Excursion 27 Bennane Head to Downan Point

Key details

Author	B.J. Bluck
Themes	Accretion of a thick sequence of lavas and sediments; types of lava and associated sedimentation; sedimentation of cherts and conglomerates and their significance; the structural significance of the contacts between the lavas and the serpentinite which bound both the north and south margins, but are examined only in the south.
Features	Sedimentation of cherts, slumping, tuff-beds and their significance; recognition of various volcanogenic features; evaluation of the tectonic regimes of sediment accretion and the origin of the ophiolite.
Maps	O.S. 1: 50 000 Sheet 76 Girvan B.G.S. 1: 50 000 Sheet 7 Girvan 1: 25 000 Sheets NX 08, 18 and 19 (in part) Ballantrae
Terrain	Rough walking along foreshore, walking on cliff edge past headlands; slippery and sometimes difficult rocks to cover.
Distance and Time	Distance 2 km. The less agile should visit localities 1–4. 4–6 hours.
Access	Although all the localities are on the foreshore and are part of a coastal SSSI access is mostly via private roads or over private land.

It is vital therefore, that the rights of the owners should be respected.

These include Melville (Bennane Lea and Meikle Bennane), Shanklin (Little Bennane) and Melville (Troax). Otherwise access may be refused to these most significant and instructive geological localities. See details under particular localities.

Some important problems raised by the Bennane Head section

There are four important points raised by this section which have considerable bearing on the origin of the Ballantrae Complex as a whole.

1. The origin of the sedimentary pile which sits above the lava sequence. In particular, was it of shallow or deep water origin? Was it deep but close to a source in shallow water? Was it deposited in a tectonically stable or unstable regime? Is it conventional layer 1 of the ocean crust–if not, what is it?
2. The nature of the volcanogenic pile; did it form in deep or shallow water and what is the importance of water depth anyway? Are the lavas and the sediments they produce all basic in composition? Is this sequence conventional layer 2 of oceanic crust?
3. If these aspects of the section (1, 2 above) are different from conventional oceanic crust, what is the significance of that difference?
4. What is the nature of the contact beween high level spili tic lavas and mantle-depth serpentinite; and when did that juxtapositioning occur?

The exposures on this excursion are very good, confused in places by faulting, but in general contacts are clear even if their interpretation is not. There is evidence for structural repetition of parts of the sequence (Stone and Rushton 1983) so it may not be as thick as previously supposed (Bluck and Halliday 1981). Some of the lavas from this block have been analysed for their chemistry by Wilkinson and Cann (1974), Lewis and Bloxam (1977) and Thirlwall and Bluck (1984) and all agree that chemically they resemble ocean island type basalts.

Locality 1. [NX 0921 8599] Contacts beween Triassic sandstones and Arenig serpentinite

Contacts beween Triassic sandstones and Arenig serpentinite; serpentinite and doleritic and tuff rocks belonging to the Bennane Head sequence (Figure 27.1), (Figure 27.3). The coastal road shown on (Figure 27.1) is now private although it is assumed that well-behaved groups will be allowed to walk along it to Locality 5. The A77 road has been rerouted east of Bennane Hill and joins the old road at Bermane Lea where a lay-by is to be constructed. Vehicles must be parked south of the cattle grid and well away from the cottages and their access routes. Go onto the beach via a track which leads to a sand pit just south of Bennane Burn. Localities 1, 2, 3 and 4 can be studied by keeping entirely west of the road. Note the small monument to 'Snib', a bank clerk from Dundee, who finally settled for a life free of income tax and other boring attributes of modern living. He adopted a cave in the cherts as his home. Snib, a man suspicious of what he assumed to be 'authority', had many very articulate discussions with this writer about what he could do with the subject of geology and where he could put the plane table set-up used to draw (Figure 27.3).

The southern margin of the Bennane Head Block is bounded by a fault dipping at a fairly low angle to the south which brings volcanic rocks and cherts in contact with the southern serpentinite (Figure 27.3). Much of the foreshore and the raised beach platform farther to the south is underlain by Triassic red beds which along the raised beach cliff and at Ballantrae comprise breccias of serpentinite and other local rocks. The raised beach cliff is therefore a little more complicated than it seems at first sight: it is at or near to an old boundary of a Triassic basin. When there is little sand on the beach, as in winter, it is possible to trace out the contact between the Triassic rocks and the serpentinite. The Triassic sediments are red sandstones and shales; the sandstones often showing rippling which is particularly clear in section where they show-up as small scaled cross strata.

The serpentinite at this point is red stained and forms the southernmost of the dark rocks. It is thrust over the volcanic rocks of the Bennane Head sequence, which youngs towards the south. The trace of the reverse fault is marked by a band of carbonate breccias and mineralisation and it is a thrust of some magnitude: it places mantle lithologies over the superficial sediment of the ocean basin–a depth difference of 10's of km. However the serpentinite may have been emplaced at high levels in several stages; indeed by comparison with present-day marginal basins the serpentinite could have been brought up structurally even at the time of chert sedimentation; there are clasts of carbonate rock which contain chrome spinel (Bailey and McCallien 1957).

The dolerite-tuff may have been intruded into the chert at quite high levels as this would account for the development of associated tuffs and breccias. However, the contact between dolerite and chert on the coast does not have the kind of pepperite mixtures of both lithologies which characterises intrusions into wet sediment. This may be due to the nature of the chert or may indicate that the chert was indurated at the time of intrusion.

Locality 2. Folded cherts (Figure 27.3)

Below the dolerite-tuff there are red bedded cherts interstratified with coarse-grained, buff-coloured tuffs. Both these lithologies are deformed by a series of slump folds in which the limbs of the folds are thinned and the axes considerably thickened. The tuff bands comprise angular sand sized grains of a variety of volcanic rock fragments including acidic, intermediate and basic, together with some angular clear quartz. The cherts have small circular holes, often filled with fibrous silica, which are sections of radiolaria. Some of the coarser cherts have numerous, partly chloritized glass shards and angular grains of clear quartz.

The tuff bands show flame-structures, some of which inject the axial planes of the folds; other bands in differing parts of the outcrop here and at Locality 3 show extensional faults cutting them but with the tuffs thinned along the fault planes (Figure 27.3). All these features attest to the syn-sedimentary origin of the extensional and compressional features and have probably formed at different positions in the slumped sheet (Figure 27.3).

The cherts are followed by breccias and conglomerates which have clasts of volcanic (including acidic) rocks which form the main component, together with a pink coloured, coarse grained igneous rock, limestones of uncertain origin, clasts of dark coloured and red coloured chert. These clasts are often angular but some are very well rounded. They have clear, sharp erosive contacts with the underlying cherts; but the conglomerate-chert contact is often marked by contortion in the cherts and the incorporation of breccias and conglomerates into the slumps.

Locality 3. Deformed cherts and interstratified, interfingering rudites (Figure 27.3)

There are a number of important features to examine at this locality. The contact between chert and overlying conglomerate-breccia is marked by abundant deformation (a). The conglomerate has no visible bedding and has large rafted blocks of chert within it. The cherts within the blocks are folded, suggesting either that the conglomerate was deposited by a mass flow which displaced some of the soft cherts, or that both the emplacement of the conglomerate and the slumping of the chert were produced by the same mechanism, such as a seismic shock or a grossly oversteepened surface of sedimentation. In any event the tectonic regime in which this sediment accumulated is unstable and close to an abundant supply of coarse grained sediment.

Massive chert is seen to interfinger with the conglomerate (b), with once again the disruption of the cherts at the contact. As at locality (a) the cherts are overfolded with a vergence towards the east and in this direction the conglomerates of the shore are replaced by the cherts in the raised-beach cliff. Mapping at low-tide and in the shallow waters to the west has shown that there is an almost entire boulder-bearing conglomerate to the west which is replaced by cherts to the east, and the shore section is along the interfingering zone between the two.

At (c) is a beautifully exposed fold, although there may be divergent opinions as to its origin. There are beds in the fold which appear to have been plastically deformed; but the main fold itself may be a late brittle feature.

Locality 4. [NX 0912 8618]

Black and red cherts, black shales and breccias with clasts having a range of compositions (Figure 27.2), (Figure 27.3). On the rocky foreshore platform, near the most northerly of the high chert stacks, the red chert sequence rests on breccias and green-gray tuffs with abundant volcanic clasts. At this locality (Figure 27.3) there are excellent extensional features, such as boudinage in the tuffs and some fine glass shards in some of the cherts. In addition, there are very fine breccias with basic and acidic volcanic fragments; tuffs (lithic-arenites) with abundant quartz, feldspar, and basic-acid rock fragments; black cherts and interstratified black shales.

The black shales have yielded graptolites which indicated to Stone and Rushton (1983) a mid-Arenig age. These graptolites include *Tetragraptus fruticosus*, *Sigmagraptus praecursor*, *Didymograptus extensus* and *D.* cf. *protomurchisoni*. The first two graptolites are illustrated in (Figure 27.2).

The breccias and lavas are some 300 in thick and can be traced as far as Port Vad, Locality 5, where they rest on spilitic pillow lavas. They represent a mixture of breccias and conglomerates which contain both reddened and dark grey coloured clasts: some are poorly sorted with boulder-sized clasts randomly scattered through them; others are well stratified with rounded clasts in a distinctive white calcite cement. Some beds are dominated by accretionary lapilli enclosed in hyalo tuff, and these must represent very shallow-water accumulations. It is clear that this section represents the sediment accumulating on the periphery of a volcanic centre. When the rate of lava eruption was high, basic lavas reached well out into the adjacent sea bed and developed extensive pillow basalts. These may have been accompanied by mass flow deposits comprising volcanogenic breccias; and during periods of intermediate and acidic volcanic activity volcanogenic sediment would have been produced in the marine realm whatever the rate of lava extrusion. At times when the rate of volcanic activity was low, the sediment underwent recycling during a transgression of the sea with the result that well rounded clasts accumulated in well stratified conglomerates (Figure 25.14). The reddened colouration of some of the clasts may well be the result of subaerial weathering (as Locality 5. Port Vad [NX 0927 8695] Spilitic pillow lavas and associated tuffs (Figure 27.1). Port Vad may be reached (on foot only) from the south after studying localities 1 and 4 by rejoining the private road north of the northernmost gate and walking for less than a kilometre to a point where the road cuts through solid rock. It is then possible to descend, with great care, into Port Vad. Coming from the north, park vehicles in the prominent car park [NX 100 875] above Balcreuchan Port and follow the old road southwards to the point above Port Vad. At this locality some excellent exposures of pillows and associated sediments are to be seen. The pillows are relatively undeformed, and show the interpillow carbonate growth typical of Downan Point, Locality 6 and some have tuff within the inter-pillow spaces. At the south side of Port Vad it is possible to trace these pillowed beds into the overlying tuffs and breccias, although there is much faulting here and some splendid examples of sheared pillows.

To the north of this locality there is a thick sequence of interstratified pillows, conglomerate-breccias and tuffs. Stone and Rushton (1983) demonstrated repetition within the lava within this sequence and cautioned against unconditionally assuming the lava sequences to be thick.

Significance of the Bennane Head sequence

The Bennane Head sequence illustrates a number of important features which have relevance to the interpretation of the whole ophiolite. The section from the red cherts through the breccias to the pillow lavas at Port Vad is comparable with a section through the layers 1 and 2 of normal oceanic crust, where sediments cover the lavas produced at the spreading ridge. But there are significant differences:

1. The cherts interfinger with boulder bearing breccias and conglomerates, and the cherts are themselves often highly contorted. This suggests that the cherts formed in or close to a zone of much tectonic instability where the slope of the floor on or near which they accumulated changed radically to allow mass flows to enter the basin and the cherts to slide.
2. There is also much significance in the presence of tuff bands with acid-basic lithologies, layers of crystal tuff and the presence of glassshards within the cherts. These features, together with clasts within the interstratified conglomerates and breccias which are acid to basic in composition, all point to much contemporaneous volcanic activity. Volcanic activity of the kind which produces large volumes of tuff is not a characteristic of most mid-ocean ridges, neither is acidic volcanic activity normally associated with ocean ridges, which are dominantly totally basic in character. This volcanic activity took place during the periods of instability which produced the slumping: the instability was probably caused by faulting and the faulting probably took place in an extensional regime.
3. The great thickness of breccia and conglomerate occurring below the cherts implies that volcanic activity persisted over a considerable period of time. The record here is dominated by rudaceous rocks; lavas form <10% of the record. The presence of well rounded clasts in this sequence also implies shallow water depths and the presence of mass flows, a fairly copious supply of volcanogenic sediment. Indeed the whole sequence through Bennane Head, from Bennane Bridge to Games Loup, comprises an alternation of breccias, conglomerates, tuffs and lavas. Although faulting and the repetition of strata make estimates of the thickness of this sequence difficult, there is at least 2 km of such lithologies there.

Any hypothesis for the origin of these sequences must therefore account for a thickness of fairly shallow water lava related activity, the presence of contemporaneous acidic volcanic activity towards the top of the pile, general tectonic instability, particularly during the sedimentation of the cherts, and the fairly rapid change in facies from coarse volcanic detritus to fine grained chert.

Of the three possible ways of producing oceanic crust, the sequence at Bennane Head does not resemble the crust of a mid-oceanic ridge, although a possible exception may be the crust found in Iceland which sits astride the Mid-Atlantic ridge. Oceanic islands show a trend from deep water at the base to shallow at the top, and this trend is not seen at Beruiane Head. Island arcs, and in particular the basins which lie within or alongside them, have abundant acidic volcanic activity, an abundance of volcanogenic sediments, rapid facies changes from the ground bordering the volcanoes to the deeper basins, and much instability produced not only by the volcanic eruptions but also by the structural fragmentation of the arc during periods of marginal basin formation (see (Figure 25.5)). It is therefore concluded that the Bennane Head sections represent the basement (Port Vad and the ground to the north) and the rift facies (breccias and cherts of the upper part of the sequence) of a splitting arc. The doleritic intrusive-extrusive unit at the top of the sequence is thought to represent a shallow sill intruded into this extensional regime.

Locality 6. North of Downan Point [NX 0748 8100]

Pillow lavas, showing clear examples of how they are formed, lava caves and the relationship between massive and pillowed lavas (Figure 27.5). Take the A77 road south from Ballantrae. Shortly after crossing the bridge over the River Stinchar branch off to the right along the road through Garleffin. Cars and minibuses can take the next turn right, near a bungalow, and drive through Kinniegar. Turn right down a rough track c. 300 m SW of Kinniegar and drive towards the storm beach. Although the route is private, geologists are at present allowed to open (and close) the gate and park near to the old cottage. Coaches, however, should discharge passengers at the T-junction beyond Garleffin and then proceed south-westwards to the cemetery where there is ample parking space. From here, the driver can watch the party returning from the shore and meet them at the drop-off point. Vehicles must not be parked at or near Downan Farm unless prior written permission has been obtained from Mr. E. MacIntyre, Downan Farm, Ballantrae, Ayrshire KA26 OPB.

Follow the path on foot to the headland c.100 m to the south and stop at the gravel beach south of the stream (Figure 27.5). The north face of the headland is a magnificent exposures of pillow lavas and their geometry can be seen in some detail.

Pillow lavas are magnificently exposed along this coastline to as far south as Dove Cove. The age of these pillows has been the subject of some controversy. Lewis and Bloxam (1977) thought they were Caradoc in age. Thirlwall and Bluck (1984) obtained an age of 468 Ma with a rather large error of 22 Ma, which taken at face value would be roughly Caradoc. The chemistry of these lavas has been studied by Wilkinson and Cann (1974), Lewis and Bloxam (1977) and Thirlwall and Bluck (1984) all of whom found that they resembled the chemistry of ocean islands.

On the intertidal, well washed exposures it is possible to see some fine details of the pillows. They have green chloritic rims which are the result of the alteration of glassy chilled margins ((Figure 27.6) A a). Young pillows wrap around older giving a clear indication of younging to the west, and the abundant vesicles, sometimes arranged concentrically with the pillow outline, are concentrated near their the top margins ((Figure 27.6) A b). Interpillow spaces are filled with calcite, and only rarely do these show a geopetal infilling ((Figure 27.6) A c).

Moving to the north, and on the north side of a small indentation of the sea, (b), (Figure 27.5) A, there are thin bands of dark chert and tuff amongst the pillows showing a clear NE–SW strike. At this locality it is possible to see a whole range of important attributes of this sequence. Although in section the pillows have a roughly circular outline, examination of faces which are in the strike of the beds reveal them to range in shape from long tubes with many pillow buds on them ((Figure 27.6) B T1, T2) to irregular flat bottomed masses with many tubes and buds coming off them ((Figure 27.6) B P;27.6 C). It is readily apparent that the first face visited showing the classical pillow shapes gives a false impression of their real shape.

Some pillows at this locality have hollow centres now partly filled with stratified chert ((Figure 27.6) D). These must have been inflated with lava and then drained to leave a space subsequently to be filled with the chert.

From these localities it is possible to speculate on the origin of the pillow pile. The almost spherical pillows are produced from the buds which appear on the lava tubes. These buds grow by the lava pressure forcing out the tube wall at points of weakness or points where there is a greater pressure in the tube. They inflate to a size where they are unstable and then roll off. The lava tubes grow along the floor, sometimes climbing over pre-existing tubes and sometimes filling the inter-tube spaces, all the time budding and breaking up into separate tubes. In this way the pillow lava pile grows upwards.

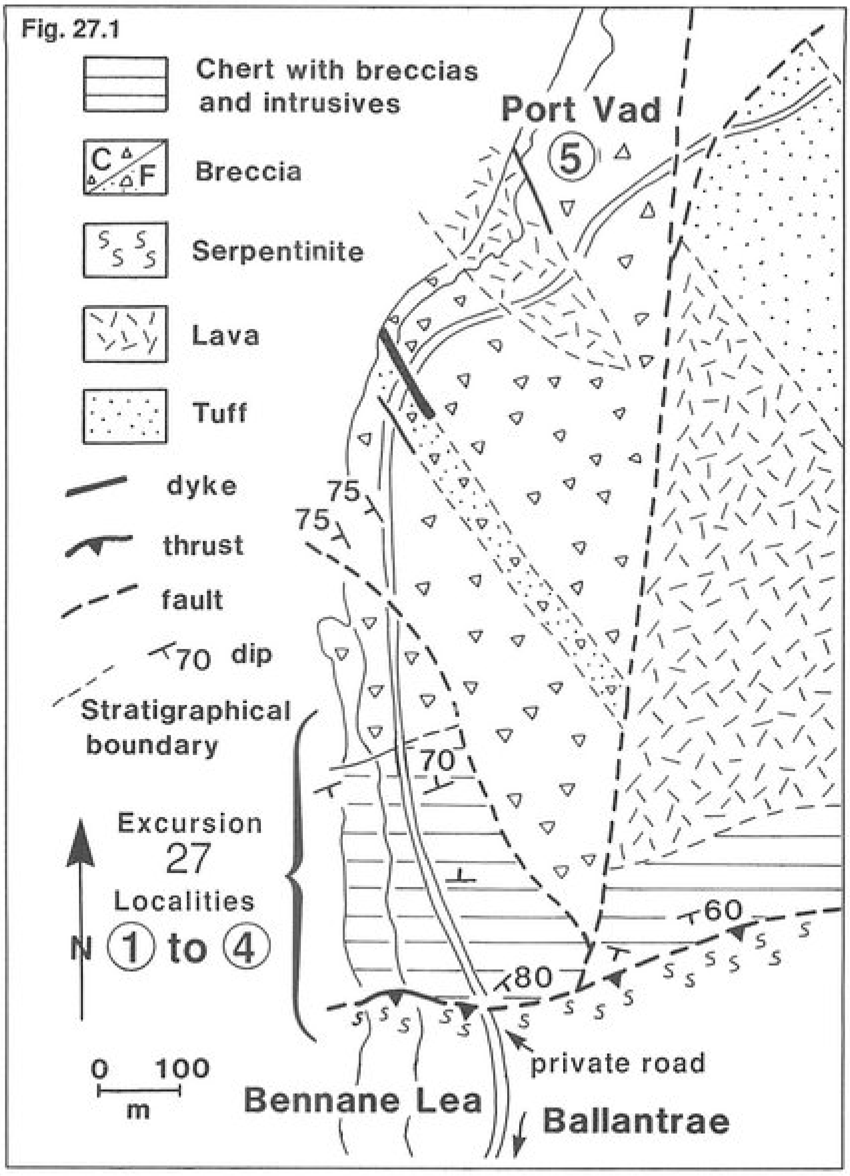
A little to the north, at (d), (Figure 27.5), there are larger lava caves, where up to 2 m wide holes in the lava, now partly filled with stratified lava and tuff, probably represent the routeways for lava through horizontal conduits in the lava pile. There is much alteration along these small lava caves and it is probable that much gas escaped along here during the later degassing phases of the lava pile.

There are numerous exposures of pillow lavas and massive spilite to the south of this locality, and many of these are worth examination for the insights they give into the growth of lava piles of this type. However some 200 m to the south of locality 6 there are excellent exposures showing the development of pillow tubes off a massive lava (see (Figure 25.13)). In this instance the rate of lava extrusion was so great that it did not break down into tubes except at the edges where it was easily chilled. The relationships between the various types of pillows, tubes and massive lavas are illustrated in (Figure 25.13).

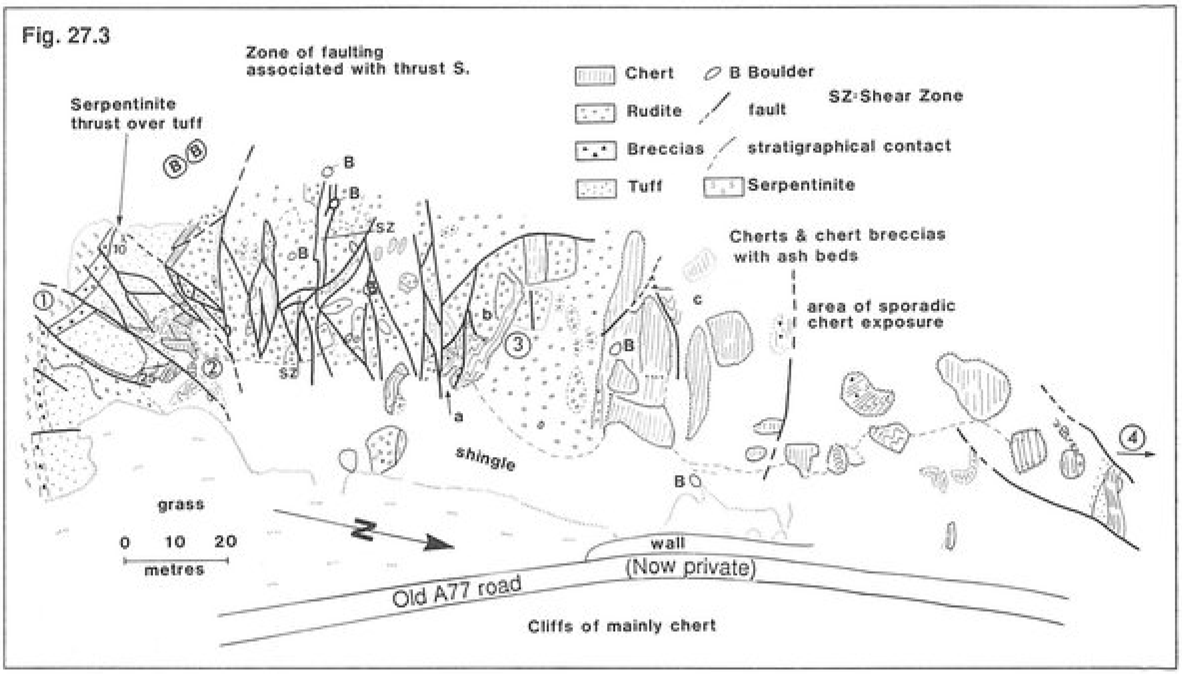
The lava flows of Downan Point differ from those studied at Pinbain (Excursion 25) and at Beimane Head (Excursion 26) in having comparatively little volcanogenic clastic rock present. This implies that the environment of extrusion was different and an obvious factor in this respect is the water depth. The Downan point lavas were probably extruded in deeper water than most of the lavas in the Ballantrae Complex. They may well be much younger than the Ballantrae Lavas, and many geologists now put the Southern Uplands Fault along the river Stinchar, so making Downan Point part of the Southern Uplands.

References

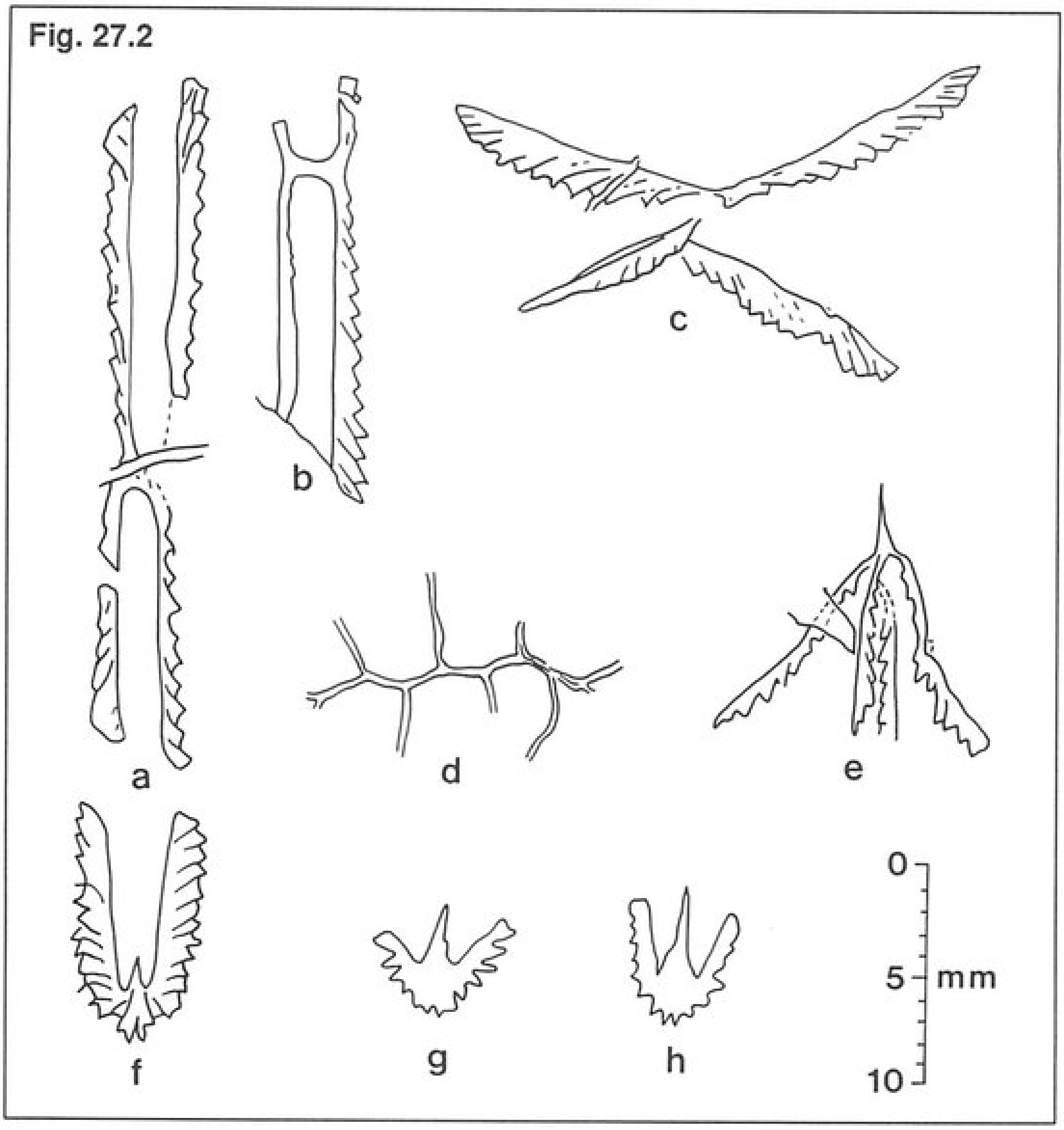
References for excursions 25–31



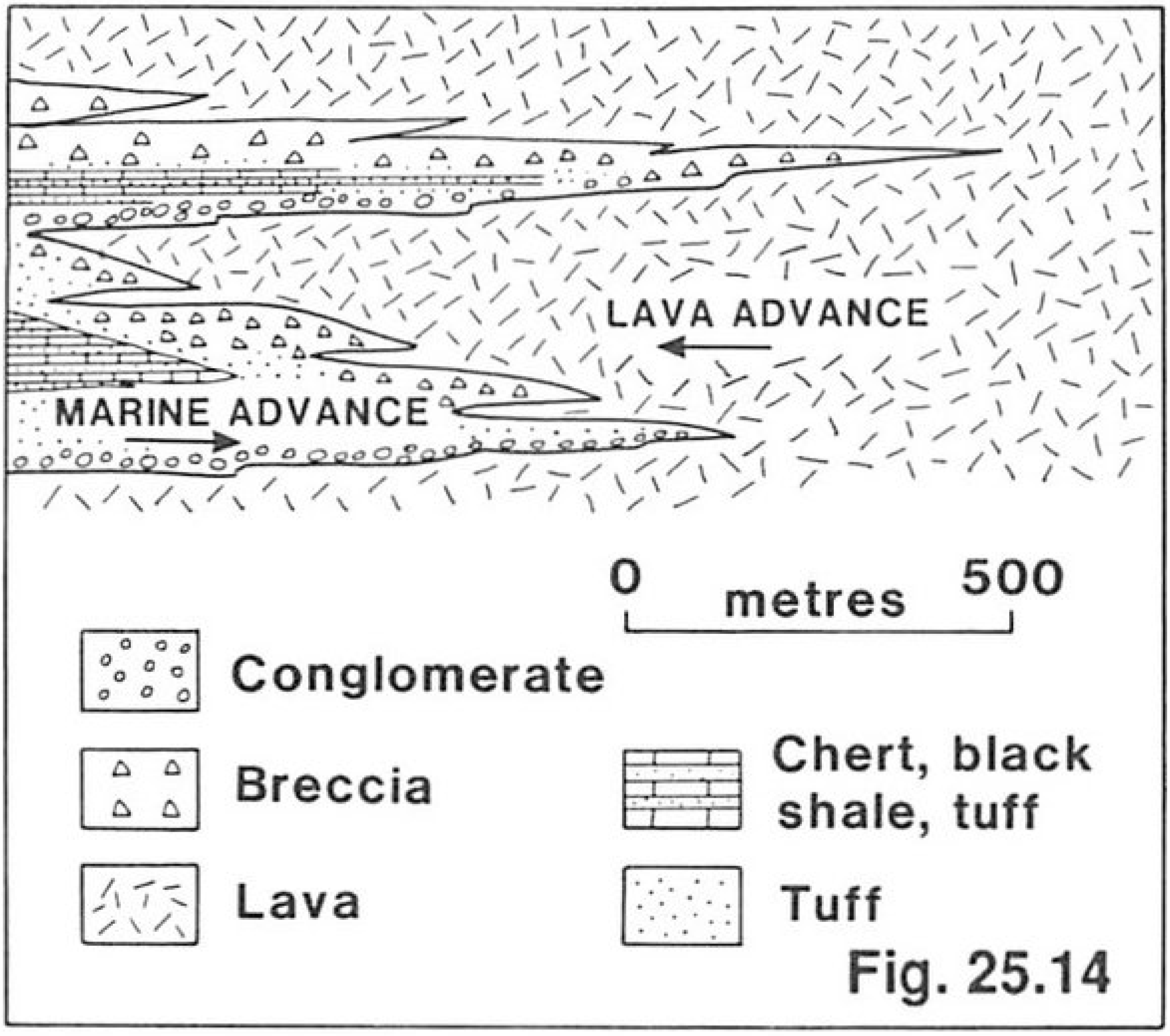
(Figure 27.1) Simplified map of Bennane Head. In the breccia symbol, C refers to coarse, F refers to fine grain size. (Note that the A77 road has been rerouted to the east of Bennane Hill and reaches the coast at the south of this map.)



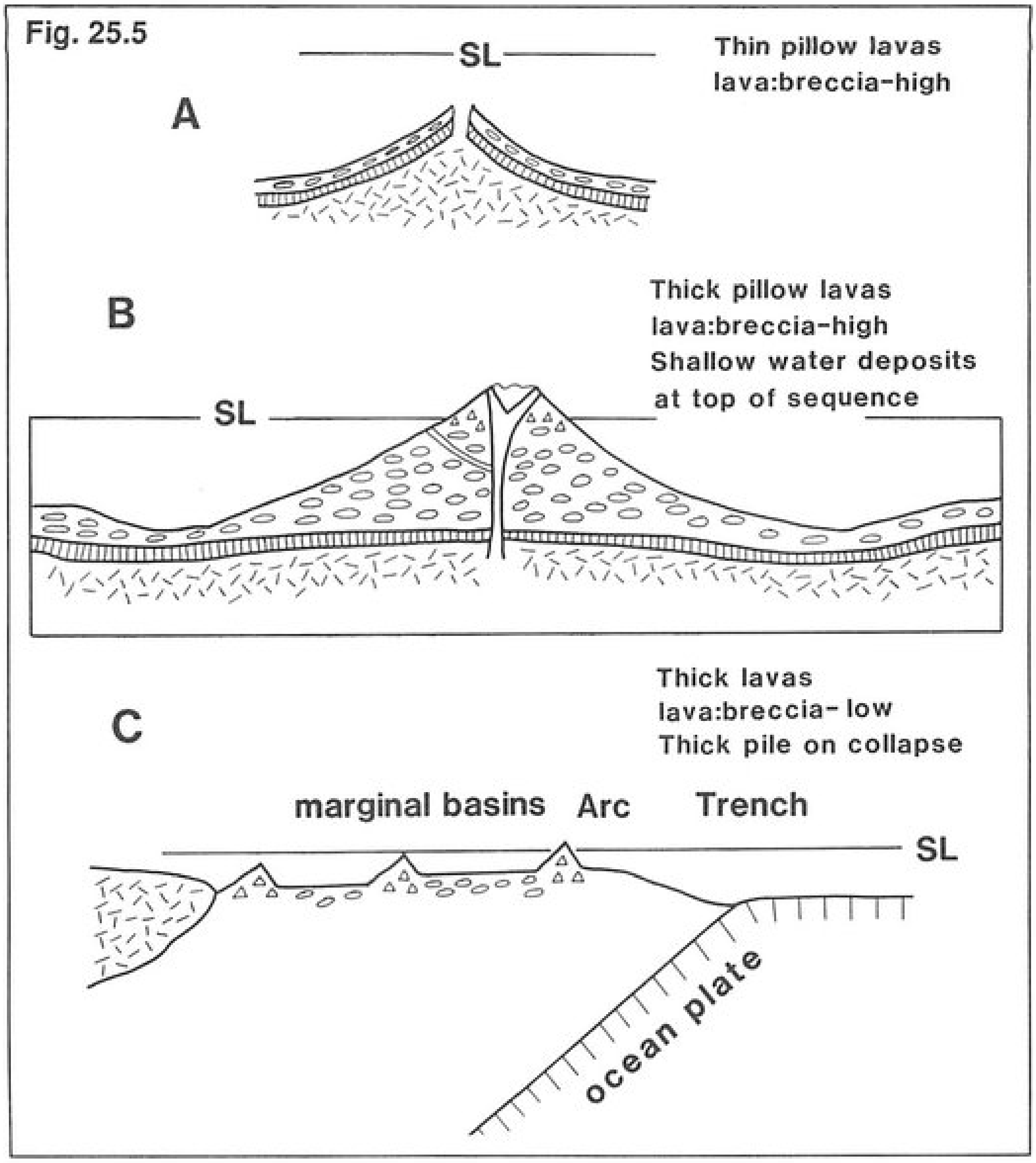
(Figure 27.3) Detailed plane-table map of the contact beween the serpentinite and the dolerite-tuff and chert; the cherts and conglomerates and associated rocks, N of Bennane Lea.



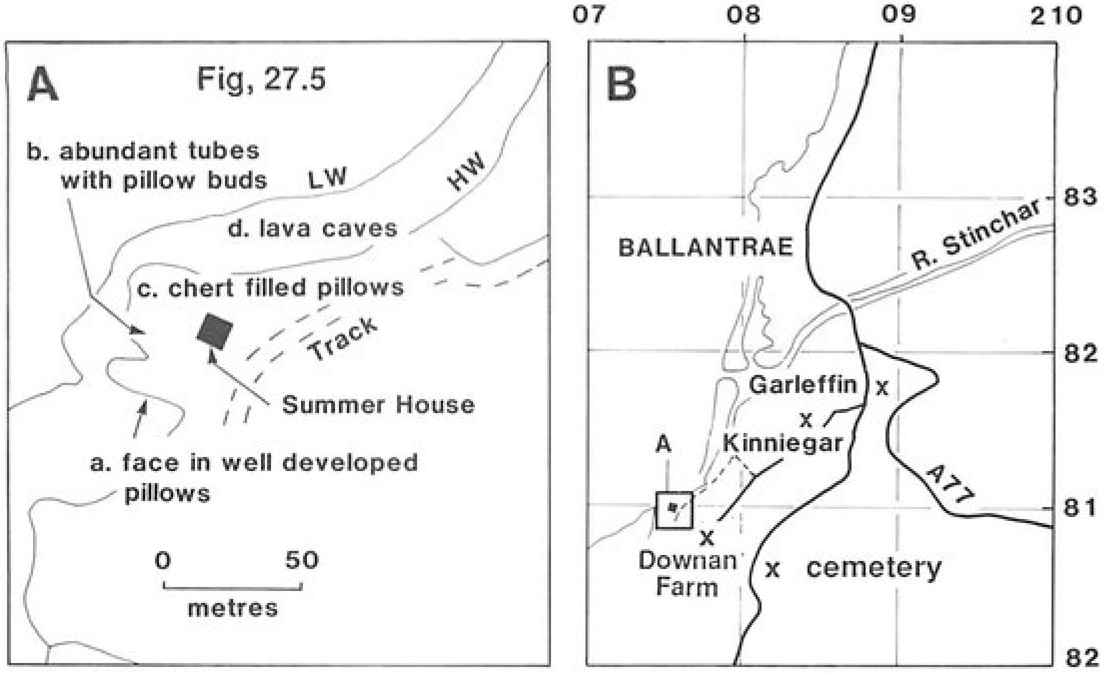
(Figure 27.2) Graptolites recovered from the Bennane Head sequence by Stone and Rushton (1983) a, b. Tetragraptus approximatus, c. Tetragraptus reclinatus reclinatus. d. Sigmagraptus praecursor, e. Tetragraptus fruticosus, f. Isograptus caduceus, g, h. Pseudoisograptus dumosus



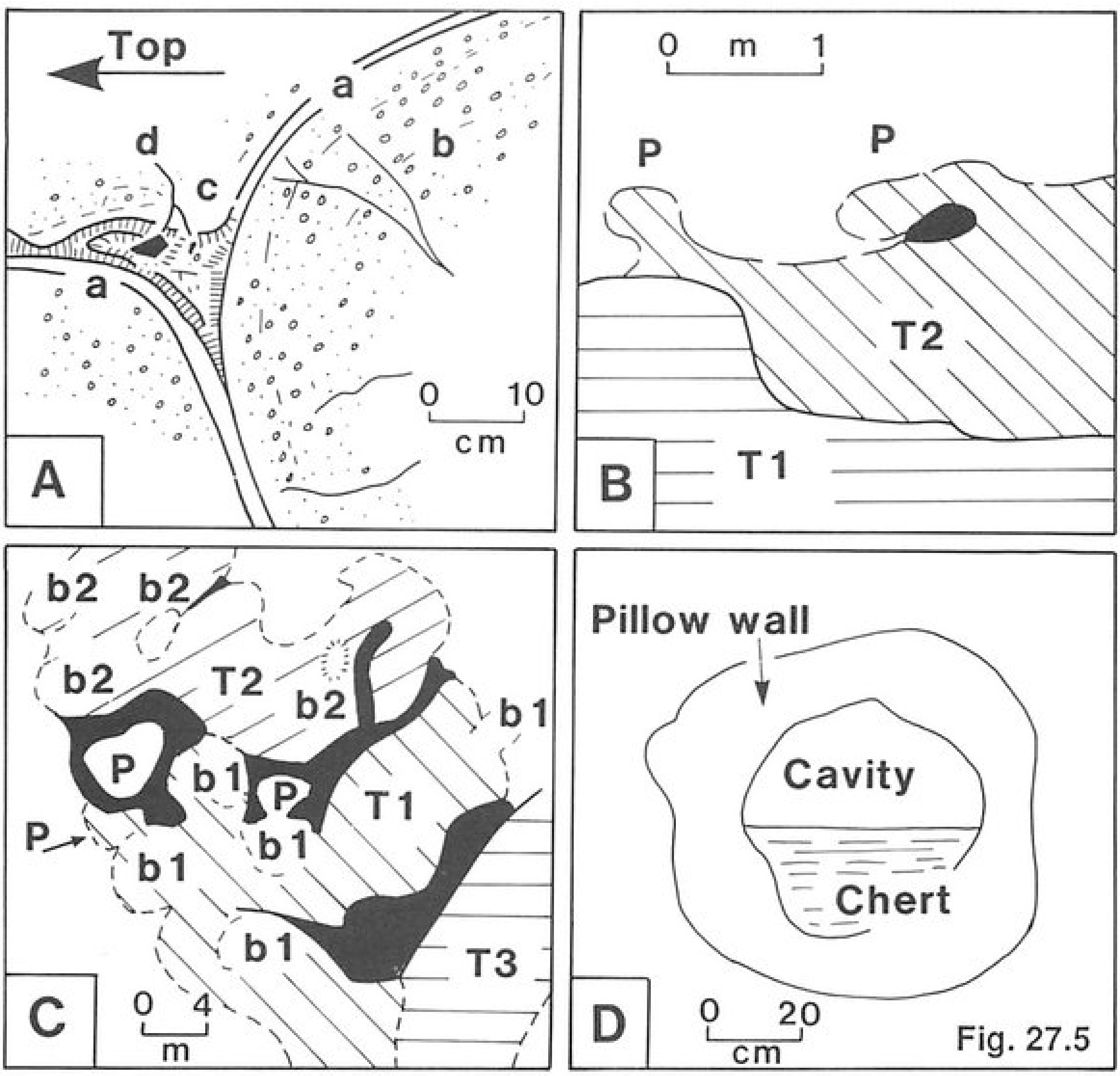
(Figure 25.14) Explanation of the sediment-lava cycles in the Pinbain Block and elsewhere. When the rate of lava extrusion is rapid or the rate of sea-level change is slow, the lavas advance into the sea. Because of seawater-lava interactions, where the lavas break down by explosive or erosional activity, lavas are always associated with tongues of lava entirely enclosed in breccia. However further towards the source of the lavas there are fewer breccia deposits. Shales and cherts on the other hand accumulate in deeper water and associated with them are tuffs which were deposited there either by air-fall (from explosive activity), storm deposition or turbidites. When volcanic activity has ceased or is waning the sea transgresses over the lavas to yield well rounded conglomerates, sometimes with reddened clasts if the lavas have been subject to subaerial exposure. This association of lava and breccia is common in nearly all the major lava sequences at Ballantrae, and in this Pinbain section massive lavas characterize Pinbain Hill; interfingers of breccias and lavas are seen on the coastal section (Localities 1–10) Transgressive conglomerates are seen at Localities 2 and 7).



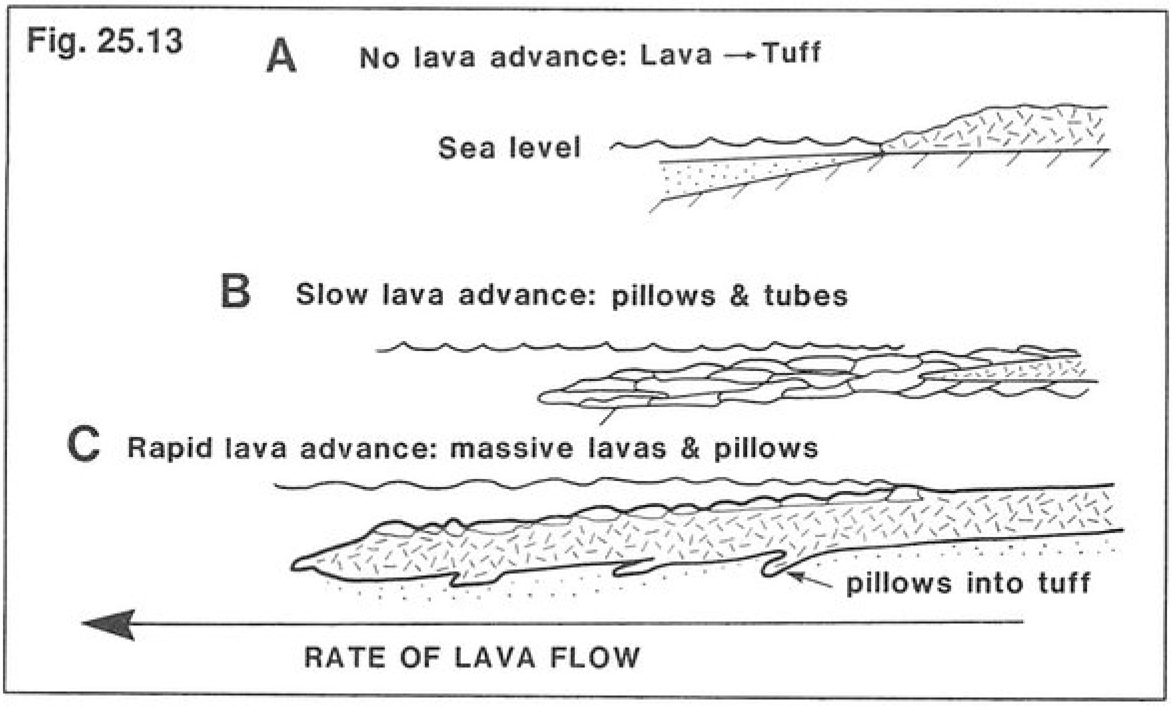
(Figure 25.5) Diagram showing the various ways in which ophiolites form, together with some of the main characteristics which typifies each one. A. Formation at a spreading ridge; B. At an ocean seamount, C. At a marginal basin-arc. SL = sea level. The symbols are as for (Figure 25.3) and 25.4.



(Figure 27.5) Maps showing the location of the pillows north of Downan Point, Locality 6. A, detailed map, LW, low water and HW high water marks; B, general map of the region.



(Figure 27.6) A, sketch showing the details of some of the pillows. The outer surface (a) is chilled, and can rarely be seen as a glass; mostly it is glass which has been almost totally replaced by chlorite, thus giving many of the pillows a green external colour. The interior of the pillow often has vesicles (b) which may be in radiating trails or in concentric lines which are preferentially developed towards the top of the pillows. The spaces beween the pillows are often filled with a fibrous calcite (c) and the centre of the pores may be filled with chert (d) B, illustrates two tubes T1 and T2 in section, with the lavas flowing from the right. T1 has provided the relief over which T2 has flowed; P are the two pillow-buds (incipient pillows) developed on the top of T2, and one pillow probably flopped over after it was inflated. The dark area is unfilled space. C is a plan sketch of the base of a sequence of pillow lavas. T1, T2 and T3 are the bases of three tubes. T1, 2 in particular have grown many pillow-buds b1 and b2, and some pillows (P) The dark areas are pore-space fillings which occur between the tubes and pillows. D, a section through a pillow which, when inflated did not fill with lava. It was subsequently partly filled with chert.



(Figure 25.13) Explanation of the development of various lava structures and tuffs in lavas which enter the sea from the land. A, the lava front is moving slowly and as it enters the sea where it is rapidly chilled, all of it is converted to tuff at the shoreline. Waves and currents move the tuff offshore. If the tuffs are generated in sufficient abundance then the lavas will flow over them to build up a hyalotuff delta, as seen at Slockenray. B, Lava is moving sufficiently rapidly to enter into the sea, but much of its outer skin is chilled by contact with the sea water. The chilled skin is inflated by magma which is under pressure and many pillows are produced. C, the lava advance is rapid, so that the outer skin chills and forms pillows, either by contact with water at its top surface or by tuff at the base. However the rapidly moving interior is insulated by this pillow growth and cools to form a massive lava which cannot be chilled by contact with the sea water. The porphyritic lava at Slockenray is of this type: it is pillowed at the top and sometimes at the base, but has a thick, massive interior.