Bennane Lea

[NX 091 861]

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Introduction

At Bennane Lea two major components of the Ballantrae Complex ophiolite, the central sector of the volcanosedimentary Balcreuchan Group and the Southern Serpentinite Belt, are separated by a major fault. The locality lies on the south side of Bennane Head and the massive basalt breccias seen there continue southwards forming steep sea cliffs. Higher in the succession, towards Bennane Lea, pillowed and massive lava flows appear intercalated with the breccias near sea level while the main cliffs are composed of breccia, here rather finer grained and with more sandstone and chert interbeds. In the foreshore exposures the breccia and lava are succeeded southwards and up-sequence by a sedimentary assemblage, initially of black mudstone followed by chert and coarse conglomerate; tuffaceous sandstone interbeds occur sporadically throughout the succession. The major fault, trending approximately E–W cuts out the higher sedimentary beds and juxtaposes serpentinite against the chert and conglomerate. Coinciding with this abrupt lithological change is an equally abrupt change in topography. The softer serpentinite has been more readily eroded so that the steep sea cliffs and restricted foreshore typical of the volcanic rocks are replaced by a broad sandy beach and an extensive raised beach backed by relict sea cliffs cut in glacial till. Within the broad, sandy foreshore small exposures show that here Permian red sandstone (the fringe of a major, mainly offshore basin) overlies the serpentinite unconformably.

Since the coastal and foreshore exposures at Bennane Lea contain such a wide variety of lithologies with complex structural relation ships, it has been the focus for much geological investigation. Detailed sketch maps have been published by Peach and Horne (1899), Bailey and McCallien (1957) and Bluck (1978a, 1992) and the area has featured in most of the controversies over the origin of the Ballantrae Complex. Peach and Horne regarded the ultramafic rock, now serpentinized, as intrusive into the volcanic sequence; a position defended by Anderson (1936), using some evidence from Bennane Lea, against the then-current consensus that it formed an older basement to the lavas. Bailey and McCallien (1957) proposed the radical alternative that the serpentinite originated as a submarine lava interbedded with the volcanic rocks. The interpretation of the Ballantrae Complex in ophiolitic terms (Church and Gayer, 1973) provided an integrated model for the igneous rocks, with the sedimentary assemblage regarded as a deep-water, slumped olistostrome. Detailed work by Bluck (1978a) built on this hypothesis, with evidence from the Bennane Lea conglomerates supporting his proposition that the complex had suffered considerable structural disruption prior to its final obduction. Bluck envisaged an island-arc–marginal basin environment for its original generation.

Description

Basalt breccias form the steep sea cliffs of Bennane Head and from there extend south towards Bennane Lea where they are succeeded by a mixed assemblage mainly composed of chert and conglomerate. A detailed geological sketch map of the Bennane Lea area is shown in (Figure 2.39).

The Bennane Head breccias overlie aphyric pillow lavas seen at the southern margin of the Balcreuchan Port to Port Vad GCR site and extend that volcanosedimentary sequence southwards. A thickness of between 200 and 300 m is present and, for the most part, the breccias are very coarse with clasts up to 2 m across and commonly in the 2–10 cm range. They are composed exclusively of aphyric basalt although there is considerable difference in the vesicularity, with some clasts completely devoid of vesicles whereas others are scoriaceous (Figure 2.37). Although some clasts are partially reddened there are no clasts of the distinctive, reddened porphyritic basalt seen lower in the sequence towards Balcreuchan Port. The clasts are generally angular although a small proportion always show some degree of rounding and this proportion increases slightly up-sequence, towards the south. Bedding is difficult to detect in the massive breccia units but sporadic interbeds of volcaniclastic sandstone define an approximately NW–SE strike and a very steep dip;

grading in the sandstone confirms younging towards the SW continuing the trend established farther north between Balcreuchan Port and Port Vad.

Lava flows reappear at the top of the breccia sequence but the flows are relatively thin and pillows are only developed locally. The lava is aphyric basalt, vesicular in places, with interbeds of breccia, sandstone or siliceous mudstone between the flows. The proportion of intercalated sedimentary rock increases up-sequence, southwards, and the clast size of the breccias reduces. Bluck (1992) reported that the composition of the breccias also becomes more variable with the inclusion of acid volcanic lithologies. Near the top of this lava-dominated unit, which is about 100 m thick, black siliceous mudstone is particularly well developed and contains a mid-Arenig graptolite fauna (Peach and Horne, 1899; Stone and Rushton, 1983). The mudstone contains chalcopyrite and fracture surfaces within it are coated by green, secondary copper minerals.

Minor faulting complicates this part of the sequence and across the faulted zone there is a change of strike to almost E–W, the dip remaining steep. However, the sedimentary interval continues and any stratigraphical break is thought to be fairly small. It is also possible that there is a minor intra-formational unconformity at this point but the evidence is obscure and inconclusive. Immediately south of the fault pale-green volcaniclastic sandstone is interbedded with chert and the relationship between the two lithologies suggests that the sandstone remained fluid after the chert had become partially lithified. The resulting soft-sediment deformation structures were first described and illustrated by Bailey and McCallien (1957).

Southwards and up-sequence the proportion of chert increases sharply. It is reddish-brown in colour and individual beds rarely exceed 10 cm in thickness; radiolaria were described by Aitchison (1998) and Bluck (1992) reported that locally the chert may contain glass shards. Boudinage and other features characteristic of soft-sediment deformation are widely present and increase in both size and frequency towards the south. This trend towards increased deformation is made more complex by a concomitant increase in tectonic folding with several large fold hinges, plunging steeply seawards, affecting the cherts on the foreshore. The old sea cliffs behind the raised beach provide a more extensive and spectacular view of these structures. The range of deformation features makes it difficult to assess the thickness of the chert unit but around 30 to 40 m seems likely.

Towards the top of the chert sequence coarse conglomerate makes an abrupt appearance, overlying and interdigitating with the chert beds. Clast size ranges up to about 1 m. In the vicinity of the conglomerate the soft-state deformation of the chert reaches a maximum with slump folds showing bulbous thickening of their hinge zones (Figure 2.40). The clasts in the conglomerate are mainly of either aphyric basalt (generally rounded) or chert (generally angular), both with an obvious local provenance, but rarer clast types include a pinkish, coarse-grained syenitic lithology, massive pyrite and carbonate. The latter is of some interest in that Bailey and McCallien (1957) reported dissolving fragments in hot acid and recovering grains of chrome-spinel; the carbonate was therefore regarded as a highly altered ultramafic rock. In addition to the above Bluck (1992) reported clasts of acid volcanic rock. The conglomerate does not extend inland from the foreshore exposures but Bluck described it as increasing in proportion towards and beyond the low-tide mark. The shoreline would therefore seem to coincide with an interfingering zone between two distinct lithofacies.

The southernmost of the conglomerate beds is only a few metres short of the major fault juxtaposing this volcanosedimentary succession and ultramafic rock of the Southern Serpentinite Belt. In this interval lies an enigmatic lithology that has some characteristics of an intrusive dolerite and some of a volcaniclastic sediment. Its northern margin appears to be in conformable contact with chert but its origin remains uncertain; Bluck (1992) refered to it as 'dolerite-tuff' and speculated that it might be a high-level sill, despite an absence of peperitic margins. The southern margin of this body is faulted against serpentinite with a thin zone of quartz-carbonate alteration along the contact. The serpentinite itself is pervasively reddened and contains large enclaves . of altered gabbroic rock. These form small bosses between which exposure of the serpentinite is only sparse. A few metres farther south the outcrop of ultramafic rock ends at the unconformable contact with Permian red sandstone.

Interpretation

The Bennane Lea section illustrates the domi nantly sedimentary and volcaniclastic upper part of a Balcreuchan Group lava sequence. Coarse, oligomictic basalt breccia in the north of the section probably accumulated as flow-front talus and in terms of their petrography and geochemistry the clasts are identical to the subjacent lavas seen farther north at Port Vad. The presence of interbeds of graded volcaniclastic sandstones suggests deposition in relatively deep water but the rounding of some lava clasts probably arose through wave action in shallow water. The most likely combination of events would seem to be the eruption of aphyric basalt lava into shallow water, autobrecciation of the lava front (and perhaps some wave erosion) with partial rounding of some fragments by wave action, followed by avalanching of the talus accumulation into deeper water to cover basalts erupted earlier in the same eruptive episode. A few lava flows then extended across the accumulated breccia.

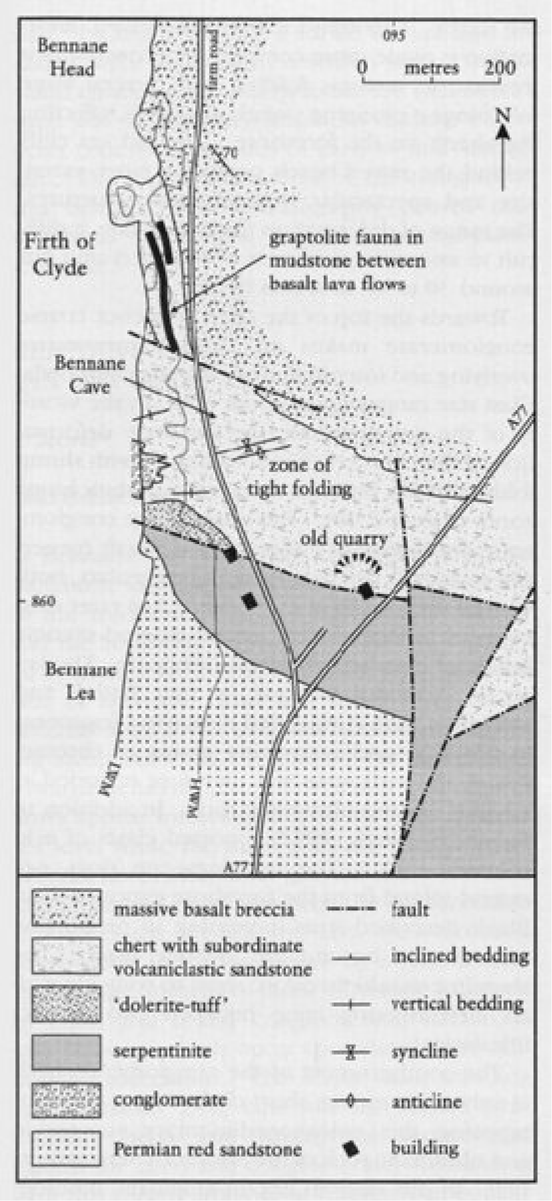
The association of these later lava flows with graptolitic mudstone is also indicative of a deep-water depositional environment but the evidence of the overlying chert–conglomerate sequence is ambiguous. In straightforward lithological terms the chert might be regarded as a deep-sea deposit but its extensive soft sediment deformation requires slumping to have occurred, presumably on an unstable slope. The interdigitating conglomerates with their rounded clasts appear to have slumped from a shallow-water environment and the glass shards in the chert indicate relatively proximal and probably subaerial, contemporaneous volcanicity. Cobbles and boulders in the conglomerate are derived from ophiolitic lithologies, including altered ultramafic rock, which suggests that obduction was already in progress when this part of the Ballantrae complex was deposited. Overall, a tectonically unstable environment is indicated, interpreted by Bluck (1978a) in terms of obduction within an active marginal (back- or intra-arc) basin. Developing this theme, Bluck (1992), emphasized the evidence for acid volcanicity and the abrupt fades changes, concluding that the Bennane Lea succession represents the rift facies developed during the splitting of a volcanic arc. The lavas to the north were regarded as part of the original arc structure. This interpretation was also influenced by the thickness of the succession which, at over 2 km, Bluck thought anomalous for anything but an island-arc environment. However, this figure was reached by including within the same succession the whole coastal outcrop between Bennane Lea and Games Loup, which a series of geochemical studies has shown to be polygenet-ic (Wilkinson and Cann, 1974; Thirlwall and Bluck, 1984; Stone and Smellie, 1990). On the geochemical evidence (Figure 2.38) the Bennane Lea strata overlie within-plate, ocean-island basalts with both the breccia clasts and the lavas above the breccia showing the same geochemical characteristics; on this basis none of these lavas can have any direct connection with an island arc. Further, when the evidence for structural imbrication presented by Stone and Rushton (1983) is taken fully into account the exposed thickness of the succession seen in part at Bennane Lea does not exceed 900 m (Stone and Smellie, 1988). The dilemma remains unresolved but the problem cannot be addressed by evidence from the Bennane Lea GCR site taken in isolation; comparison with the contiguous outcrop, as represented by the Balcreuchan Port to Port Vad and Games Loup GCR sites is important. It is also useful to compare the Bennane Lea succession with the within-plate, ocean-island volcanosedimentary rocks of the Slockenray Coast GCR site, which show some remarkable similarities.

Whatever the correct interpretation of the Bennane Lea volcanosedimentary sequence, at its southern margin it is faulted against serpentinized ultramafic rock. The fault is one of the major structures of the Ballantrae Complex juxtaposing mantle rocks of the Southern Serpentinite Belt and upper crust of the Balcreuchan Group, represented here by the chert–conglomerate–volcaniclastic assemblage. Movement on this scale seems unlikely to be achieved in a single phase of faulting and a history of periodic re-activation is probable. However, in this context the narrow zone of quartz-carbonate alteration adjacent to the fault is significant. This developed as a side-effect of serpentinization at a relatively early stage in the history of the complex. Its presence suggests that the Bennane Lea Fault was also an early-formed feature.

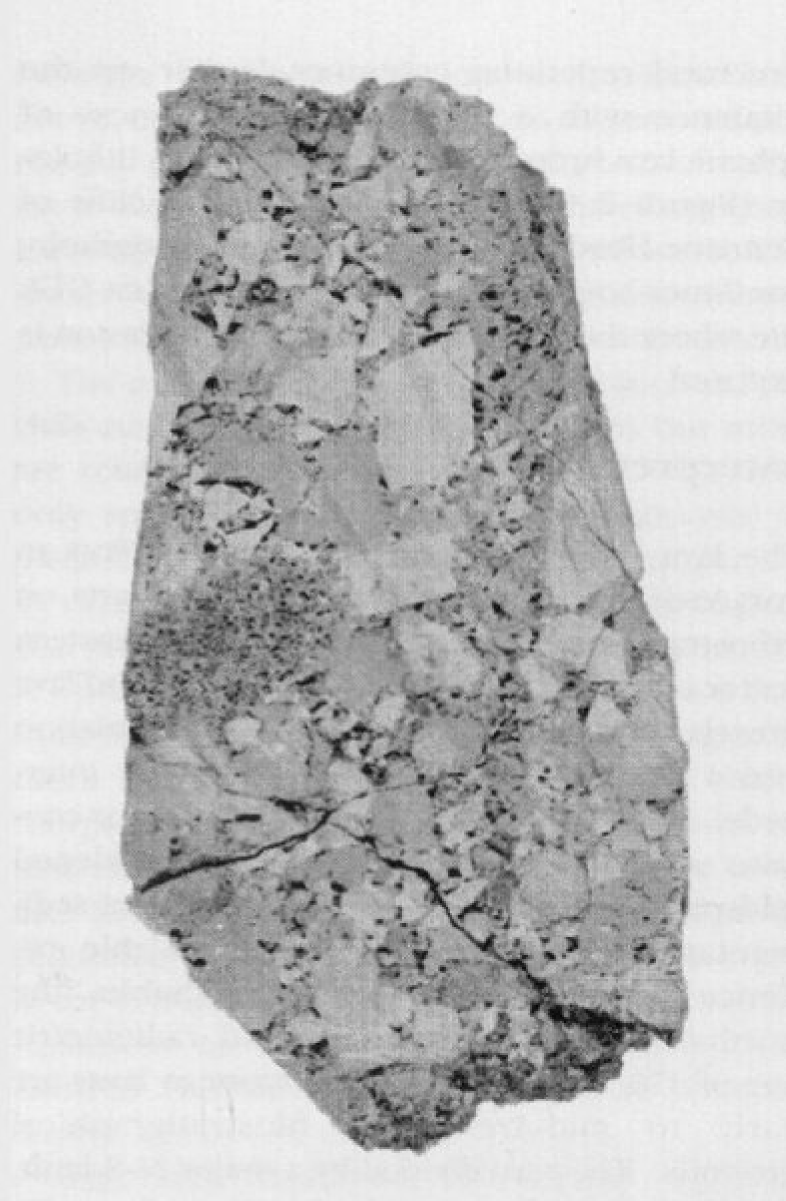
Conclusions

The Bennane Lea GCR site reveals several unique features of great importance in the interpretation of the Ballantrae Complex as an ophi-olite. Some aspects remain controversial. The exposed strata form the highest preserved beds of a volcanosedimentary sequence dominated elsewhere, in its lower part, by basalt lava. These lavas have the geochemical characteristics of within-plate, ocean-island eruption, a feature shared by large clasts within breccias and sporadic lava flows within the Bennane Lea sector. However, the unusual chert–conglomerate–volcaniclastic rock assemblage has been interpreted, on mainly sedimentological grounds, as being more compatible with a volcanic arc environment. The compositional range of clasts in the conglomerate suggests that ophiolite obduction was already in progress when it was deposited; graptolites in subjacent mudstones give deposition a maximum age of mid-Arenig. At the southern margin of the site, volcanosedimentary upper crustal rocks are faulted against serpentinized mantle rocks, across one of the major lithological breaks within the Ballantrae Complex. Bennane Lea provides rare exposure across a fault of this magnitude.

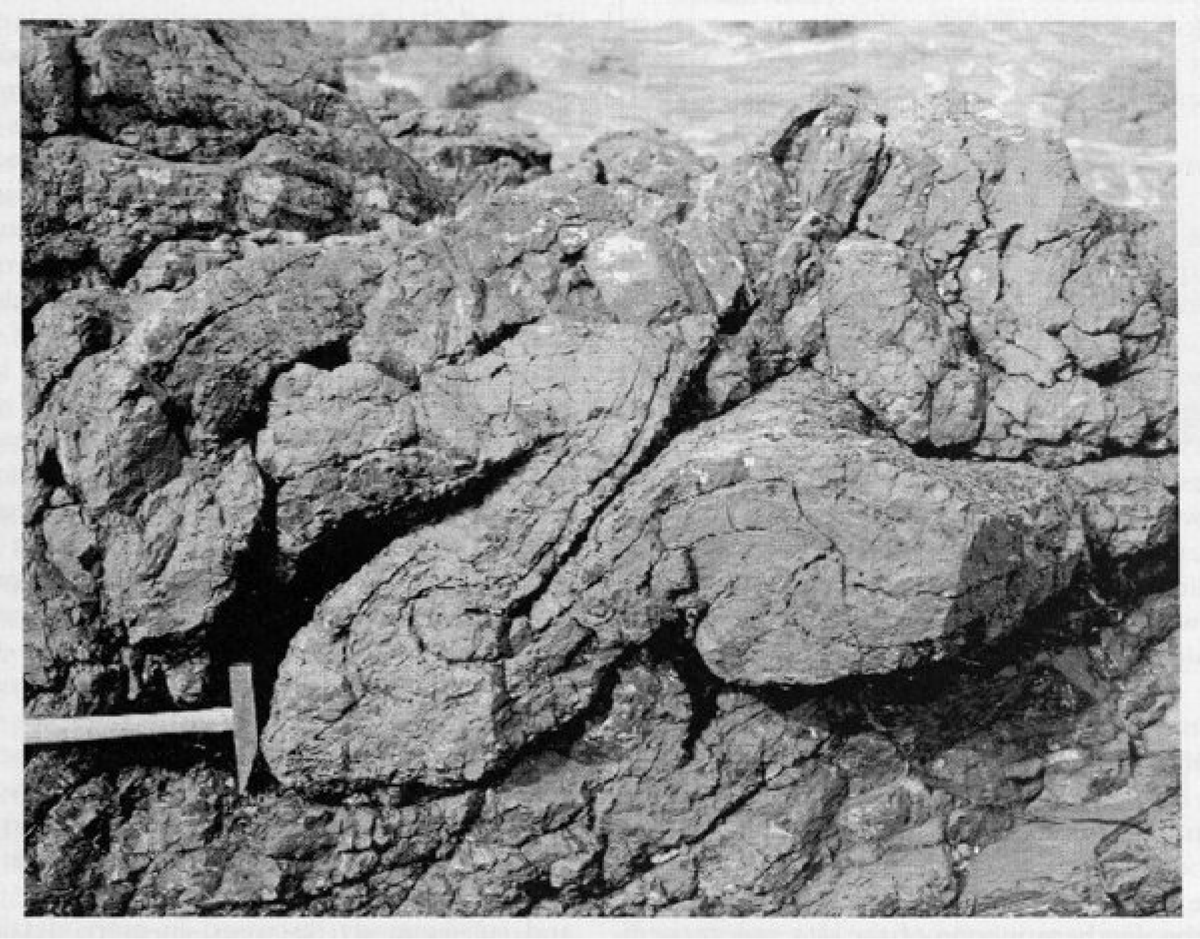
References



(Figure 2.39) Map of the Bennane Lea area, after BGS 1:25 000 special sheet, Ballantrae (1988) and Stone and Smellie (1988).



(Figure 2.37) Volcaniclastic breccia of aphyric and vesicular lava clasts from Bennane Head. The long axis of the sample is 165 mm. (Photo: BGS no. MNS3838.)



(Figure 2.40) Slump fold in chert interbedded with conglomerate and volcaniclastic sandstone at Bennane Lea. (Photo: BGS no. D3333.)

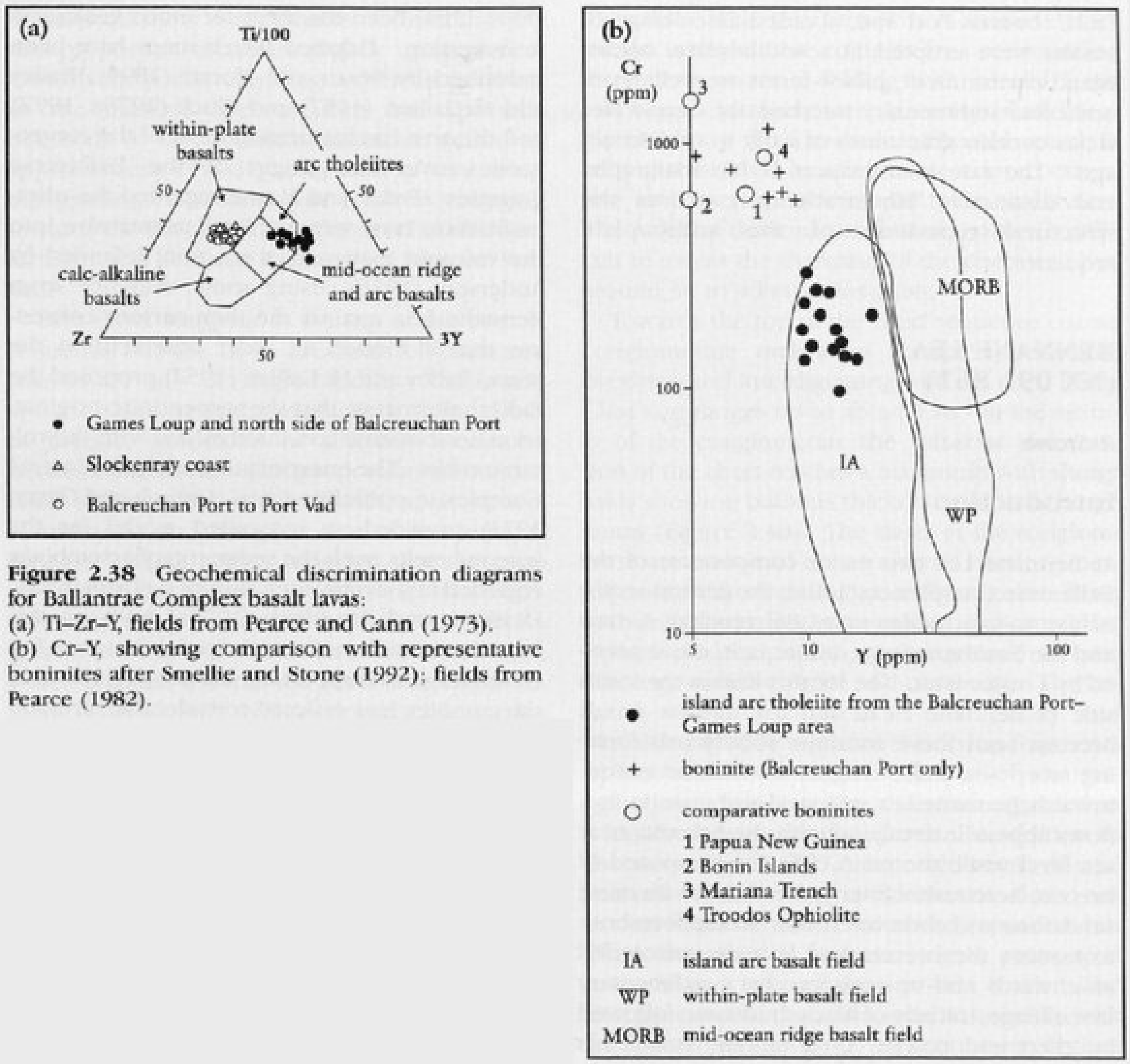


Figure 2.38 Geochemical discrimination diagrams for Ballantrae Complex basalt lavas:
(a) Ti–Zr–Y, fields from Pearce and Cann (1973).
(b) Cr–Y, showing comparison with representative boninites after Smellie and Stone (1992); fields from Pearce (1982).

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