enclosing plagioclase, and sparkling medium-grained doleritic gabbro with lathy plagioclase both occur in the road-cutting. In the small quarry west of the road gabbro, with primary brown hornblende subordinate to pyroxene, forms the main rock and contains veins and patches of coarse feldspar-hornblendepegmatoid (S43535) [HU 340 685] which carries both thomsonite and analcime as interstitial filling to albitized plagioclase tablets. Diorite composes the Mavis Grind isthmus and is cut by granite dykes on the eastern coast while vein networks of granite in dioritic and gabbroic rock are to be seen on both sides of the head of Mangaster Voe and in the large quarry [HU 342 683] which borders the road along Ell Wick. The main material in this quarry is grey fine-grained diorite cut by irregular veins of pink granite; in the centre of the quarry a coarse gabbroic rock overlies massive red granite and both the basic and the acid rock appear to be cut off by the grey diorite. If this relation is a real one there must be two periods of granite intrusion. Proximity to the Mangaster Voe Fault is reflected in the broken and crushed condition of the rock in this quarry; lines of dislocation strike NNE–SSW and

ESE–WSW, and along the north-north-easterly lines ribs and bands of white or pinkish scapolite are present.

Muckle Roe

Two comparatively small areas of diorite and more basic rock occur on Muckle Roe (Figure 5). They are separated by an outcrop of gneiss which extends from Roe Sound southwards to Kilka Water and from the margin of the Muckle Roe granophyre eastwards to the bridge over Roe Sound. That an irregular contact of gneiss and igneous rock lies close to the existing surface is shown by the appearance of outcrops of gneiss within the diorite, and of diorite within the gneiss in the Stabaness–Burn area [HU 330 664] and by the embayed contact of the two formations around the north end of Kilka Water. Over the northern area the igneous rock is mainly medium-grained grey diorite cut by granitic veins and traversed by granitic vein networks between Lee Skerries [HU 323 670] and Otter Ayre and on Roe Sound north of Burn [HU 333 662]; with these networks coarser-grained types of diorite with small feldspathic clots and granodioritic varieties are associated. The association of basic gabbroic types usual farther north is repeated in the occurrence of fine-grained gabbro on the higher ground west of Stabaness croft [HU 328 664].

The southern area of dioritic and gabbroic rock on Muckle Roe extends from Kilka Water almost as far south as the Burn of Scarfataing. It is separated from similar but generally more gabbroic types along the Busta Voe coast by a strip of gneiss of irregularly changing width. The contact between diorite and gneiss is seen only in a low knoll west of Orwick Water. At this exposure the igneous rock is fine-grained dolerite, in part porphyritic, and has a chilled appearance against hardened hornblende-rich gneiss; the contact curves from E–W to NE–SW to E–W again on the low surface but its inclination is not observable. The contact of the diorite with granite or granophyre on the west and south of its outcrop is conjectural owing to poor exposure under drift. In the most southerly exposure, south-west of Orwick Water, the diorite has granodioritic variations which produce a directional structure striking south by east. Combined with the similar directions of elongation of the gneiss enclaves in the granite along the Burn of Scarfataing this directional structure in the diorite may indicate a tongued type of contact of the diorite and granite rather than the blunt contact shown on the map.

Along the Busta Voe coast gabbro is found on Scarfataing [HU 340 637] and in the cliffs under Lubba and Southpund [HU 343 654] crofts. Diorite is most in evidence along the stretch between Greentaing [HU 343 645] and a fault 600 yd (549 m) to the south but here also gabbroic and granodioritic variation is common. The more basic rocks enclose masses of basic gneiss and the assemblage is riddled by granitic sheets and dykes. Superimposed on this mixture of rocks are the effects of crushing along the Walls Boundary Fault which obscure the original relations of the formations and which by convergent retrograde changes in the mineralogy of the basic components make field determination of their igneous or metamorphic origin uncertain or impossible. Still further complication is caused locally by scapolitization, concurrent with or later than the faulting, which results in the production of medium-grained speckled rocks without foliation, resembling diorite.

Structure of the diorite-gabbro complex

No clear evidence of the form of this intrusive mass has been found in the region under description. On the east it is bounded by granite which may be of dyke-form (p. 190) and by the Walls Boundary Fault. On the west it is cut off by the ocean and by the granophyre of Muckle Roe. At the south end there are indications of a steep orientation striking south-south-east in a variable, probably hybridized diorite. On the north it is continuous with the diorite of Northmaven, the form of which has not yet been determined. Internal evidence of structure such as banding of rock types and mineral orientation is practically non-existent; though variation in grain and composition is everywhere apparent in only one instance has a banded type of relation between the fine-grained and the usual granular diorite been noted. The distribution of gabbroic facies throughout the diorite seems to have no such regularity as would indicate any layered or zonal arrangement. Finlay (1930) suggested that the diorite-gabbro of Northmaven forms the lower, nonuniform component of a great granite-diorite-gabbro sheet inclining gently and becoming more acid westwards, and he noted the common occurrence of gabbros in the southern part of Northmaven, that is in the area under description here. The widespread occurrence of gabbro from east to west of this area, however, gives no support to the hypothesis of a basic layer reaching deeper levels westwards. The only regularity shown by the mapping is that of a general increase in outcrops of gabbro to the south—in Busta peninsula and in the east of Muckle Roe. If the diorite-gabbro mass is in fact the lower part of a sheet which becomes more basic in its lower levels the evidence of greater abundance of gabbro in the south would indicate a northward inclination of the sheet. It has been pointed out in an earlier chapter (pp. 25–30) that, so far, there is no clear evidence whether the gneiss of the Skipadock [HU 342 691] and Busta–Muckle Roe areas overlies the igneous rock as a roof with pendants or underlies it with upward projections from an uneven floor. If the gneiss forms a roof the general slope of the surface between the two formations must rise northwards from Muckle Roe and must be faulted down by the Mangaster Voe Fault to allow reappearance of the gneiss at Skipadock, on the assumption that the super-positional relation is the same there as in the Busta peninsula. On Finlay's hypothesis, however, the surface between gneiss and igneous rock will fall northwards and consequently the gneiss at Skipadock will lie on the upthrow side of the Mangaster Voe Fault. Steep north-easterly dips in the gneiss close to the fault suggest that the gneiss is downthrown on the Skipadock side, if the fault is a normal one, thereby favouring the gneiss-roof alternative. The occurrence of a massive enclave of gneiss in granite at Djubi Dale [HU 336 743], 3 miles (4.8 km) N of Skipadock also indicates that gneiss overlies the igneous rock. The nature of the Mangaster Voe Fault is not known. From the general picture of Bouguer anomaly (Figure 23) in this gravitationally confused area no reliable conclusions can be drawn whether downthrow is to south-west or to north-east. It is possible, too, that the superposition relations of gneiss and igneous rock are not the same at Skipadock as around Busta. At Skipadock the gneiss may be roof and in the Busta peninsula floor. In such circumstances the direction of throw of the fault is not critical to the problem.

In the Busta peninsula the gravity map (Figure 23) shows low anomaly of saddle-form over the area where gneiss crops out most extensively. Here also the gravity picture is a confused one since the gravity changes in an E–W direction resulting largely from low values over granophyre in Muckle Roe and high values over pyroxenite south of Brae. The coincidence of the saddle-form low anomaly over the gneiss outcrops appears, however, to indicate that the underlying rock is more probably a basement of gneiss than basic igneous rock of batholithic depth. The consistent increase in gravity northwards from this area implies increasing thickness of the basic rock in that direction, with maximum thickness occurring between Gunnister Voe and Hamar Voe, just north of the area under description.

The tentative conclusions reached on consideration of the possibilities and uncertainties is that the gabbro-diorite has the form of a sheet which thins southward and that it may be a lopolith with its feeder conduit lying between Gunnister and Hamar voes. The occurrence of amphibolite and garnet-magnetite rocks of Clothister type among the gneiss outcrops south of Bays Water [HU 334 668] suggests that the lopolith may have been intruded along a folded thrust dislocation like the one postulated (p. 22) between the two metamorphic formations on the east side of the Busta–Haggrister Fault.

Granites and granophyre

As shown on the geological map and (Figure 23) there are three main bodies of granitic rock in the area. The most northerly of these is here termed the Eastern Granite. It consists of coarse red granite and extends from the north edge of the Sheet south to the east end of Roe Sound. A small mass of coarse red granite crops out in the south-east part of Muckle Roe around Scarfataing. The largest granitic body is the Muckle Roe Granophyre which occupies the greater part of that island. Numerous smaller bodies of granite appear within the gabbrodiorite, and these are of considerable size north of Mangaster Voe. From their irregular and tongued junctions with the diorite it appears probable that they are, in part at least, of sheet form. In this district however it is obvious in the field that granite spreads from its main N–S trunk into the diorite as a complex stockwork of thick and thin veins and sheets. Away from this complex area the smaller granitic bodies appear mainly in the form of dykes, of short length in relation to their thickness, and in small oval outcrops which may be of stock or lens form. In many cases the outcrops are mapped as irregularly embayed, as for example to the south of Gunnister Voe, and it seems probable that the acid rock has penetrated the diorite as a sheet-dyke complex. This probability is strengthened by the common occurrence, close to masses mapped as red granite, of areas in which granitic and aplitic veins of random direction are abundant; such areas are indicated on the geological map by short line ornament in red. Dyke-form aplites are common as individual intrusions in places where granitic networks have not been observed, for example on the north side of outer Mangaster Voe and in the centre of the Islesburgh peninsula, and this independent mode of occurrence may indicate them as the last phase of granitic intrusion. Pegmatites have been noted only rarely and only in association with granitic vein networks; they appear to be merely local coarse-grained facies of inconsiderable magnitude. The field characters and lithology of the granitic bodies are described below in the order: the Scarfataing Granite, the Eastern Granite, the Muckle Roe Granophyre, the smaller bodies and veins.

Scarfataing Granite

This granite is intrusive into and encloses large enclaves of the gneiss. From the elongated shape and generally vertical dip of the enclaves and from dentate contact of granite with the larger enclaves it would appear that the granite was intruded vertically as sheets. Exposures in Scarfataing Burn show that in the broad outcrop 300 yd (275 m) up from the river mouth (Figure 5) the gneiss and granitic sheets wedging into the gneiss have a moderately high dip to the north-west, while in the next outcrop upstream red granite is interposed between two vertical strips of gneiss. In these stream exposures and in the outcrops between the stream and Scarfataing crofts the granite contains streaks of gneiss relics and the xenoliths of gneiss are locally penetrated by granitic laminae. Both granites and gneiss have a sheared or crushed appearance in some outcrops. The enclave of gneiss farthest upstream shows sheared granite-ribbed gneiss cut by an unsheared clean red leucogranite. Along the coast between Scarfataing and Pobies Geo [HU 337 633] several exposures of gneiss appear as vertical or steep bands within the granite which also contains inclusions of gneiss elongate in a vertical direction so that they simulate dykes. West of Pobies Geo the granitic rocks are greatly crushed, at least seven dislocations with a north to north-westerly trend being present between Pobies Geo and the burn at Knowe; granophyre becomes identifiable with certainty on the coast about 100 yd (91 m) E of the mouth of this burn. Thus the contact relations between the Scarfataing Granite mass and the granophyre are uncertain, but since the granophyre is in general unaffected by shear while the granite is so affected along with the gneiss which it penetrates, it is probable that the granophyre is younger and that either its eastern boundary was guided by the existence of a marked zone of crushing or that its imminent intrusion produced a zone of crushing in the granite-gneiss cover. The contact relations between the Scarfataing Granite and the gabbro-diorite complex are unknown.

From the observations described above it is suggested (i) that the Scarfataing Granite is in the main early in the magmatic history and was intruded in sheet form under physical conditions which allowed some assimilation of the gneiss country rock to take place, and (ii) that at a much later period, separated from the first phase by an interval during which crush lines were formed, a further intrusion of granitic material was emplaced. It is of interest to recall here the occurrence of layers of ophitic dolerite in the gneiss enclaves (p. 30) as further evidence of early intrusive units probably even earlier than the Scarfataing granite.

Eastern Granite

This intrusion extends along a 9 mile (14.5 km) long outcrop from the eastern end of Roe Sound northwards to Ronas Voe. Its width is 1 mile (1.6 km) near Eela Water, in One-inch Geological Sheet Northern Shetland, but varies down to 500 ft (150 m) in the stretch between Busta Voe and Ell Wick [HU 344 680]. The form of the outcrop is thus that of a dyke, and the intrusion was so described by Finlay (1930). Its eastern margin is concealed over most of its length by superficial deposits but exposures are sufficiently numerous and close to show that the boundary is everywhere against metamorphic rocks and runs north–south in a course which is only slightly undulating. In the area under description the contact with the metamorphic rocks is a steep faulted one well exposed on the west side of the Bight of Haggrister [HU 346 700]. It has been suggested on an earlier page (p. 22) that the eastern limit of the intrusion was controlled by the existence of early dislocations along the line of the Walls Boundary Fault-zone.

On its western margin, however, the granite presents contact relations entirely different from those of a steep dyke-form intrusion. Everywhere on this side it is in contact with the gabbro-diorite but the contacts take the form of a plexus of large and small sheets, dykes, and veins of granite which can be mapped only in a general way, so that in places diorite appears on the map to be surrounded by granite, in other places granite by diorite. This complex is well exposed in the knolls and cuttings along the road between the head of Mangaster Voe and Glussdale Water where the interweaving of dark diorite and bright pink or red granite in a rocky topography produces a vivid scenic effect. The basic rock in contact with the granite is in places gabbro or coarse dolerite which may be of the porphyritic variety and locally is granitized to granodiorite. It is clear that the granite was intruded into the consolidated basic rock with only limited reaction and interchange of material.

Thus while the outcrop of the granite is in general that of a dyke-form body the complex relations on its western margin show that it was intruded under conditions which permitted easy lateral penetration of the consolidated gabbrodiorite. The ease of penetration may have been due partly to incipient cracking as the basic mass cooled, partly to shivering on reopening of an ancient locus of faulting along which the granite later ascended.

Throughout its extent from Busta to the north margin of the One-inch Sheet the granite maintains the aspect of a pink to red leucogranite composed of a base of coarsely crystalline feldspar in which are set blebs, up to 3 mm across, or less regular and larger aggregates of quartz. Ferromagnesian mineral is consistently present but in small proportion. It is largely biotite and usually forms interstitial aggregates of grain much finer than the quartz and feldspar; this character and the occasional laminar form of the aggregate suggest its genesis as xenolithic rather than primary crystallization. Some specimens of the rock are slightly cavernous; the small vacuoles may be druses but in many cases seem to be due to disappearance of loose interstitial aggregate. Slight variation from the type is shown by a specimen, from the roadside above Innbanks [HU 338 700], which contains porphyritic feldspar of very pale pink colour in a base which is of finer grain than normal. Pink aplite with small porphyritic feldspar tables and fine-grained biotite-granite with irregularly distributed coarse feldspathic aggregates, the whole having a hybrid aspect, have been noted as 'bands' in the coarse red granite on the west side of the Loch of Haggrister [HU 337 705].

Muckle Roe Granophyre

This granophyre forms a mass which, though its western and southern boundaries are cut off by the sea, seems to have been of roughly circular outline. As now exposed it extends for 3 miles (5 km) in a north–south direction. As already stated (p. 190) the nature of its contact against the Scarfataing Granite is obscured by a broad zone of crush lines between Pobies Geo and Knowe, and the location of the boundary on this 400 yd (360 m) stretch of coast has not been determined. No contact is visible along the eastern boundary which runs from the coast on a general but slightly undulating S–N to SSE–NNW course towards Kilka Water and can be located to within 120 yd (110 m) by outcrops of granophyre and diorite to the west of Orwick Water and by outcrops of granophyre and hornblendic gneiss west of the north end of Kilka Water. West of this loch the trend of the boundary swings from north-north-west to north-west to reach the sea in the notch of the coast which forms the root of Lothan Ness. Along this stretch the country rock to the north-east is at first hornblendic gneiss, within which lie bodies of granite and of diorite, followed by gabbro-diorite south of Stabaness, and at the north-west end the country rock is diorite invaded and locally granodioritized by a granitic network of veins. Throughout its outcrop the granophyre maintains a distinctive aspect conferred partly by the almost aphanitic nature of the pink micro-pegmatite base, partly by a characteristic close ragged jointing which on the hilly slopes in the interior of the island is responsible for the weathering of the rock into immense screes. The rock is of pink colour locally tinged with yellow and shows numerous blebs of clear quartz in a stony base in which individual crystal outlines of feldspar are only rarely seen but in which feldspar cleavage surfaces up to 1 cm long are usual and impart a ragged fracture to the rock. Drusy cavities containing more and less well terminated crystals of quartz are common and black ferromagnesian mineral is a minor constituent but always present in shapeless clots. Rarely, as in a specimen collected in the south-west of the island, 400 yd (360 m) W of Gilsa Water [HU 302 633], the base of the rock is locally microgranitic (S28909) [HU 300 634]. The occurrence of small masses of hornfelsed banded hornblende-rich gneiss in the granophyre has already been mentioned (pp. 30–31).

The roughly circular form of the granophyre, though the existing outcrop is only partial, and its cross-cutting relations to the gneiss and gabbro-diorite, and also to the later granitic vein network in the latter suggest that the mass is of stock form and of late date in the plutonic history of the district. Its intrusion was earlier than the dykes of felsite, porphyrite, and basalt or dolerite by which it is cut. The shape of the low gravity anomaly over the granophyre (Figure 23) though incomplete is consistent with its occurrence as a stock-form body of roughly circular section and low density.

Smaller acid bodies and veins

Small acid bodies and veins are intrusive into both the diorite-gabbro and the gneiss. Macroscopically they include three main types: coarse-grained granite, feldspar-phyric fine-grained granite, and aplite. The coarse granite contains less or more abundant clots of dark minerals and closely resembles the rock of the Eastern Granite. It occurs as small boss-like bodies in the gneiss of the Busta peninsula and as thick forked intrusions in the gneiss at Skipadock. Throughout the gabbro-diorite it forms masses of any size from 500 yd (450 m) downwards in length, in places of oval outline, in places irregularly and repeatedly embayed, as for example in the central part of Mangaster Voe. Though these masses are numerous towards the head of that voe as if spatially related to the Eastern Granite they are equally as large and common south-west of Gunnister. Even as small bodies they appear to make outcrops less regular than dykes. In places they appear where no granitic vein network has been mapped in the gabbro-diorite, which suggests that they represent a distinct phase in the evolution of the complex. Finlay regarded the larger granites within the gabbro-diorites as forming two broad dykes running respectively north-west from the eastern end of Roe Sound and north-north-west across the Islesburgh peninsula to Gunnister Voe and he noted that 'on higher ground they are in places impersistent, failing to reach the surface altogether or represented by a medley of smaller dykes and narrow, fine-grained or felsitic veins ramifying through the diorite' (Finlay 1930, pp. 691–2). From their distribution, shape of outcrops, and variability of direction of their length as shown on the Geological Survey six-inch maps it appears more probable that these coarse-grained granites have penetrated at random as sheets and dykes and combinations of sheets and dykes, and that no persistent direction of extension from a focus exists.

The fine-grained and aplitic rocks have the form of dykes or veins and no definite trend can be discerned. Exposures along the east coast of Muckle Roe and around Mavis Grind provide examples of the coarse-grained and the feldspar-phyric types cutting diorite. Aplite dykes or veins are common on the high ground [HU 333 6931 west of Islesburgh croft.

Petrography

Ultrabasic rocks

The ultrabasic rocks of Glussdale Water and Moora Waters show cleaved poikilitic crystals, up to 5 mm across, in a dense black microgranular base. Fracture surfaces have a greasy lustre like that of fractured serpentinite. In thin section the rocks are seen to be composed of orthopyroxene and clinopyroxene, plagioclase, olivine and minor hornblende, biotite, iron ore and serpentine; the relative proportions of the plagioclase and the two pyroxenes vary within the area of a thin section though olivine is uniformly distributed. In mineral composition the rock therefore varies from that of a troctolite-dolerite resembling harrisite, through olivine-dolerite to lherzolite. The plagioclase forms large irregular plates without noticeable zoning (S30016) [HU 332 732] or large and smaller prismatic crystals slightly zoned with optically negative core and positive envelope (S29994) [HU 319 730]. In powder from the analysed specimen (S33683) [HU 326 727] the highest refractive index observed was $\gamma = 1.576$ and the lowest $\beta = 1.565$ corresponding to variation from bytownite (An_{80}) to calcic labradorite (An_{65}). The large plates are irregularly interlocked with both pyroxenes but smaller prisms are subophitic. The pyroxenes generally are in the form of irregular plates but orthopyroxene locally has good prismatic shape in its smaller crystals and may be enclosed along with the small crystals of olivine within plates of clinopyroxene (S29994) [HU 319 730]. It shows a very faint pleochroism and in powder from the analysed specimen has $\gamma = 1.697–8$ corresponding to $En_{72}Fs_{23}$; the optic axial angle is about 75° (by Mallard's method) and the sign negative. Olivine is uniformly present as almost fresh to considerably altered, small (0.2 to 0.4 mm) crystals singly or in clusters enclosed in the plagioclase, pyroxenes, hornblende, and biotite ((Plate 22), fig. 2). The optic axial angle $2V\alpha$ 90° — and refractive index $\beta = 1.691$ indicate the composition $Fo_{83}Fa_{17}$. Cracks radiate in plagioclase from its slightly serpentinized crystals (S33683) [HU 326 727]. The minor constituents hornblende and biotite form grains of irregular shape interstitial to and intergrown with plagioclase and pyroxenes; they appear to be primary crystallizations and local poikilitic growth enclosing plagioclase and pyroxene indicates that they are the last products of an aqueous cafemic residuum. They have the same dichroism a pale yellow, $\beta = \gamma$ reddish orange, the colour being deeper in biotite. Iron ore is abundant as small octahedral grains in plagioclase and pyroxenes and as rods, streaks, and chains of granules in serpentinized olivine. The serpentine is usually pale brown and isotropic but locally passes into interstitial packs of curved flakes of a pale brown material possessing moderately high birefringence; marginal between olivine and plagioclase however the colour is persistently apple-green.

The chemical composition and norm of the Moora Waters rock (S33683) [HU 326 727] are given in (Table 4) where the composition is compared with those of some other Scottish ultrabasic rocks of similar composition; distinction from the hornblende-peridotite of Lugar, which is associated with titaniferous alkaline rocks, is apparent in the difference in titania and in alkalies relative to alumina. In view of the heterogeneous distribution of the mineral constituents it is relevant to note that all the rocks with which the Moora Waters rock is compared in the table are in the field transitional types or portions of variable bodies.

Gabbro and diorite

Corresponding to the difficulty of separating gabbro and diorite in the field, the collection of sliced rocks from the complex shows continuous variation from true gabbro to hornblende-biotite-diorite with minor quartz and potassium feldspar, which with increase of the latter components becomes a mesocratic granodiorite. No chemical analysis of any of the basic or intermediate rocks of this area has been made. For the purpose of petrographical description the rocks of the complex are grouped as gabbro, dolerite, gabbro-diorite, and diorite.

(Table 4) Chemical analyses of enstatite-harrisite from Northmaven and comparable Scottish rocks

	1	A	B	C	D
SiO_2	40.58	40.82	40.35	43.09	42.52
Al_2O_3	7.57	10.66	3.75	7.51	8.12
Fe_2O_3	3.18	1.80	3.53	FeO½ 0.52	2.41
FeO	9.01	8.92	9.86	7.14	8.72
MgO	27.50	28.08	25.69	33.48	27.42
CaO	4.51	6.11	4.64	5.75	6.27
Na_2O	0.76	0.58	3.14	NaO½ 0.65	0.72
K_2O	0.15	0.21	0.80	KO½ 0.12	0.23
H_2O >105°C	5.74	2.00	5.28	1.18	1.90
H_2O < 105°C	0.33	0.16	0.83	—	0.17
TiO_2	0.39	0.16	2.12	0.16	0.49
P_2O_5	0.04	—	0.25	nil	0.04
MnO	0.20	019	0.20	0.05	0.18
CO_2	0.09	0.00?	tr.		0.56
FeS_2	0.11	S 0.02			
Fe_7S_8	tr.				
Cr_2O_3	0.26	0.25		0.39	0.20
BaO	0.02		0.06		
SrO	0.01 (s)				
Cl	—	—			
	100.45	100.12	100.56	100.04	99.95

(s) Spectroscopic determination

	Norm of Lab. No. 1065
Or	0.89
ab	6.29
an	17.07
di	3.72
by	12.79
of	48.01
mg	4.64
it	0.76
em	0.38
	94.75

- Symbol 4.1.4.1.2: *Custerose*
- 1 Enstatite-harrisite. NE shore of Moora Waters, Northmaven, Shetland. One-inch 128 Scot., Six-inch 24 SE. Lab. No. 1065. Anal. C. O. Harvey; spect. det. H. K. Whalley. Guppy and Sabine 1956, pp. 35–6.
- A. Harrisite, Tertiary intrusion. Roadside near Dornabac Bridge, Rhum. The total includes (Ni, CO) O 0.11, CuO 0.05. Guppy and Thomas 1931, pp. 97–8.
- B. Hornblende-peridotite, Lugar sill. Glenmuir Water, Ayrshire. Tyrrell 1916, pp. 113–4.
- C. Feldspathic peridotite. An Garbh-choire, Skye. Weedon 1965, p. 57.
- E. Ultrabasic dyke No. 1, 4 ft 4 in from edge. Ben Cleat, Skye. Gibb 1968, p. 628.

Gabbro

The gabbros include feldspar-phyric and non-porphyritic types. The former, which are less common, show stout prisms of plagioclase in a base of plagioclase laths 0.3 to 1 mm ophitically related to colourless augite which forms shapeless grains up to 1 mm across. In the freshest specimen (S55657) [HU 337 717] the augite is locally replaced by and grades marginally into amphibole of a neutral brownish grey tint; microcrystalline pale green amphibole felt forms a patchy cement and occupies larger pockets resembling vesicular fillings. Titaniferous magnetite is accessory. The feldspar phenocrysts are usually aggregates of large stout broadly twinned prisms which have a composition of about 85 per cent An, by the simultaneous extinction method, are optically negative, and have refractive index β close to 1.575; they may show a narrow marginal, slightly less calcic zone (S55656) [HU 337 701] and in this rock the larger crystals are senate to the ground-mass laths. The latter are continuously zoned from centre at least as calcic as An_{70} per cent to margins in which extinction angles of about 20° indicate their composition as andesine with about 35 per cent An. The augite is colourless or faintly brown, shows an isogyre with normal curvature for augite, and has β = 1.693. No olivine has been seen but some small, 0.3 mm, round aggregates of bright green microcrystalline amphibole or chlorite may represent early crystallizations of olivine (S55644) [HU 336 669]. The place of augite may be taken by hornblende which may retain the ophitic texture (S55656) [HU 337 701] or may form subhedral prismatic grains interfering with the lathy plagioclase (S55670) [HU 320 713]. In this rock the plagioclase is traversed by many chlorite-filled cracks and contains granular epidote and small groups of actinolitic hornblende like that of the interstitial filling. This small group of porphyritic rocks might be classed as bytownite-phyric dolerite in view of the small grain size of the groundmass but since the rocks show senate transition from phenocryst to groundmass plagioclase and local change of grain size in the groundmass they are retained in the gabbro group. There is no indication in the field that these relatively fine-grained feldspar-phyric gabbros are earlier or later than the non-porphyritic gabbros but since most occur close to the margin of the complex, they may represent an early partly chilled phase of the gabbro.

The non-porphyritic gabbros are in general coarse-grained rocks ((Plate 22), fig. 3) in which plates of colourless augite up to 5 mm across ophitically enclose prisms of calcic plagioclase which is zoned at the margins but centrally has an average composition of An_{70} as indicated by the high refractive index and by an optic axial angle ~ 90°. Brown hornblende varies from minor (S53593) [HU 333 683] to major (S30017) [HU 332 733] proportions in relation to pyroxene. It may occur only as marginal portions of the pyroxene plates and is present also as large shapeless crystals ophitically enclosing the plagioclase. No fresh olivine has been observed but several specimens (S29992) [HU 315 746], (S30006) [HU 307 687], (S30017) [HU 332 733] contain small (0.2 to 0.4 mm) aggregates of colourless microcrystalline amphibole and finely granular ore which are pseudomorphs of a mineral on which the pyroxene and plagioclase are moulded and which may have been olivine. These pseudomorphs occur singly and are not poikilitically enclosed by pyroxene as in the ultrabasic rocks. Both augite and hornblende are replaced in variable degree by uralitic amphibole and the pseudomorphs of ?olivine tend to act as centres for the growth of the pale green fibrous and acicular amphibole which forms a constant cement to the main minerals. Biotite of a deep brown colour occasionally forms short micropoikilitic plates among this infilling but more usually occurs in accessory proportion as irregular flakes marginal to or moulded on the main minerals and often enclosing large grains of black ore. The only other accessory mineral is magnetite. In distinction to the extensive alteration of primary brown hornblende and pyroxene to secondary uralite or amphibole felt the feldspar of the gabbron is not altered. A variety of gabbro containing orthopyroxene has been collected from the lenticular basic body exposed between outcrops of gneiss on the coast of Busta Voe, 200 yd (183 m) ESE of Northpund, Muckle Roe [HU 343 655]. Of three specimens representing this mass two are gabbro composed of large shapeless crystals of colourless augite and brown and green hornblende, both pyroxene and amphibole being locally uralitized (S45133) [HU 342 640], (S45134) [HU 342 640]. These crystals ophitically enclose plagioclase prisms of very varying size and brown biotite, locally chloritized, also shows ophitic relations to the plagioclase. The third specimen is of finer grain and is composed mainly of stout, zoned prisms of labradorite enclosed subophitically by equant grains of augite and less abundant green hornblende. The augite is pale green or pink in colour and encloses small grains of orthopyroxene (S45035) [HU 343 652]. Fresh dark brown biotite forms long plates which enclose both plagioclase and augite poikilitically. The genetic relationship of the rock to the coarse gabbroic specimens is clear but whether it is a local variant, an enclave, or a penecontemporaneous minor intrusion in the gabbro is not known.

Most of the gabbroic rocks in the collection are more appropriately classed as hornblende-gabbro or bojite but some less coarse rocks are hornblende-dolerites. The coarser rocks retain the texture of the gabbros but hornblende is as abundant (S29415) [HU 335 687], (S55642) [HU 340 649], (S55651) [HU 341 687], (S55653) [HU 334 687] as the pyroxene or considerably more abundant (S55647) [HU 341 682], (S55648) [HU 340 679], (S55649) [HU 349 680] ((Plate 22), fig. 4). In those rocks hornblende includes both the primary brown variety and the neutral tinted and pale green type which is not uralitic in habit but appears to replace pyroxene and, in some cases, brown hornblende by reaction concurrent with crystallization of the rock. The plagioclase is still calcic with average composition 65 to 75 per cent An and the optic sign is variable. Brown biotite is usually present in flakes irregularly moulded on ore and plagioclase and enclosed in the interstitial fibrous amphibole felt. Deuteric alteration causes patchy replacement of feldspar by microcrystalline zeolite, opacization of biotite, and formation of chlorite and pyrite in the uralite.

The hornblende-gabbros are transitional to diorite through rocks which are texturally similar, but the strongly zoned plagioclase of which shows cores of bytownite or labradorite, in many cases turbid or sericitized, enveloped in more acid material marginally of oligoclase composition (S44324) [HU 341 670]. A little quartz (S35706) [HU 342 682] or alkali-feldspar (S55643) [HU 344 661] and analcime (S55645) [HU 333 667] may be present interstitially. In these rocks biotite is usually a minor primary constituent and may occur in plates enclosing plagioclase and uralitized pyroxene (S44324) [HU 341 670]. The iron ore is titaniferous and small stout prisms of apatite are accessory. Another type of transition involves the appearance of interstitial quartz as an essential minor constituent in a rock in which both colourless augite and brown hornblende are coarsely ophitic to labradorite laths in a base of stout plagioclase prisms zoned externally to andesine-oligoclase composition (S55664) [HU 306 742]. The term gabbro-diorite is appropriate to those rocks though Johannsen considers that this term should not be used (1937, vol. III, p. 226).

The basic portions of the complex also include fine-grained varieties which resemble the gabbros but petrographically are to be classed as dolerite or basalt. The mass shown as gabbro on the one-inch sheet 0.25 to 0.5 mile (400–800 m) south by east of Roe Bridge [HU 343 656] affords examples of both gabbro or coarse dolerite and basalt though no distinction has been drawn in the field. Specimens from this mass have been described on an earlier page (p. 195) as a variety of gabbro containing orthopyroxene. Farther south of the Muckle Roe coast a similar rock with micropoikilitic biotite in ophitic dolerite of varying grain-size occurs in the stretch mapped as diorite (S55169) [HU 345 669]. Basalts occur also on the east coast at Mavis Grind (S33750) [NH 153 157] [HU 340 695], (S55659) [HU 340 685], as a basic band (S55652) [HU 337 685] in diorite on the north shore of Mangaster Voe 350 yd (320 m) WNW of Mavis Grind, and on the northern margin of the Skipadock gneiss area where the 'diorite' in contact with the gneiss is an ophitic basalt in which colourless cores of augite persist within the dominant green and uralitic hornblendes while deep red brown biotite with sagenite appears as an interstitial mineral (S55165) [HU 338 694]. In these rocks the plagioclase is a labradorite (An_{65}) or bytownite (An_{75}) but is commonly much altered so that a basic sericitized core is surrounded by a strongly zoned mantle, and may be locally so altered that the laths within fresh augite plates are argillized (S55169) [HU 345 669]. Transition to the porphyritic gabbro type is seen in a rock from the east coast at Mavis Grind (S55650) [HU 341 684]. It is noteworthy that these basaltic variations are petrographically similar to those which occur within xenoliths of gneiss in granite in the Scarfataing area, and have already been described among the early hypabyssal intrusions (p. 181). These petrographical similarities and the occurrence of the basaltic and porphyritic dolerite varieties at the southern and south-eastern extremities of the gabbro-diorite complex suggest that in this direction early units of the basic phase of intrusion have entered the country gneiss as basaltic sills and that while in the south they remained as layers in the gneiss which formed the country rock to granitic intrusion, further north they were incorporated as bands in the main irruption of basic magma.

Diorite

The diorites, which occupy by far the greatest exposed area of the complex, are in general medium-grained, black and white speckled rocks which in mass give the impression of fairly homogeneous composition. Comparison of specimens from the large area of exposed rock when juxtaposed in a collection or examined under the microscope shows wide variation in grain and texture and in the relative proportions of mafic and felsic components. These variations do not have any relation to their position in the complex.

The essential minerals of the diorites are plagioclase, hornblende, biotite, and, in some specimens, pyroxene. Quartz and potassium feldspar may be entirely absent or present as accessory or minor constituents; potassium feldspar is much less commonly present than quartz and is a minor essential in only one specimen (S55662) [HU 337 701] in which microcline is concentrated with quartz in felsic pools which produce a pink mottling in the hand specimen. The main accessory mineral is black iron ore which is probably titaniferous and shows leucoxenic coatings on many grains. Apatite, sphene, and zircon are present in notable amount only in quartz-bearing varieties. Though leucoxene is common in most specimens, crystals of clear sphene, irregular in shape (S55663) [HU 303 743], (S53582) [HU 330 665] or skeletally idiomorphic (S55666) [NS 6436 5880] [HU 300 734], have been observed only in association with interstitial quartz. Zircon, always sparse, has a broken and cracked appearance as though it were relict (S30022) [HU 321 702], (S55662) [HU 337 701].

The variations in mineral composition and in texture are of petrogenetic interest. Augite is present in a minor proportion of specimens and is a colourless type with close salite striation. Only in one specimen is it present in its original primary state of crystallization. In this rock (S30023) [HU 315 742], (Plate 22), fig. 5) it forms small shapeless crystals moulded ophitically on plagioclase and stout hypidiomorphic prisms of pinkish colour which in many cases are enveloped in brown hornblende, itself ophitically related to the plagioclase. In the other specimens pyroxene forms more and less turbid cores in, but not sharply separable from, hornblende (S29412) [HU 327 673], (S30022) [HU 321 702], (S55646) [HU 326 680], (S55690) [HU 326 687]; in one case the pyroxenic core retains ophitic structure (S44322) [HU 325 667]. Hornblende is the principal mafic mineral in all specimens ((Plate 22), fig. 6) and occurs in several forms; as ophitic or subophitic plates of brown, green or particolour (S55655) [HU 345 659], (S55690) [HU 326 687], but in most specimens as hypidiomorphic or ragged, green and brown prisms which interfere with plagioclase and usually also with one another in shapeless groups. Amphibole is abundant also in aggregates of pale green, locally bluish green blades and as fibrous uralite replacing both pyroxene and brown or green primary hornblende (S29412) [HU 327 673], (S30020) [HU 309 732], (S30023) [HU 315 742]. The aggregates of the bladed or subprismatic pale green and bluish green amphibole may be intimately admixed with small scales of biotite, large and small grains of epidote and iron ore, and, less commonly, pyroxene (S30022) [HU 321 702], (S53582) [HU 330 665], (S55646) [HU 326 680], (S55665) [HU 300 725], (S55666) [NS 6436 5880] [HU 300 734]; these feldspar-free clots clearly represent recrystallized ultrabasic material. The earliest precipitation of amphibole is the brown variety but this was crystallized peneconcurrently with the green form which continues the ophitic crystallization of both pyroxene and brown amphibole. There is evidence that the brown variety crystallized also comparatively late in the consolidation of some rocks since in these it has interfering relations to anhedral oligoclase and may be in part anhedral, in part euhedral against interstitial quartz (S55669) [HU 303 712]. Biotite, which is absent in only one specimen (S55646) [HU 326 680], also is variable in type. It may be brown or green, may show fine sagenite structure (S29998) [HU 326 715], (S55669) [HU 303 712] in fresh crystals, or occur as coarse flakes interleaved with leucoxenic streaks (S55666) [NS 6436 5880] [HU 300 734], (S55667) [HU 317 733]. It may be fresh or chloritized and enclose epidote (S30020) [HU 309 732], (S55662) [HU 337 701], (S55663) [HU 303 743], (S55665) [HU 300 725]. In part it appears to be an early crystallization enclosed in the primary brown or green hornblende; in part it is, like brown hornblende, a late crystallization interfering with interstitial oligoclase and quartz (S55669) [HU 303 712], and in some cases becoming poikilophitic (S29998) [HU 326 715], (S30008) [HU 345 730]. Large ragged flakes which are spattered with epidote and streaked by leucoxene show growth of small flakes orientated with the basal plane normal to the base of the large crystal (S55666) [NS 6436 5880] [HU 300 734]; no colour difference exists. Plagioclase, the principal mineral constituent of the diorites, likewise shows great variety of composition, textural relations, and alteration. It is always zoned and in most specimens the crystals have a core of andesine-labradorite, An 40 to 55 per cent, which is surrounded by a zoned mantle with the An content decreasing marginally in the range 25 to 15 per cent as indicated by the refractive index relative to quartz. The core has usually a prismatic shape and is slightly zoned across the prism whereas the mantle may be hypidiomorphic prismatic, idiomorphic against quartz or quite allotriomorphic by growth against contiguous feldspars. Higher anorthite content in the core is in some cases indicated by saussuritization ; in a few fresh augite-bearing types An contents of 75 to 65 per cent can be deduced from the optic sign, shape of the isogyres, and symmetrical extinction angles. Such calcic plagioclases are ophitically enclosed in pyroxene or amphibole but even within these minerals they show outward normal zoning to less calcic composition and corrosion of the pinacoids with discontinuous deposition of plagioclase of markedly lower refractive index (S30023) [HU 315 742], (S55690) [HU 326 687].

Xenolithic and hybrid rocks

Xenoliths occurring in the Wilson's Noup–Lang Head area in concentrations so great as locally to produce the appearance of breccia are black fine-grained rocks of basaltic appearance. They are composed essentially of a base of granoblastic oligoclase and green hornblende with minor green biotite; quartz is present in some specimens (S55674) [HU 310 720], (S55693) [HU 302 716] but it may have been introduced since it forms comparatively large grains enclosing small plagioclase and hornblende crystals; iron ore coated by sphene, apatite and epidote are accessory. Most are microporphyritic with prismatic plagioclase crystals up to 2 mm in length and aggregates of granular, colourless to bluish green hornblende of equant shape, about 1 mm across, which probably represent original pyroxene; these aggregates and the large plagioclase prisms are locally cumulophyric (S55674) [HU 310 720]. The plagioclase phenocrysts consist of a calcic core mantled by zoned feldspar which is intercrystallized anhedrally with the minerals of the groundmass and at the margin has a composition in the An 15 to 20 per cent range. The core is usually turbid and altered by epidotization, sericitization, or analcitization but can be shown to be at least as calcic as An 55 per cent (S55693) [HU 302 716] and in one case probably An 75 to 80 per cent (S55676) [HU 302 706]. The oligoclase grains of the groundmass usually show central lathy relics of andesine-labradorite composition; the transition may be continuous or discontinuous and in the latter case alteration of the core to analcime (S55674) [HU 310 720] can emphasize the discontinuity. A parallel arrangement of subprismatic groundmass and porphyritic plagioclase indicates the existence of fluidal structure in one xenolith (S55693) [HU 302 716], and to the former presence of this structure the local roughly parallel orientation of large andesine-oligoclase ovoid crystals in the coarsely recrystallized portion of another xenolith may be due also (S55692) [HU 301 718]. While most of the xenoliths show sharp but intercrystallized contacts with the more acid rock which encloses or cements them, interaction both mechanical and chemical is shown by the occurrence of slivers of xenolith, and diffusion of quartz and potassium feldspar into reconstructed xenolith. The latter process is particularly well observed in those specimens (S55692) [HU 301 718]-(S55693) [HU 302 716] which show fluxional structure under the microscope and in hand-specimen a platy structure, to which the fluxional structure is parallel. The macroscopic platiness corresponds with a parallel lenticular arrangement of granoblastic xenolithic material. The latter contains microaugen of microcline, some coarser tonalitic rock with potassium feldspar locally interstitial to or perforating the plagioclase, and granodioritic rock composed of granular quartz and microcline, turbid hypidiomorphic plagioclase, and hypidiomorphic and idiomorphic hornblende and minor biotite. Allanite appears in association with the dark minerals of the granodioritic portions. The composition and the microscopic and macroscopic structures in combination with the areal concentration of the xenoliths suggest that they represent a formation of basic andesitic or basaltic lavas broken up, perhaps by the forces leading to irruption of the gabbro-diorite intrusion, and incorporated into the latter by penetration of its more mobile acid fractions. It is relevant to draw attention to the frequent occurrence of concentrations of fine-grained basaltic xenoliths in the gabbro-diorite in its northern outcrop between Hamar Voe and Ronas Voe (One-inch Geological Sheet Northern Shetland). Though these concentrations are not of the 'breccia' type characteristic of the Wilson's Noup–Lang Head area they also indicate the existence of a fine-grained basaltic formation prior to intrusion of the main gabbro-diorite.

Other xenoliths occurring sporadically in the area north of Mangaster Voe are of the same thermally altered type as those described in the earlier part of the preceding paragraph. Some are porphyritic fine- to very fine-grained basic rocks (S55268) [HU 326 724], (S55679) [HU 325 723], in which compact aggregates of granular hornblende coated by biotite represent pyroxene phenocrysts and altered prisms of calcic plagioclase are mantled by andesine-oligoclase. Others are non-porphyritic (S55678) [HU 323 713]. None shows fluidal structure but in one a radial grouping of the larger plagioclase laths gives a vague suggestion of variolitic structure (S55677) [HU 338 699]. Petrographically they may represent basic lava or fine-grained hypabyssal types. Their contacts with the host rock, generally quartz-diorite but in one case granite (S55677) [HU 338 699] of the eastern mass, show very restricted marginal intermingling with penetration of quartz into spaces and channels in the xenolith close to the contact. In one specimen, however, there has been extensive potassium metasomatism leading to the formation of shapeless plates of microcline, 3 mm across, which isolate and enclose turbid plagioclase prisms and granular and idioblastic hornblende and biotite of the xenolith (S29993) [HU 320 726].

The hybrid rocks fall into two groups on the basis of their field occurrence: (1) heterogeneous hybrid rocks of strictly local development usually in association with xenoliths, and (ii) hybrid rocks which form more acid facies of the main diorite mass. The heterogeneous hybrids are exemplified by the acid material cementing the xenoliths of the Wilson's

Noup–Lang Head area already described (S55674) [HU 310 720], (S55675) [HU 303 717], (S55676) [HU 302 706], (S55678) [HU 323 713], (S55679) [HU 325 723]. They range from tonalitic to granitic in mineral composition and characteristically show uneven proportions of potassium feldspar to plagioclase and of mafic to quartz-feldspar constituents. In some the difference in habit of the hornblende and biotite derived from xenolithic material and that of these minerals of the invading rock is clear, but the distinction can be obscured by idiomorphic recrystallization of the mafic minerals against the invasive quartz (S55267) [HU 305 731]. Late idiomorphic recrystallization of the hornblende and biotite is seen also in a fine-grained type which appears to be composed entirely of a leucocratic granular quartz and microcline base enclosing small plagioclase laths and grains of hornblende and biotite of xenolithic origin (S30005) [HU 298 687]. Rarely the granodiorite may show indications of fluxional structure by orientated elongation of mafic streaks or of basic xenoliths (S55267) [HU 305 731]; one of the xenoliths in this rock shows a curved lineation of its plagioclase laths.

The most common hybrid type occurring as a facies of the main diorite mass is a rock in which potassium feldspar is present as specks, irregularly distributed interstitial matter, or patches (segregations), up to about 1 to 2 cm across but occasionally 5 cm (S30011) [HU 331 771]. These rocks are composed of turbid, sericitized or epidotized prisms of plagioclase with which hypidiomorphic hornblende and biotite interfere, interstitial granular quartz and potassium feldspar and accessory iron ore, sphene, apatite and epidote. The plagioclase prisms usually show a calcic core mantled by a more sodic zone of oligoclase in both the more dioritic and the quartzo-feldspathic portions of the rock but in the latter the plagioclase is partially clarified of the alteration products and seems less calcic (An_{35-15}) than the original was. A noteworthy feature of the leucocratic patches is the common predominance in them of potassium feldspar over quartz (S29411) [HU 335 668], (S29416) [HU 338 685], (S55696) [HU 348 702], and idiomorphic crystallization of hornblende adjoining that feldspar. Unlike hornblende, biotite is only rarely recrystallized in quartzose areas in fresh brown books (S53569) [HU 342 645]. In the sections just referred to and also in (S29506) [HU 321 670] it is extensively replaced by chlorite and iron ore or epidote, and it is possible that potassium has been withdrawn from the dioritic rock to add to the concentration in the potassic patches. The variability of this group is illustrated by specimens (S55691) [HU 337 696], (S55694) [HU 340 699], (S55695) [HU 343 702] in addition to those already cited.

Less common acid facies of the diorite are tonalitic in composition and differ from the usual dioritic types by the presence of interstitial quartz as an essential mineral and by the greatly diminished proportion of dark to light components. They consist mainly of zoned plagioclase prisms with which ragged prismatic prisms of green hornblende interfere. Small amounts of biotite may be present in clots of small scales or as flakes. Quartz is abundant interstitially. Of the accessory minerals apatite and iron ore rimmed or interlayered by sphene are abundant, zircon and potassium feldspar scarce. The plagioclase may show epidotized cores (S30009) [HU 298 728], (S43768) [HU 316 739] with zoned oligoclasealbite mantles or it may be mainly oligoclase with still more sodic margins (S55673) [HU 297 727]. Hornblende characteristically is idiomorphic against quartz but is otherwise hypidiomorphic and has a close polysynthetic twinning. The mafic constituents tend to be aggregated in shapeless groups. A more leucocratic specimen (S29999) [HU 302 722] contains green biotite as a major constituent; accessory microcline occurs interstitially and as a honeycomb pattern of replacement in plagioclase.

The larger granite masses

Scarfataing Granite

The single specimen available of the Scarfataing Granite is composed of mutually interfering coarse-grained prismatic albite, granular perthitic potassium feldspar, and quartz (S55680) [HU 338 635], with a minor amount of matrix composed of the same minerals, ragged aggregates of oxidized and chloritized biotite, and grains of magnetite and epidote. The rock contains no quartz-feldspar intergrowth but has a characteristic enclosure of tiny idiomorphic prisms of turbid plagioclase in the perthite. Similar turbid plagioclase occurs as subhedral grains interstitially and in small aggregates enclosed in large perthite crystals. This rock occurs within the broad shear zone on the east of the Muckle Roe Granophyre and all the minerals in it are conspicuously deformed.

Eastern Granite

The Coarse Eastern Granite consists of large irregular plates of perthitic feldspar and large grains of quartz which in places interlock with the feldspar in a coarse intergrowth without pattern. Prismatic alkalic plagioclase (An 5–10%) is subordinate and usually has a stout prismatic habit, interlocking with the perthite and also crystallized in smaller prisms enclosed in quartz. It may contain irregular patches of potash feldspar (S46601) [HU 336 701] or show an antiperthitic pattern (S29419) [HU 343 692]. The close association of two phases of perthitic feldspar is also shown by crystals composed of a microperthite core, a sericitized sodic plagioclase shell, and a mantle of microperthite optically continuous with the core (S29997) [HU 338 704]. This rock contains patches of finer-grained albite rock in which uniformly distributed olive-green biotite is a minor constituent.

The accessory minerals of the granite, mainly chlorite after biotite and epidote, form clots in which grains of magnetite, ilmenite, and sphene are common. Zircon is abundant in one specimen (S46601) [HU 336 701]. New biotite and sphene sometimes crystallize in the mafic aggregates (S29997) [HU 338 704] and alteration of biotite at an early stage in the crystallization of the rock is suggested by the manner in which quartz and feldspar grow through the mafic aggregates.

Quartz is always strained and dusty, in patches very dusty owing to an unusual abundance of very minute inclusions (S28913) [HU 346 665].

The Muckle Roe Granophyre

The granophyre of Muckle Roe consists of micropegmatite crystallizations which, usually spreading each from a nucleus of idiomorphic quartz or feldspar, interfere with one another (S29505) [HU 314 674], (Plate 22), fig. 8) or coalesce with the quartz of interstitial coarse-grained pools (S28909) [HU 300 634], (S55689) [HU 317 675]. Thus quartz always seems to exceed feldspar. The feldspar is a very turbid orthoclase or microperthite; only rarely is albite twinning seen and then it affects prismatic crystals which appear to be surrounded by the micropegmatitic growth rather than to form a nuclear part of it (S44320) [HU 322 668]. The mafic aggregates, meagrely represented in the thin sections though conspicuous in hand specimen, are composed mainly of iron ore grains and scraps of chlorite. The only variation from this type of rock is one in which albite occurs in equant prisms along with granular quartz and potash feldspar as aplitic patches within the granophyre (S28905) [HU 334 631].

The smaller acid bodies and veins

Specimens of red granite from the smaller acid bodies are of finer grain than the typical rock of the Eastern Granite. They are composed of perthitic feldspar in tabular or shapeless crystals, prisms of albite ($An_{5–10}$), and granular quartz. Both perthitic feldspar and albite may in some cases have marginal micropegmatitic intergrowths with quartz (S44331) [HU 325 690], but in others no micropegmatite may occur (S29410) [HU 338 662]. Biotite forming stout prisms moulded on plagioclase is only slightly chloritized and oxidized and is more abundant than in the Eastern Granite.

The feldspar-phyric acid rocks occurring as small bodies in gneiss or diorite consist essentially of large crystals or perthitic potassium feldspar, prisms of plagioclase in some specimens, and large grains of quartz in a groundmass of quartz, perthite or microcline, and minor albite ($An_{5–10}$) with accessory biotite, chlorite, ore and epidote in small clots or dispersed aggregates. The textures show that these rocks are not direct consolidations from a magma. The large perthitic feldspars show post-crystallization effects such as recrystallization to a patchwork of smaller grains and invasion by quartz (S55681) [HU 342 658], rounded outlines of large cores mantled by similar potassium-rich feldspar or by micropegmatite (S55685) [HU 329 696], granulitized margins grading into the quartz-feldspar base (S55687) [HU 300 722], (S55688) [HU 321 709], replacement by quartz with formation of micropegmatite (S55684) [HU 324 698]. Composite aggregates may show zonal alteration which passing without interruption through contiguous crystals is clearly later than their consolidation (S55686) [HU 314 740]. Some large irregular xenocrysts of highly strained (S55685) [HU 329 696] or fractured (S55684) [HU 324 698] quartz are mantled by micropegmatite. The ratio of perthite to plagioclase changes so abruptly that the rock is clearly of mixed origin (S29410) [HU 338 662], (S55686) [HU 314 740]. Mafic minerals are usually present in only small amount and include biotite, chlorite, epidote and iron ore. They tend to form clots of small grains which appear to be derived from earlier rock (S55687) [HU 300 722], (S55688) [HU 321 709] but biotite also occurs in thick flakes as a primary constituent (S29410) [HU 338 662], (S55684) [HU 324 698], (S55684) [HU 324 698], (S55686) [HU 314 740]. Hornblende is either not present or is only accessory in these rocks. It is however an important constituent of two small quartz-syenite bodies which cut the diorite in Egilsay. In these rocks (S55682) [HU 313 697], (S55683) [HU 318 694] hornblende forms primary hypidiomorphic crystals which interlock with feldspar and occurs also as fibrous uralite, with cores of augite, which form clots of prismatic grains incorporated from inclusions of more basic rock. Scarce accessory minerals in the small granitic bodies include sphene, epidote, and rare zircon and allanite. Sphene in some cases forms large crystals, partly idiomorphic, partly fractured or irregular (S55684) [HU 324 698], (S55687) [HU 300 722] which appear to be relict from incorporated material. Rarely such small bodies have a granodioritic composition. A specimen from Green Ward [HU 326 740] is composed of large and small prismatic crystals of sericitized and epidotized plagioclase, - Anio, in a granular base of quartz and microcline with groups of raggedly terminated prisms of olive brown biotite as a minor constituent. The plagioclase often shows a zoned alteration and some crystals are mantled by microcline (S29991) [HU 325 740].

The aplitic veins are composed of allotriomorphic feldspar and quartz with little or only accessory biotite, chlorite, and epidote. The feldspar is in some cases perthite and minor microcline and albite, $An_{5–10}$ (S55271) [HU 333 660], in others microcline and oligoclase, $An_{10–15}$ (S55272) [HU 316 704], or a cryptoperthite with a moire pattern of extinction which suggests potash-oligoclase (S55273) [HU 305 725]. Quartz in all cases is strained and in some appears to replace perthite marginally. Perthite may be granulitized in pockets or along short lines which are also the loci of chloritization and oxidation of ore (S55273) [HU 305 725].

Late hydrothermal activity

Field relationships

Late hydrothermal activity affecting the gabbro-diorite mass and associated gneiss along the line of the Walls Boundary Fault-zone and minor parallel crush lines has resulted in scapolitization and analcimization of the rocks and in the case of the gneiss is of later date than the late phase of silicification to which reference has already been made (p. 37).

The scapolitized rocks are exposed on the coast of Muckle Roe to north and south of the mouth of the Burn of Scarfataing, in the quarry and exposures along the main road bordering Ell Wick, and on the high ground of Hurda Field between Mangaster and Sullom voes. In the Scarfataing exposures scapolitization affects both gneiss and basic igneous rocks to produce a mottled or speckly medium-grained material resembling black and white diorite so that recognition of scapolitized hornblendic schist, which is the main component of the gneiss in this area, from scapolitized dolerite or gabbro-diorite is possible with certainty only when banded or foliated structure is visible.

In the quarry at Ell Wick and on Hurda Field scapolite occurs in veins in sheared dark rock. The veins may be thick and composed of massive aphanitic pinkish scapolite as seen in the quarry (Plate 23A) (Plate 23B) or they may form a zone of narrow veins, from 3 or 4 in (8 or 10 cm) to a tenth of an inch (3 mm) thick, separated by crushed dark rock, as observed on Hurda Field. At both localities the country-rock traversed by the veins is diorite.

Petrography

Specimens from the Scarfataing coast include both basic igneous rock (S45034) [HU 343 643] and gneiss (S28904) [HU 340 636], (S45029) [HU 339 639], (S45030) [HU 339 639], (S45031) [HU 339 639]. The former is a coarse ophitic biotite-hornblende-gabbro. Most of the plagioclase and much of all varieties of amphibole have been replaced by coarse shapeless grains of scapolite ((Plate 22), fig. 7), while very scarce and local tourmaline, dichroic from bluish green to colourless, has replaced pale green amphibole. Biotite appears to have been replaced in part leaving a powder of sphene in the replacing scapolite but much has recrystallized in groups of small flakes which persist enclosed in scapolite. Locally aggregates of calcite and idioblastic chlorite replacing hornblende and biotite may represent earlier alteration products which were stable during recrystallization. Grains of sphene are abundant within biotite and hornblende and large round grains of apatite are local in the scapolite. Scapolitization appears to have been aided by an earlier fracturing, mainly without shearing, of the rock.

The scapolitized gneiss of the Scarfataing area includes a variety of banded rock-types, and the nature of the pre-scapolitization rock may be uncertain. A calcitechlorite-biotite-scapolite rock (S28904) [HU 340 636] shows foliation in respect of a roughly parallel banding of biotite-rich and calcite-chlorite-rich bands. Original reddish brown biotite is commonly margined by green biotite, and similar green biotite in groups of unorientated small flakes is enclosed in scapolite; in part large grains of the reddish brown biotite are irregularly corroded and embayed by scapolite without intervention of the green variety. Both reddish brown biotite and chlorite show strained cleavages indicative of shear stress prior to scapolitization. Other scapolitized rocks include biotitehornblende-andesine-granulites which are banded by alternating dominance of the component minerals or by variation in grain-size (S45029) [HU 339 639], (S45030) [HU 339 639], (S45031) [HU 339 639]. The coarser layers of these rocks greatly resemble diorite and in the field this resemblance is enhanced by the resemblance of the granular scapolite to feldspar. The mineral layering, the granoschistosity of plagioclase, and the hornfels texture of some laminae are sufficient to identify them with the contact-altered gneiss of the area.

The degree of scapolitization in the Scarfataing gneiss is very variable and its distribution is patchy though controlled at least in part by the foliation and grain size of the gneiss; the very fine-grained granulites are not scapolitized. Within coarse-grained bands transition from fresh gneiss to rock in which the plagioclase is almost completely replaced is abrupt though relics of plagioclase persist and in general the disposition of biotite and hornblende persist unchanged. Locally recrystallization of hornblende to sharp, notched prisms of a blue species has occurred (S45030) [HU 339 639]. The crystals, entirely enclosed within scapolite, vary in depth of colour from pale to deep greenish blue; the darkest variety has pleochroism X yellow, Y bluish green, Z indigo blue, refractive indices $\alpha < 1.699$, $\beta > 1.699$, $\gamma = 1.712$, 2V (by Mallard's method) 30–35°. The paler varieties have lower refractive indices and higher optic axial angles. These properties are similar to those of ferrihastingsite in the Clothister skarn (Phemister, in press). The scapolite itself is usually turbid because of alteration to analcime but fresh material was found to have $\alpha = 1.555$–6, corresponding with that of the sodic scapolite described from elsewhere in Shetland (Mykura and Young 1969). The alteration initially produces a turbid streakiness parallel to the c axis of the mineral and proceeds through a diffuse network until the scapolite is replaced by large patches of greatly cracked turbid isotropic zeolite in which optically continuous but ill-defined spots of scapolite persist. The refractive index of the zeolite is 1.490 and it is therefore referred to analcime. Most of it is isotropic, yielding no figure in convergent light, but some patches yield a good negative uniaxial figure which is thought to arise from unaltered scapolite not otherwise detectable.

The specimens of scapolitized rock from Ell Wick, the quarry south of Mavis Grind and Hurda Field are essentially of vein scapolite containing rock relics. They afford much fresher scapolite than the Scarfataing rocks and its refractive indices have been determined on several specimens as $\omega = 1.555$ or 1.556, $\varepsilon = 1.544$ or 1.545. There is evidence of several phases of crystallization of scapolite. For example fragments of biotitic rock in which large idioblastic scapolites have grown are embedded in finer grained scapolite felt (S55701) [HU 341 682]. Rock replaced by coarse granoblastic scapolite is cut by irregular channels of fine-grained lathy scapolite (S53595) [HU 343 683] or embedded in finer grained scapolite (S55698) [HU 341 682]. Scapolite is locally replaced by analcime (S55701) [HU 341 682] and the zeolite occurs also in narrow channels cutting scapolite and quartz (S55697) [HU 341 682]. Late crystallization of pale green prochlorite in shapeless ophiblastic plates enclosing prisms of scapolite is seen in several specimens (S53604) [HU 342 693], (S53635) [HU 341 696], (S53636) [HU 341 695]; the chlorite is almost isotropic, optically positive, with γ 1.631.

The rock material which is enclosed in the scapolite consists mainly of quartz, biotite aggregate, chlorite aggregate, rare plagioclase, calcite, and accessory black ore, sphene, apatite and zircon; a single sharply wedged crystal of yellowish colour, strong relief, probably biaxial negative, which is idioblastically intergrown with scapolite, may be axinite (S53636) [HU 341 695]. Quartz is present in all specimens generally as large shapeless or angular, strained or fractured grains which are corroded by scapolite. It occurs in association with prismatic acid plagioclase and interstitial biotite and chlorite in one specimen as fragments in a scapolitized granitic breccia (S55699) [NN 2439 1391]. In other rocks it is granular, unstrained, and cemented by pale green biotite aggregate and this material may represent a paraschist (S53635) [HU 341 696]. Brown biotite is commonly present as aggregates of microcrystalline and unorientated flakes with or without granular quartz and the texture of these groups as well as the sparse occurrence of linear trails of ore granules suggests derivation from a quartzified pelitic hornfels (S53604) [HU 342 693]. Biotite of a pale brown colour occurs also in very fine-grained almost cryptocrystalline aggregates in which prisms of pale green hornblende are locally enclosed; in some groups the minute scales are schistose and the schistosity is interrupted by idioblastic scapolite (S55701) [HU 341 682]. Schlieren of this type of biotite foliated with strained calcite and deformed chlorite and enveloping small prisms of pale green hornblende suggest derivation from a schistose rock (S55698) [HU 341 682], but in this case and in the preceding also the rock is considered to have been decomposed sheared diorite; grains of plagioclase occur only rarely (S55700) [HU 341 682]. It seems probable that rocks of both igneous and pelitic origin and vein quartz also are represented in the relics within the scapolite.

Evolution of the igneous complex

In reviewing the field and petrographical descriptions set out in the foregoing pages it becomes clear that the phenomena characteristic of this complex and cardinal to a hypothesis of its evolution are the following:

1. A complete transition, spatial and mineralogical, between ultrabasic, gabbro and diorite components;
2. the lack of any regularity in spatial arrangement of those components, relative to one another or to position in the massif;
3. the ubiquity of minor acid material in varying amount throughout the gabbrodiorite;
4. the separateness of major granitic members from the gabbro-diorite body;
5. the predominance of primary hornblende throughout the gabbro-diorite;
6. the predominance of secondary amphibole over biotite and chlorite in the interstitial component of all basic rocks plutonic or hypabyssal.

From the random distribution of gabbroic rock in the more voluminous dioritic mass and from the total absence of contacts between these components it is deduced that the magma at the time of emplacement was of heterogeneous composition. The ubiquitous conversion of pyroxene to amphibole contemporaneously with consolidation shows that the intrusive magma carried an important content of water which, in addition to promoting mineralogical change, would assist in maintaining fluidity during emplacement. The absence of compositional banding within the gabbroic components and their lack of any regular form against the diorite indicate that the process of emplacement was slow and tranquil, effectively under hydrostatic conditions. The diorite component is variable in respect of the content of pyroxene, the proportion of mafic to felsic constituents, and degree of conversion of calcic to more sodic plagioclase. This variability combined with the evidence of the existence of minor quantities of quartzo-feldspathic fluids, varying in amount but present throughout the gabbro-diorite body, suggests that during the emplacement continuous acidification of the basic rock was operating, that in effect there did not exist at depth a magma of diorite composition, but that two 'primary' magmas were available for intrusion—one of basic composition with ultrabasic differentiates and acid residues which were dispersed in the process of intrusion, the other of granitic composition which was tapped only in small amount during the irruption from the basic reservoir. This conclusion is supported by the separateness of the major gabbro-diorite and granite-granophyre masses and by the separateness of the late dyke swarms of acid and basic compositions (see Chapter 16). The diorite is therefore considered to be an essentially hybrid material produced from gabbro by reaction, during emplacement, with more hydrous and quartzo-feldspathic fluids derived partly from its own differentiation, partly from the adjacent reservoirs of granitic magma which were later intruded as dykes, sheets, the Eastern Granite mass and the Muckle Roe Granophyre stock.

This hypothesis affords also an explanation of the production of the recrystallized actinolitic amphibole which is so persistent as the interstitial material throughout the gabbro-diorite, since the close presence of acid magma in an immediately irruptible state would make available the heat and fluid required for the recrystallization. In conclusion attention is drawn to the many examples of partial replacement by mica, epidote, silica and by both calcic and sodic scapolite, which have been mentioned in the earlier pages. Some are only locally intense but all together indicate the activity of hydrothermal solutions in the intrusive and the country rock over a very long period of time extending to the last stages of dislocation on the Walls Boundary Fault-Zone.

Summary

The sequence of the main events in the history of the unfoliated igneous rocks of Old Red Sandstone age in Muckle Roe and southern Northmaven has been tentatively deduced from the field and laboratory work as follows:

1	Intrusion of early basic dykes and sills into gneiss in Muckle Roe and Busta peninsula; local intrusion or extrusion of basaltic magma in the area north of Lang Head.
2	Intrusion of granite at Scarfataing as sheets into gneiss, with associated granitization.
3	Brecciation, possibly explosive, of the volcanic or subvolcanic rocks of the Lang Head zone and invasion of the breccia by quartzo-feldspathic liquor.
4a	Intrusion of basic magma carrying ultrabasic enclaves and containing an important proportion of hydrous component to form the main gabbro-diorite body; this intrusion caused thermal alteration of the gneiss country rock.
4b	Reaction within the gabbro-diorite intrusion to produce a variable dioritic rock and plexiform diorite-granodiorite-granite mélange; the formation of the mélanges may be due in an unknown degree to an initial phase of event 5.
5	Intrusion of coarse uniform granite as large and small dykes and sheets.
6	Intrusion of the Muckle Roe Granophyre stock.
7	Intrusion of a parallel swarm of felsite-acid porphyrite dykes originating at the locus of the Muckle Roe Granophyre.
8a	Intrusion of a parallel swarm of basic dykes.
8b	Intrusion of pyroxene-porphyrite dykes possibly from a focus in the Busta peninsula (N.B. for the sequence 7, 8a, 8b see Chapter 16).
9	Crushing and scapolitization associated with faulting along the Walls Boundary fault-zone, followed by local analcimization.

The main gabbro-diorite body may have the form of a lopolith, its main conduit lying in the area between Gunnister Voe and Hamar Voe (One-inch Sheet 130) approximately on the line of the Lang Head zone of earlier brecciation.

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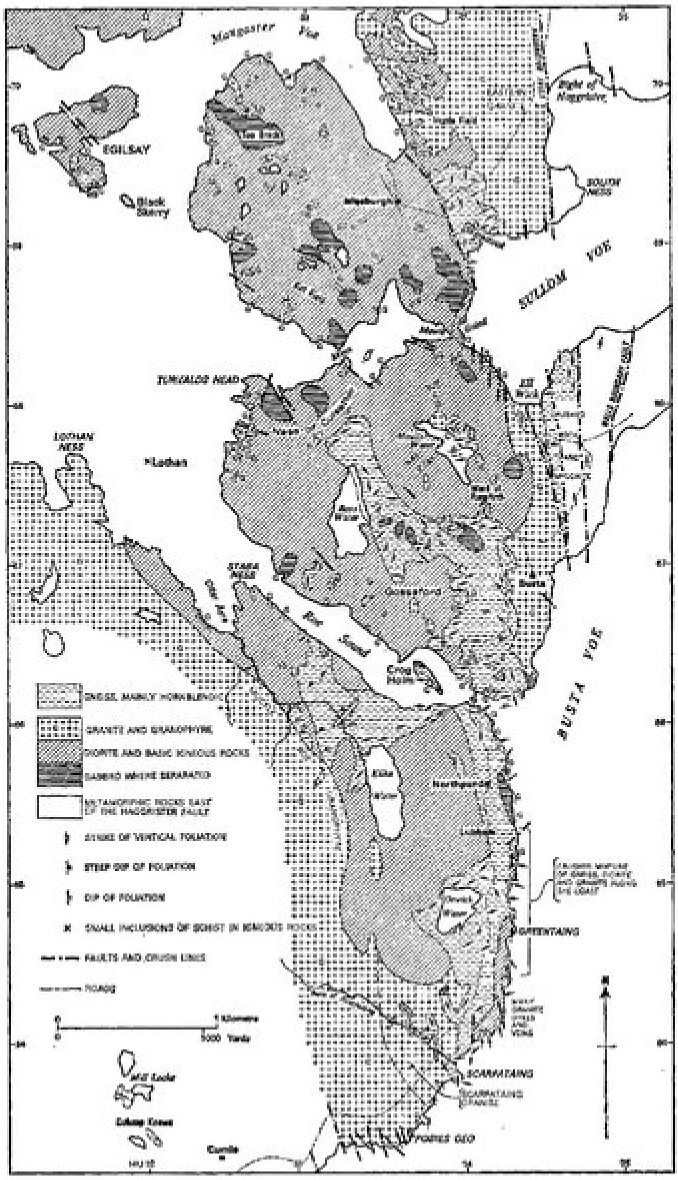
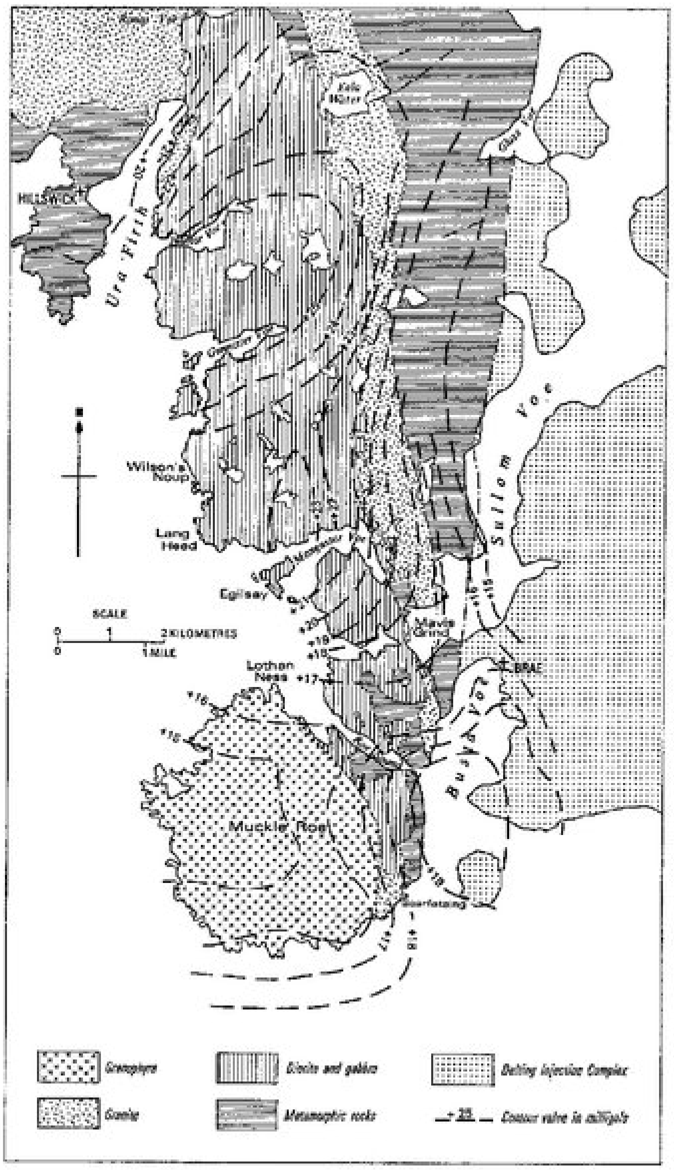
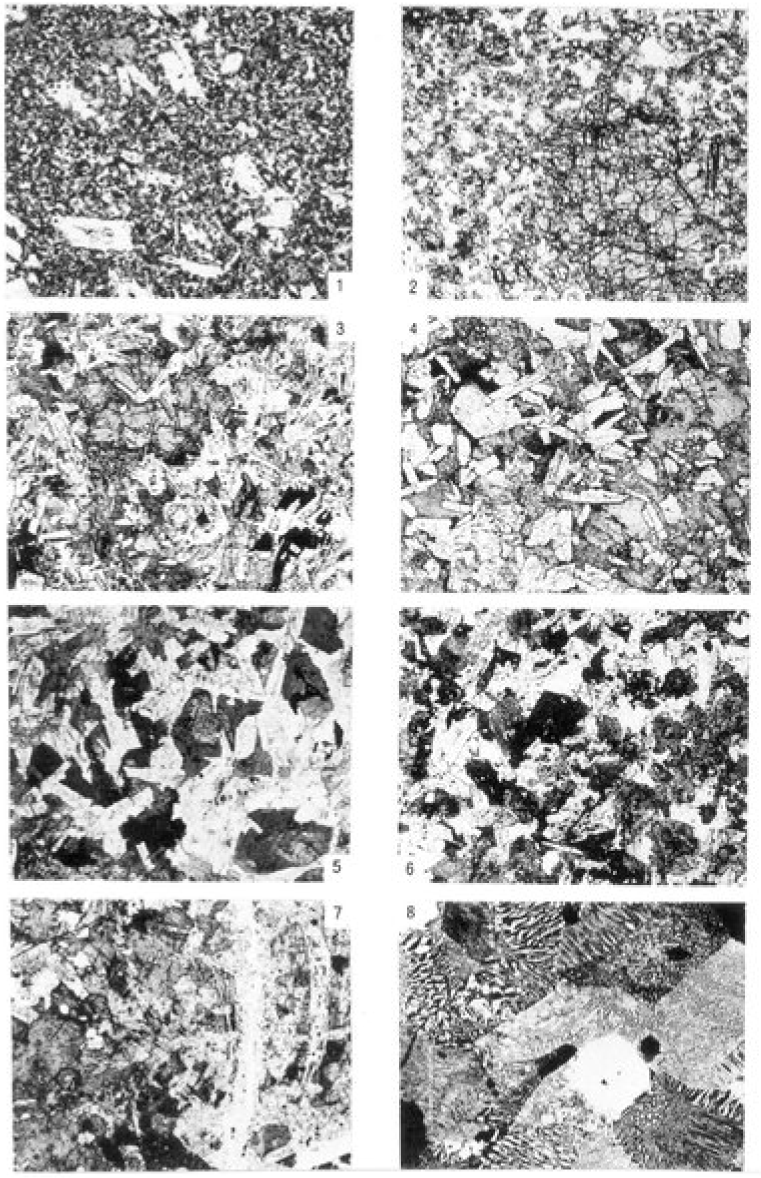


(Figure 5) Distribution of metamorphic rocks in the Muckle Roe–Mangaster Yoe area.



(Figure 23) Bouguer anomalies over the Muckle Roe–Ura Firth area.



(Plate 22) Photomicrographs of rocks of the Northmaven–Muckle Roe Plutonic Complex Fig. 1. Slice No. (S44284). Magnification × 25. Plane polarized light. Early basic dyke, thermally altered. The plagioclase (An 50%) phenocrysts are recrystallized at their margins to interlock with the recrystallized base consisting of microgranular andesine and small idioblastic prisms of hornblende and biotite; small ferromagnesian phenocrysts are recrystallized to compact aggregates of interfering microprisms of hornblende. West side of Egilsay [HU 316 695]. Fig. 2. Slice No. (S30016A) [HU 332 732]. Magnification × 14.5. Plane polarized light. Bytownite-peridotite. Numerous small crystals of olivine are enclosed poikilitically in large plates of bytownite and clinopyroxene. The relative proportions of these minerals are variable; orthopyroxene and reddish brown hornblende and biotite are variable minor constituents. South-east shore of Glussdale Water [HU 332 734]. Fig. 3. Slice No. (S30017A) [HU 332 733]. Magnification × 11.5. Plane polarized light. Gabbro. Large plates of augite enclose prisms of calcic labradorite ophitically; brown hornblende margins augite and also forms smaller ophitic plates. A late crystallization of deep brown biotite is moulded on plagioclase. West shore of Glussdale Water [HU 332 734]. Fig. 4. Slice No. (S55647) [HU 341 682]. Magnification × 10. Plane polarized light. Hornblende-gabbro (bojite). Large partly uralitized plates of brown and green hornblende enclose zoned plagioclase (An 65–45 %) prisms ophitically. Deep brown biotite is moulded on plagioclase. Cliva Hill, 150 yd (130 m) SSE of Mavis Grind [HU 340 682]. Fig. 5 . Slice No. (S30023) [HU 315 742]. Magnification × 10–5. Plane polarized light. Hornblende-augite-quartz-diorite. Prisms of augite are subophitic to plagioclase; brown hornblende is moulded on plagioclase and idiomorphic against quartz. Plagioclase prisms are zoned from acid labradorite core to oligoclase margin. South shore of Gunnister Voe [HU 315 742]. Fig. 6. Slice No. (S55665) [HU 300 725]. Magnification × 12. Plane polarized light. Biotite-hornblende-quartz-diorite. Tables of zoned plagioclase (An 55–15 %) interfere with hypidiomorphic brown and green hornblende which show good crystal forms against quartz (top centre). Peninsula 195 yd (180 m) WSW of Nibon [HU 304 730]. Fig. 7. Slice No. (S45034) [HU 343 643]. Magnification × 14. Plane polarized light. Scapolitized

gabbro. On the left, gabbro of unaltered plagioclase, hornblende and augite resembles that of Figs. 3 and 4; on the right, plagioclase is completely, hornblende partially replaced by xenomorphic, coarsely crystalline scapolite. East coast of Muckle Roe, 435 yd (400 m) NNE of Scarfa Taing [HU 334 639]. Fig. 8 Slice No. (S29505) [HU 314 674]. Magnification × 14.5. Crossed polarisers. Granophyre. Muckle Roe, west side of Roda Geo [HU 314 674].

(Plate 21A) Wilson's Noup, Northmaven [HU 302 716]. Brecciated basalt in granite and granodiorite. (D1345).

(Plate 21B) Wilson's Noup, Northmaven [HU 302 716]. Brecciated partly permeated basalt cut by a stream of granodioritic material full of elongate, variably assimilated basaltic enclaves. (D1347).

	1	A	B	C	D
SiO_2	40·58	40·82	40·35	43·09	42·52
Al_2O_3	7·57	10·66	3·75	7·51	8·12
Fe_2O_3	3·18	1·80	3·53	$FeO\frac{1}{2}$ 0·52	2·41
FeO	9·01	8·92	9·86	7·14	8·72
MgO	27·50	28·08	25·69	33·48	27·42
CaO	4·51	6·11	4·64	5·75	6·27
Na_2O	0·76	0·58	3·14	$NaO\frac{1}{2}$ 0·65	0·72
K_2O	0·15	0·21	0·80	$KO\frac{1}{2}$ 0·12	0·23
$H_2O > 105°C$	5·74	2·00	5·28	1·18	1·90
$H_2O < 105°C$	0·33	0·16	0·83	—	0·17
TiO_2	0·39	0·16	2·12	0·16	0·49
P_2O_5	0·04	—	0·25	nil	0·04
MnO	0·20	0·19	0·20	0·05	0·18
CO_2	0·09	0·00?	tr.		0·56
FeS_2	0·11	S 0·02			
Fe_7S_8	tr.				
Cr_2O_3	0·26	0·25		0·39	0·20
BaO	0·02		} 0·06		
SrO	0·01 (s)				
Cl	—	—			
	100·45	100·12	100·56	100·04	99·95

(s) Spectroscopic determination

Norm of Lab. No. 1065

or	0·89	ol	48·01
ab	6·29	mg	4·64
an	17·07	il	0·76
di	3·72	em	0·38
hy	12·79		
			94·75

Symbol 4.1.4.1.2: *Custerose*

1. Enstatite-harrisite. NE shore of Moora Waters, Northmaven, Shetland. One-inch 128 Scot., Six-inch 24 SE. Lab. No. 1065. Anal. C. O. Harvey; spect. det. H. K. Whalley. Guppy and Sabine 1956, pp. 35–6.
A. Harrisite, Tertiary intrusion. Roadside near Dornabac Bridge, Rhum. The total includes (Ni, CO) O 0.11, CuO 0.05. Guppy and Thomas 1931, pp. 97–8.
B. Hornblende-peridotite, Lugar sill. Glenmuir Water, Ayrshire. Tyrrell 1916, pp. 113–4.
C. Feldspathic peridotite. An Garbh-choire, Skye. Weedon 1965, p. 57.
D. Ultrabasic dyke No. 1, 4 ft 4 in from edge. Ben Cleat, Skye. Gibb 1968, p. 628.

(Table 4) Chemical analyses of enstatite-harrisite from Northmaven and comparable Scottish rocks.

(Plate 23A) Roadside quarry, south of Mavis Grind, Northmaven [HU 342 682]. Scapolite vein in diorite-granite complex. (D1344).

(Plate 23B) East shore of Cow Head, Vementry Island [HU 309 607]. Straight clean-cut junction between Vementry granite (pale) and metamorphic rocks. (D904).