Slockenray Coast

[NX 135 911] and [NX 136 914]–[NX 143 924]

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Introduction

The Slockenray Coast GCR site includes a part of the Northern Serpentinite Belt, its faulted margin with the Pinbain volcanosedimentary block, and an olistostrome, lavas and volcaniclastic strata within that block. The site falls into three parts each of which contains an important component of the Ballantrae Complex ophiolite. The northern sector forms the major part and provides an extensive section through an Arenig volcanosedimentary sequence of lava and intercalated volcaniclastic sedimentary rocks. The central part of the site is occupied by a structurally complex zone with a coarse conglomeratic olistostrome faulted against serpentinite. The isolated southern outlier contains a remarkable pegmatitic gabbro intruded into the serpentinite, which is also traversed by veins of coarse-grained pyroxenite. A general account of the geology is given by Stone and Smellie (1988).

The good accessibility and exposure have made it one of the most intensively studied parts of the Ballantrae Complex so that it has been central to several of the historical controversies which have raged over interpretation of the regional geology. Initially there was debate over a metamorphic versus an igneous intrusive origin for the complex and crucial evidence in support of the latter was obtained by Bonney (1878) from the pegmatitic gabbro at the southern end of the section. To mark this breakthrough the name 'Bonney's Dyke' was coined for the locali ty by Balsillie (1932) and it is generally known by this colloquial name in the geological literature. The gabbroic dyke has a striking black and white appearance, created by large plagioclase and altered clinopyroxene crystals; it displays a range of textures within an overall coarse pegmatitic style. The host rock is serpentinized harzburgite of the Northern Serpentinite Belt which at this locality contains numerous veins of coarse pyroxenite.

A short distance north from Bonney's Dyke, in the vicinity of Pinbain Bridge at the southern end of the main GCR sector, the Northern Serpentinite Belt is faulted against an unusual conglomeratic unit. This comprises a variety of clasts, both in terms of size and composition, contained in a black shaly matrix that is pervasively foliated in places. It was originally interpreted in volcanic terms but, with the development of the ophiolitic model, Church and Gayer (1973) noted its similarity to the extensive mélange deposits associated with the large-scale ophiolite bodies of Newfoundland. In this interpretation, masses of brecciated pillow lava, apparently interbedded with the conglomerate, may be rather viewed as large blocks within an original olistostrome.

The olistostrome is most pervasively foliated adjacent to its southern margin and the fabric becomes less intense towards the northern margin where there is another faulted sliver of serpentinite. This narrow zone provided the focus for much of the argument over a proposed intrusive origin for the serpentinite. The critical relationships were interpreted by Anderson (1936) in favour of intrusion of the serpentinite into the lava sequence while Balsillie (1937) was using information from elsewhere in the Ballantrae Complex to deduce that the serpentinite was much older than, and formed a basement to, the lavas (see particularly the Knockormal GCR site report). Bailey and McCallien (1957) re-examined the Pinbain locality, having been previously disposed towards the intrusive interpretation, and decided that the apparently intrusive veins are of secondary origin and are probably related to serpentinization of an ultramafic precursor. This conclusion is now generally accepted although Bailey and McCallien's broader interpretation, that the serpentinite originated as an ultramafic, submarine lava flow, has now been superseded by the ophiolite model.

Northwards from the olistostrome–serpentinite fault slice the coastal section comprises a relatively continuous volcanosedimentary succession. The beds are vertical or steeply inclined and young consistently northwards. Despite the abundant minor faulting this is the least structurally disturbed part of the Ballantrae Complex and many sedimentological and volcanic features are well displayed. Two aspects are of particular importance: a graptolite fauna collected from the southern end of the section and a remarkable lava-front delta assemblage in the central part at Slockenray itself The graptolites were recovered and described by Rushton *et al.* (1986) who deduced an early Arenig age. The Slockenray relationships have been described in great detail by Bluck (1982) who emphasized their support for eruption of the lava sequence into relatively shallow water. The lack of spilitization of some of the Slockenray rocks was also stressed by Bluck following earlier debate over their exceptional lack of alteration. This was sufficiently striking that Bailey and McCallien (1957) admitted to briefly entertaining the idea that they were contained in a volcanic neck of Palaeogene age.

Description

The outline geology of the Slockenray–Pinbain section, which encompasses the Slockenray Coast GCR site, is shown in (Figure 2.25). The Balcreuchan Group lithostratigraphy shown is based on that proposed informally by Bluck (1982).

At the southern extremity of the section, within the Northern Serpentinite Belt, a striking pegmatitic gabbro body (Bonney's Dyke) protrudes from the ultramafic rocks on the foreshore and just above the high-water mark. It is an elongate mass up to about 5 m wide, with an overall WNW trend made arcuate by the cumulative offsets of several minor sinistral faults (Figure 2.26). The gabbro is a pale-coloured rock formed almost exclusively of plagioclase and clinopyroxene, the latter in a rather fibrous variety of diopside and/or augite termed 'diallage' in the older literature. These minerals are now extensively altered, the plagioclase to a calcium-rich assemblage of pectolite, prehnite and hydrogrossular garnet and the pyroxene to an aggregate which includes actinolite and chlorite; some serpentine minerals are also present, which may indicate original olivine. Grain size is very variable (Figure 2.27) with fine-grained patches alternating irregularly with zones in which the plagioclase laths and pyroxene crystals range up to 2 cm. Xenoliths of serpentinite up to about 50 cm across are abundant locally. The margins of the gabbro body generally dip moderately to the south but three types of contact relationship are displayed: sharp contacts against serpentinite (including the xenoliths); more diffuse margins abutting coarse pyroxenite veins; and sheared margins that have recrystallized to a very fine-grained secondary mineral assemblage through calcium metasomatism. It is noteworthy that none of the gabbro margins are chilled unequivocally against the ultramafic rock.

The host rock to the pegmatitic gabbro is serpentinized harzburgite cut by abundant and anastomosing veins of coarse-grained pyroxenite. These stand out clearly as paler-green zones contrasting with the very dark background of the serpentinite. Some of the pyroxenite veins are spectacularly coarse with diallage crystals up to 10 cm long. Northwards from Bonney's Dyke the serpentinite is exposed sporadically towards the low-water mark but extensive rock outcrop does not recur until the Pinbain Bridge area (Figure 2.25). There, the faulted northern margin of the Northern Serpentinite Belt has been intruded by a dolerite dyke of Palaeogene age which has baked and hardened the adjacent ultramafic rock. Accordingly, this marginal zone of serpentinite has proved unusually resistant to erosion and now stands proud of the surrounding beach and rock platform.

Northwards, beyond the Palaeogene dyke, is an extensive outcrop of the Pinbain olistostrome. This has been described in great detail by Bluck (1978a, 1992) and is illustrated in (Figure 2.28). The southern part of the olis-tostrome, adjacent to the serpentinite and dyke, consists of a mélange containing a great variety of clasts set in a pervasively foliated, black shaly matrix. The clasts range considerably in shape and size with some boulders several metres across. An equally large lithological range is present; basalt tends to form the larger clasts with some appearing to be intact pillows of lava, large pale clasts of carbonate may well be highly altered ultramafic rock but small clasts of dark-green serpentinite are also present. The other smaller clasts have a remarkably large lithological range with records of shale, tuff, chert, basalt, dolerite, gabbro, pyroxenite and, very rarely, glaucophane- and garnet-glaucophane schist (Bailey and McCallien, 1957). A large mass of brecciated pillow lava at the northern margin of the mélange may be an interbedded unit or may be an exceptionally large clast caught up in the olistostrome. Farther north still, the lithology becomes more conglomeratic with a more restricted clast size range and a generally unfoliated shale matrix. Granitic clasts, quartz, and fragments of quartz-cemented breccia appear at this level. The northern margin of the Pinbain olistostrome is formed by a complex fault zone introducing slivers of serpentinite and intruded by Palaeogene dolerite dykes. The olistostrome is thus structurally isolated from the volcano-sedimentary sequence forming the main part of the Slockenray section.

The Slockenray coastal section provides a cross-strike traverse through the Pinbain block, the northernmost and least structurally confused of the three principal volcanic units which together form the Balcreuchan Group within the

Ballantrae Complex. Bluck (1982) divided the approximately 1500 m of lava and volcaniclastic sedimentary strata into five formations and this lithostratigraphical scheme, slightly modified by Stone and Smellie (1988, see especially table 4), is applied in (Figure 2.25). The age of the sequence is fixed by the early Arenig graptolite fauna described from the southern extremity of its outcrop by Rushton *et al.* (1986). The fossils were recovered from thin shale laminae within volcaniclastic sandstone where the beds strike NE–SW and dip steeply to the NW. This is a fairly characteristic bedding attitude throughout the section and since younging is consistently to the NW the early Arenig age applies to the base of the sequence. A variety of volcaniclastic sedimentary rocks are interbedded with lavas and lava breccias. The lavas are variably porphyritic and aphyric, although even the aphyric lavas commonly contain scattered microphenocrysts.

Plagioclase is the most common of the phenocryst minerals and there are also rare augite and olivine phenocrysts, all set in a matrix dominated by plagioclase and augite. Spilitization and low-grade metamorphism have created widespread secondary minerals including albite, chlorite, titanite, epidote and prehnite.

An area of particular interest is centred on Slockenray itself where there has apparently been mixing of two lava types, one aphyric and the other strikingly porphyritic (Figure 2.29). In the latter, large plagioclase laths are aligned in swirling patterns indicative of flow orientation and the zones of phenocrysts have relatively sharp margins against aphyric lava. However, apart from the presence or absence of phenocrysts there is no difference in the composition or appearance of the lava varieties and there are no signs of physical boundaries between them. It would appear that two different lavas, one aphyric and the other plagioclase-phyric, were erupted simultaneously and mixed together immiscibly during flow. Immediately to the south of the lavas, hyaloclastite breccia beds contain blocks of both lava types together with abundant detrital plagioclase crystals. Since the beds are sub-vertical in a north-younging sequence the breccias are older than the lavas which overlie them. The relationships at this locality have been described in detail by Bluck (1982) who considers the breccias to be lava-front accumulations ahead of an advancing flow which progressively over-rode its own frontal deposits.

In the northern part of the Slockenray coastal section features of interest include reddened, scoriaceous top surfaces of some lava flows and a bed of tuffaceous sandstone containing accretionary lapilli described by Smellie (1984). These features are of importance in any palaeoenvironmental analysis.

Interpretation

The coarse pegmatitic gabbro of Bonney's Dyke was quoted by Church and Gayer (1973) as representing one of the characteristic components of an ophiolite assemblage. Such lithologies may be found in the basal part of the gabbro unit or as a late intrusion into the upper part of the ophiolite 'stratigraphy'. However, while the lithology might be appropriate, the setting of the Bonney's Dyke example is incompatible with either of these styles of occurrence. If it originated in the basal gabbro unit its present isolated situation would require interpretation as a clast or xenolith within the serpentinite. This is not supported by the marginal relationships or by the presence of serpentinite xenoliths in the pegmatite; these features all favour an intrusive origin. The intrusion is not into the upper levels of the ophiolite 'stratigraphy' as the model would predict but instead the pegmatite has been emplaced into mantle harzburgite, the low est part of the ideal sequence. Thus, assuming that the pegmatite rose on intrusion, the implication of its current position is that the Ballantrae Complex ophiolite was structurally imbricated while the final stages of its igneous generation were still in progress. The calcium-metasomatism of the dyke margins shows that intrusion occurred before serpentinization of the ultramafic rock, further compressing the time-scale of ophiolite development, structural imbrication and alteration.

The olistostrome and breccia deposit exposed around the mouth of the Pinbain Burn is contained within a structurally isolated fault-bound block. It has been described and discussed by numerous authors, notably Bailey and McCallien (1957) and Bluck (1978a, 1992). The salient points of interpretation can be summarized as follows.

1. A wide variety of clast types are present, including the full range of ophiolitic rocks and some high-grade metamorphic lithologies.
2. Large clasts were slumped into relatively deep water where black shale was accumulating.

3. Intense shearing was focused into some parts of the unit during or immediately after its deposition to create a pervasively foliated mélange.
4. The slumped lithologies are intimately associated with tuff and pillow lava indicative of contemporaneous volcanicity.

In their original comparison of the Ballantrae Complex with the ophiolite model, Church and Gayer (1973) described the olistostrome as a syn-obduction deposit 'developed as a result of deformation beneath a forward moving thrust sheet of material previously produced by erosion from the leading edge of the self same nappe'. Bluck (1992) preferred an origin in an extensional environment, citing the volcanic activity in support of an association with normal rather than compressional faults. These brought the deeper levels of the ophiolite to the erosion level in fault scarps, the faults themselves probably rooting in the fissile shaly lithologies and there producing the localized intense ductile deformation. Such structures would almost certainly have been re-activated as thrusts during subsequent obduction-related basin inversion.

A mid- to late-Arenig graptolite was recorded from the olistostrome by Peach and Horne (1899, p. 442). Amphibolite *in situ* elsewhere in the Ballantrae Complex and lithologically identical to clasts in the olistostrome has been dated radiometrically at 478 ± 8 Ma. These relationships have been used by Bluck *et al*. (1980) to suggest a constraint on the Arenig time-scale. However, the graptolite was re-examined by Rushton *et al.* (1986) who concluded 'that it is quite undeterminable and even its graptolitic nature is questionable'. Stratigraphical deduc tions based on the Pinbain olistostrome should therefore be treated with caution.

The Pinbain volcanosedimentary sequence is approximately 1500 m thick, which suggests considerable synvolcanic subsidence during its accumulation. This point is emphasized by the abundant evidence for shallow-water sedimentation and possible subaerial eruption. Bluck (1982) described the Slockenray breccias in terms of an upward coarsening sequence built up as a hyalotuff delta, ahead of lava flows, in the shallow sub-tidal or intertidal zone. He summarized the situation as 'the lavas advanced over the sediments so a sequence was generated where these sediments have a source in lava flows which were eventually to overlie them'. Syn-eruption subsidence would seem implicit in this interpretation. Higher in the Pinbain Block succession the reddened tops of lava flows and the presence of accretionary lapilli (Smellie, 1984) are both indicative of subaerial eruption with the lapilli falling into shallow water.

Several cycles of lava advance have been described by Bluck (1992). Slow eruption rates produced a pillowed flow whereas rapid eruption produced a more massive lava; the lavas were continuously eroded into breccias and hyaloclastites and the sea may have transgressed the flow top between eruptions. The mixing of plagioclase-phyric and aphyric lavas, well displayed at Slockenray itself, requires the contemporaneous eruption of different magma types in close proximity. Flow segregation of the feldspar phenocrysts may be a possible alternative explanation but has not found much support from previous investigators.

The geochemistry of the Pinbain–Slockenray lavas has been generally interpreted in terms of within-plate, oceanic island eruption (Wilkinson and Cann, 1974; Thirlwall and Bluck, 1984; Stone and Smellie, 1990). This ,is most readily reconciled with the evidence for subsidence and shallow water in a marginal or back-arc basin. In this respect the sequence compares closely with that developed in the Bennane Head sector of the Balcreuchan Port to Port Vad GCR site but at Pinbain a geochemical curiosity occurs at the base of the succession. Here, volcaniclastic sandstones form the oldest stratigraphical level and are interbedded with graptolitic shales of early Arenig age (Rushton *et al.,* 1986). The sandstones are formed exclusively of volcanic material and on analysis prove to have the chemical characteristics of island-arc lavas (Stone and Smellie, 1990; Smellie and Stone, 1992). If this association is accepted the back-arc model is strengthened since it provides an environment in which arc-derived sands could be overlain by within-plate lavas erupted during a phase of significant subsidence. Evidence of this sort, provided by the Slockenray Coast GCR site, is of fundamental importance in the interpretation of the Ballantrae Complex as a whole. A polygenetic source for the ophiolite seems increasingly likely with island-arc and within-plate components now structurally juxtaposed.

Conclusions

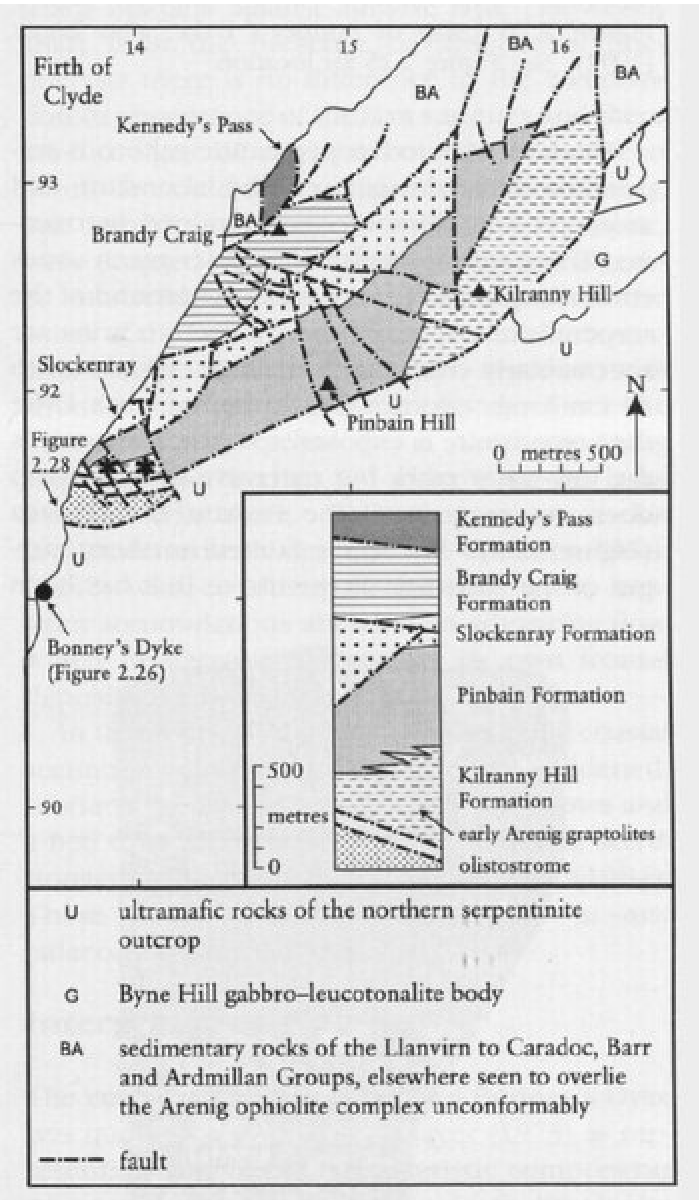
The Slockenray Coast GCR site contains three different geological components, each of which is fundamental to the ophiolitic interpretation of the Ballantrae Complex. Their characteristics are exceptionally well displayed in a section that has received much historical study.

At the southern end of the GCR site the coarse gabbro body forming Bonney's Dyke shows a spectacular development of very coarse-grained, pegmatitic texture. The lithology is an integral part of the ophiolite assemblage but its position here, intruded into serpentinite cut by pyroxenite veins, is somewhat anomalous. It suggests early structural disordering of the Ballantrae Complex while ophiolitic magmatism was still in progress.

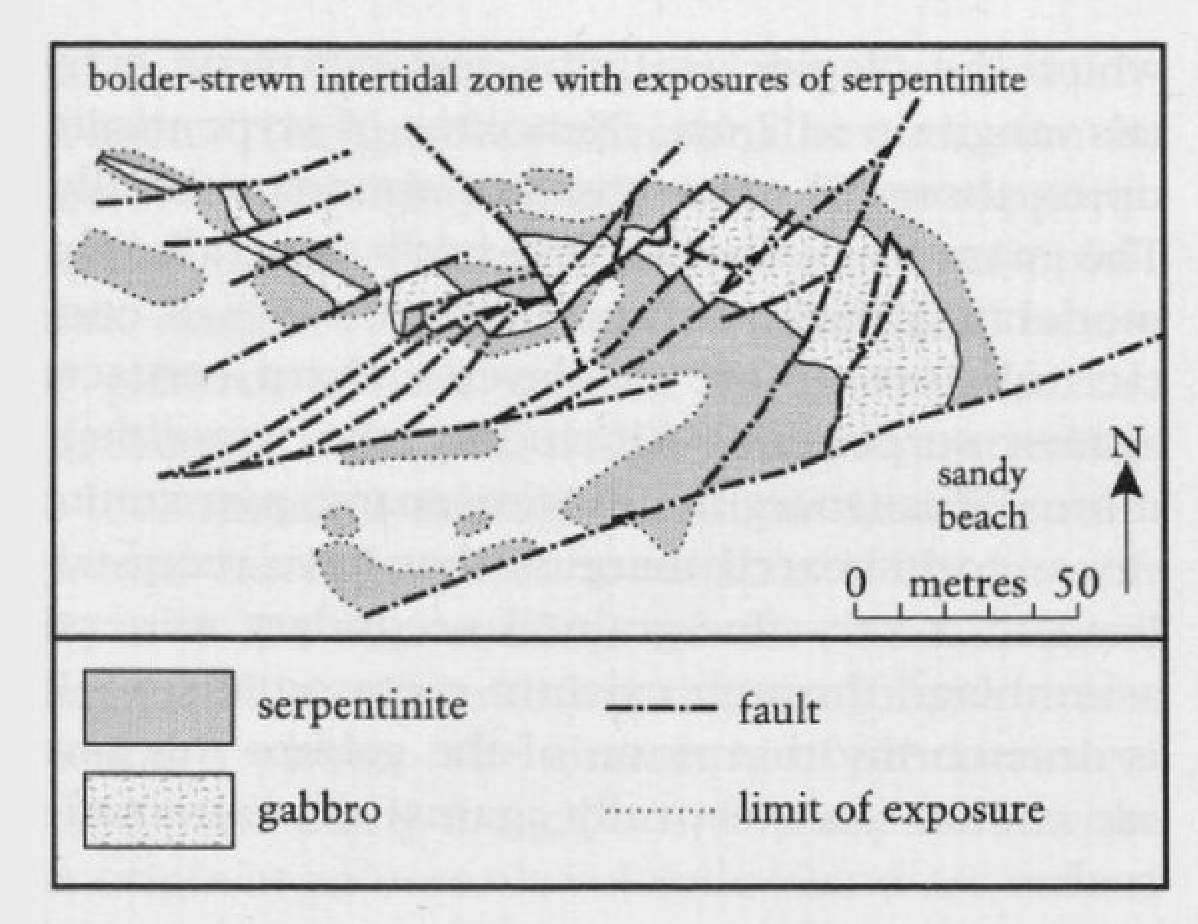
The foliated conglomeratic (mélange) deposit exposed around the mouth of Pinbain Burn has been the subject of much debate. It contains clasts with a wide size and composition range, the latter including both ophiolitic lithologies and exotic, high-grade metamorphic rocks. An origin by large-scale slumping is now generally accepted.

The accessible and well-exposed Slockenray coastal section forms most of the GCR site; it contains the most complete and least structurally disturbed volcanosedimentary succession within the Ballantrae Complex. The lavas are believed to have been erupted in an oceanic island, within-plate environment and graptolite fossils from intercalated shale at the base of the sequence fix the age at early Arenig. Some of the lavas apparently resulted from the mixing of different varieties during flow and may have been erupted into relatively shallow water. At one locality the lava–sediment relationships have been interpreted in terms of a lava front delta deposited in an intertidal environment.

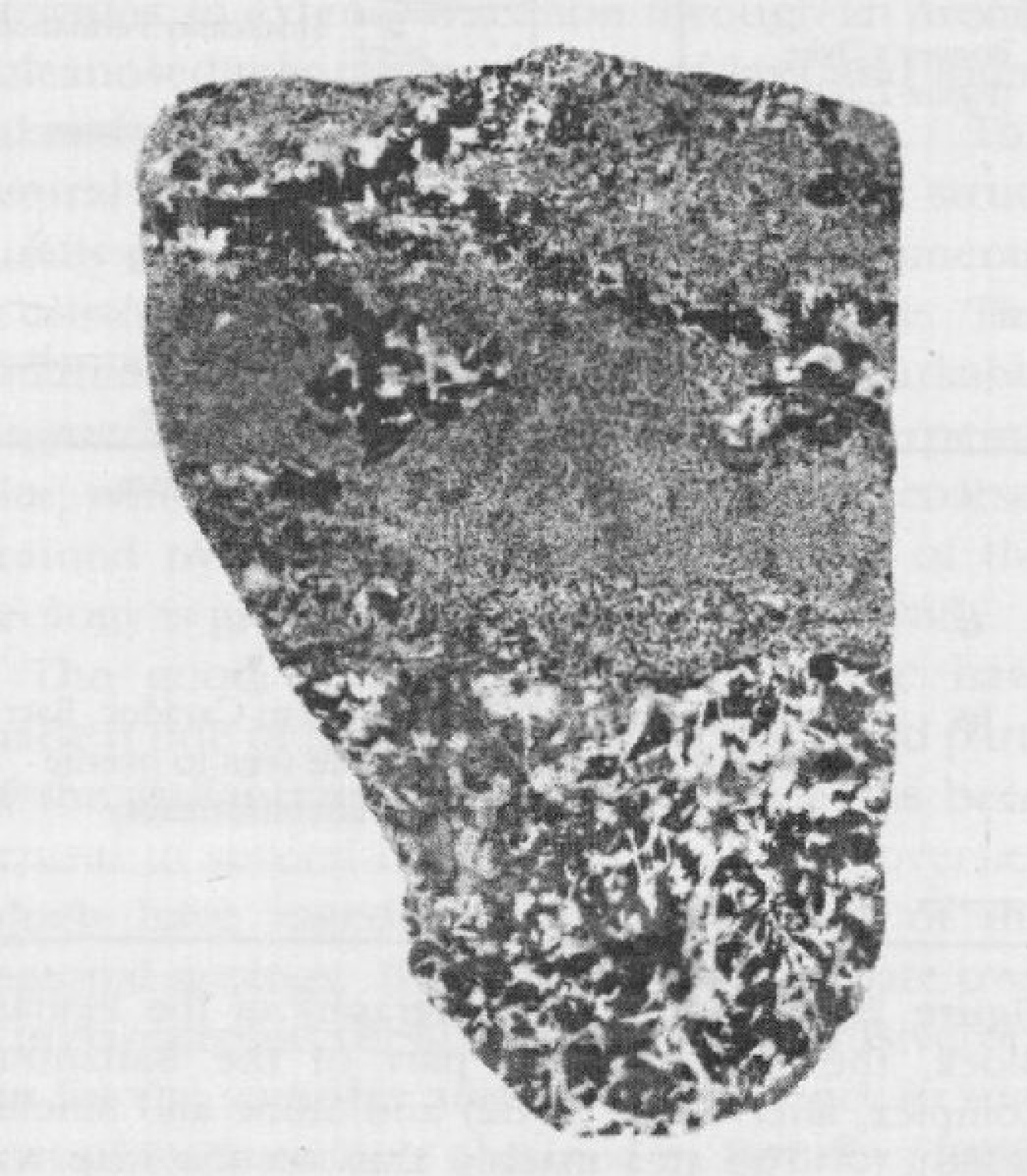
References



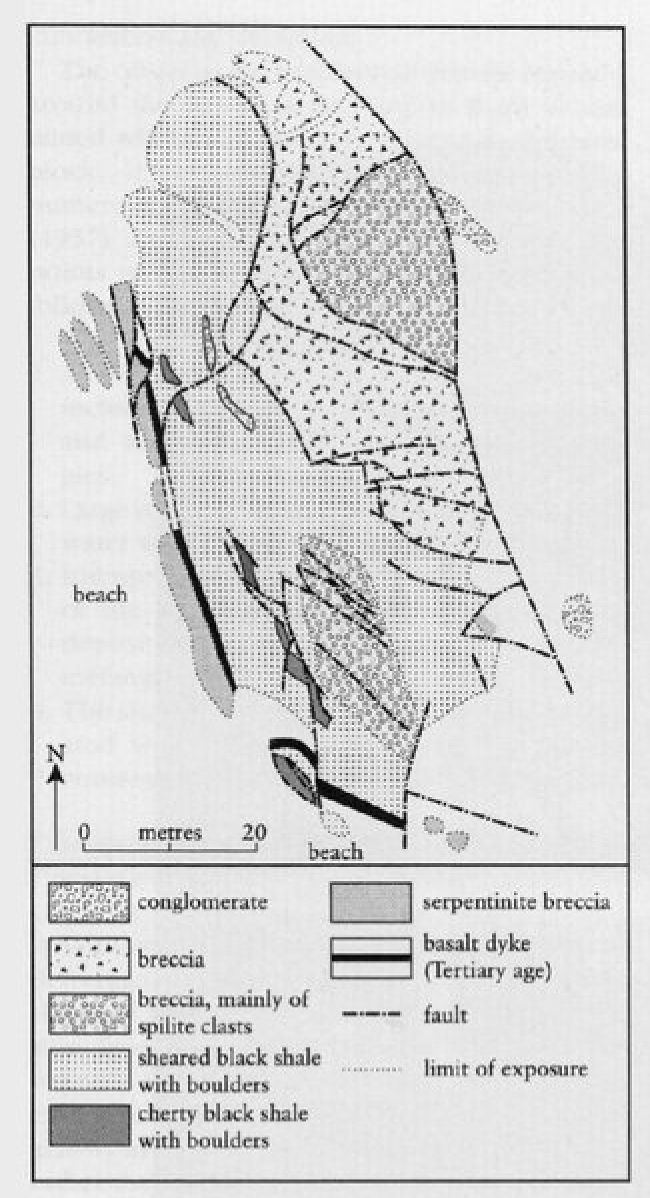
(Figure 2.25) Map and stratigraphy of the Pinbain Block, the northernmost part of the Ballantrae Complex, after Bluck (1982) and Stone and Smellie (1988). * The area marked thus on the map was included within the Pinbain Formation by Bluck (1982), but is more closely related lithologically to the Kilranny Hill Formation.



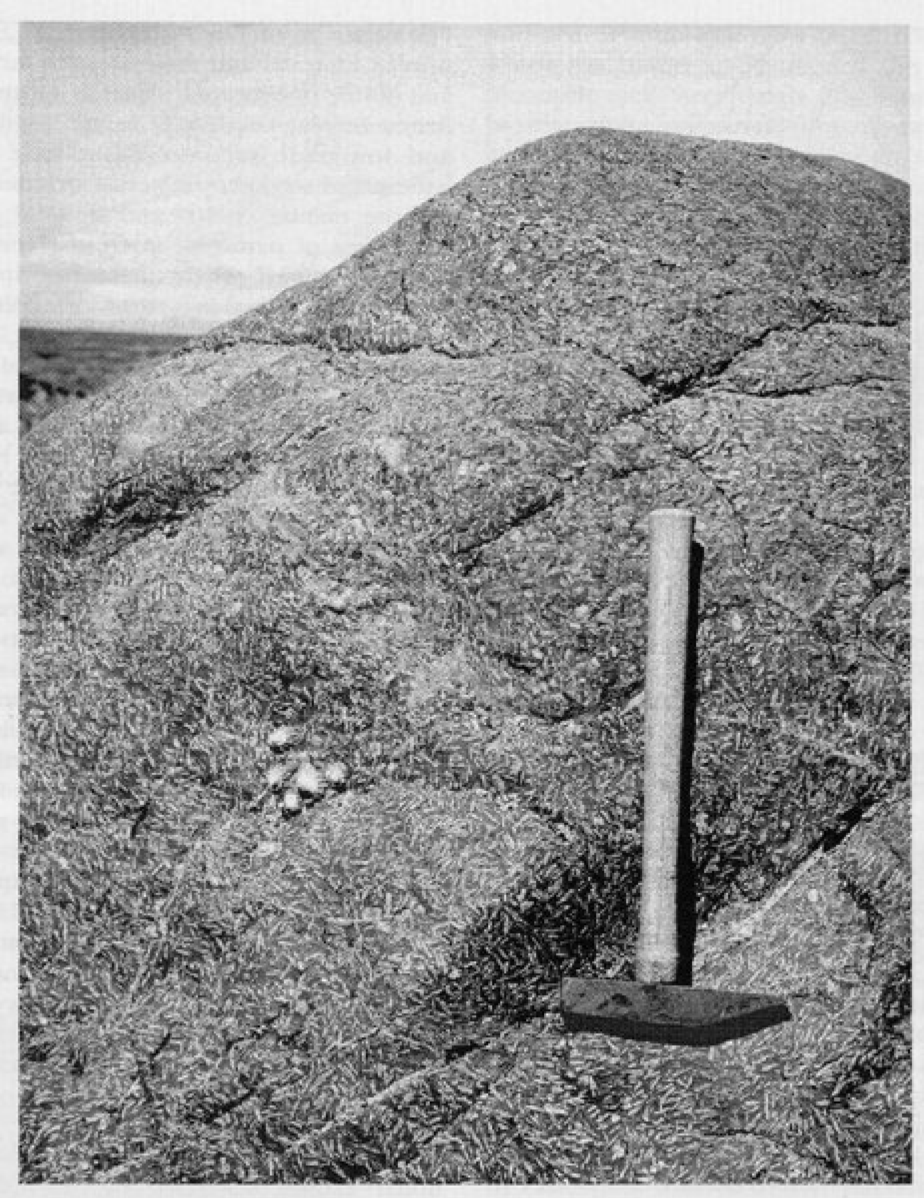
(Figure 2.26) Map of Bonney's Dyke, after Bluck (1992). See Figure 2.25 for location.



(Figure 2.27) Textural variation in the Bonney's Dyke pegmatitic gabbro between plagioclase (pale) and pyroxene (dark). The long axis of the sample is 170 mm. (Photo: BGS no. MNS4007.)



(Figure 2.28) Map of the SW margin of the Pinbain olistostrome, after Bluck (1978a, 1992). See Figure 2.25 for location.



(Figure 2.29) Massive, porphyritic basalt lava at Slockenray [NX 1403 9197]. The pale feldspar phenocrysts are tabular and range up to 2 cm in length. (Photo: BGS no. D4239.)