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## PEN CAER

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### Introduction

The Pen Caer Peninsula, located to the west of Fishguard in north Pembrokeshire, largely comprises Ordovician lavas and related intrusive rocks, chiefly of bimodal basic and silicic compositions, but rarely of intermediate composition. These are associated with pyroclastic and sedimentary volcanoclastic rocks and argillites, the latter reflecting the background sedimentation that was punctuated by the relatively short-lived volcanic inputs.

The site is of importance in view of the excellent coastal exposures, which demonstrate the nature of subaqueous extrusive and related high-level intrusive igneous processes in the southern part of the Welsh Basin in early Ordovician times. In addition, the geochemistry of the igneous rocks has been used to establish the ensialic marginal arc-basin setting in which these various extrusive and intrusive rocks were emplaced (Bevins *et al.*, 1984; Kokelaar *et al.*, 1984b).

The extrusive volcanic rocks, up to 1800 m thick, belong to the Fishguard Volcanic Group of Llanvirn age, and were emplaced entirely in a submarine environment. They show a range of forms related to their mode of eruption and emplacement, which included the quiet effusion of basic sheets and pillowed flows and silicic dome-producing extrusions, the dramatic effects of thermal shattering and breccia production, and the explosive eruption associated with the generation of hyaloclastites and silicic ash-flow tuffs.

Basic intrusive sheets show a variety of forms, directly related to depth of emplacement. Those emplaced at some depth in the sequence show parallel tops and bases and relatively coarse-grained textures. At higher levels, however, the intrusions invaded still-wet sediments, their contacts are irregular, sometimes with flame structures at the sediment–igneous contact, and textures are those characteristic of rapid quenching.

The extrusive products were subject to rapid reworking, and volcanoclastic rocks were generated. For the most part, however, the lava pile must have been well-below wave-base, as such rocks are relatively rare. More common are mudstone intercalations, which reflect temporary cessations in the volcanic activity and a return to 'normal' background sedimentation.

The first detailed description of the igneous rocks of the Pen Caer Peninsula was by Reed (1895). This study was extended subsequently by Cox (1930), and later by Thomas and Thomas (1956). The most recent investigations are those of Bevins (1979) and Bevins and Roach (1979a, 1979b). Bevins (1982) described aspects of the petrology and geochemistry of the volcanic and related intrusive rocks of the Fishguard Volcanic Complex. A detailed description of parts of the site area appears in the field guide of Kokelaar *et al.* (1984a).

### Description

The Fishguard Volcanic Group in the Pen Caer area comprises three formations, namely:

1. Goodwick Volcanic Formation (youngest)
2. Strumble Head Volcanic Formation
3. Porth Maen Melyn Volcanic Formation (oldest)

The Porth Maen Melyn Volcanic Formation is exposed to the north of the bay known as Porth Maen Melyn (Figure 6.10), to the south of Strumble Head. The lowermost unit of the formation comprises 10 m of extensively recrystallized bedded rhyolitic tuffs that show evidence of shardic textures. The tuffs appear to be non-welded, silicic ash-flow tuffs, emplaced

subaqueously. This unit is overlain by two units, 35 m thick in total, of lithic-crystal-vitric breccias and crystal-vitric tuffs. The lower unit shows a fining upwards through the lowermost 50 cm. Clasts in the breccias are chiefly of angular to subrounded rhyolitic lava, sometimes with a perlitic texture, although in the lower part of the sequence basic lava and dolerite are common. Crystals, chiefly bi-pyramidal quartz and plagioclase, are prominent in the fine-grained basal part of the sequence. Pumice clasts are represented by weathered-out streaks in the tuffs, while shardic fragments are seen in thin section. These tuffs are thought to be sediment-gravity flow deposits, derived from the reworking of primary silicic eruptive volcanic detritus. The basic clasts were most probably eroded from wall rocks in the volcanic edifice during eruption. Overlying these breccias and tuffs is a rhyodacitic lava flow up to 40 m thick; to the east it is massive, while traced westwards it becomes pillowed, showing elongate flow tube structures, associated with inter-pillow breccias. The flow is quenched and shows a perlitic texture, reflecting the recrystallization of a glass. The top of the flow is autobrecciated. The tubes and pillows are thought to result from the rapid effusion of hot magma at the steep front of a lava flow, as described by Bevins and Roach (1979b).

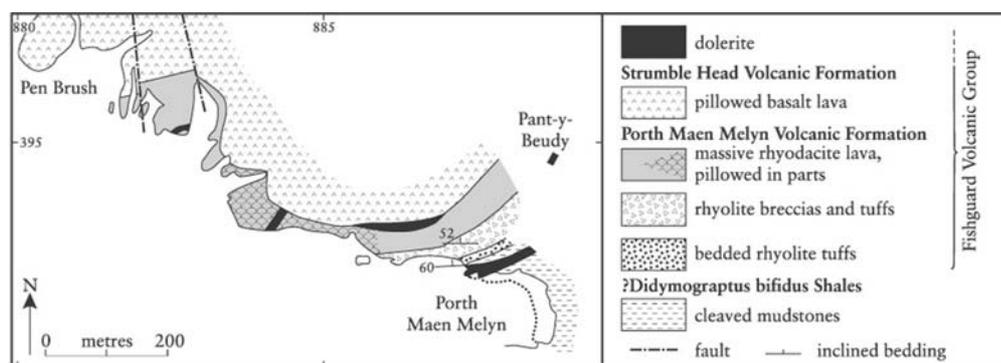
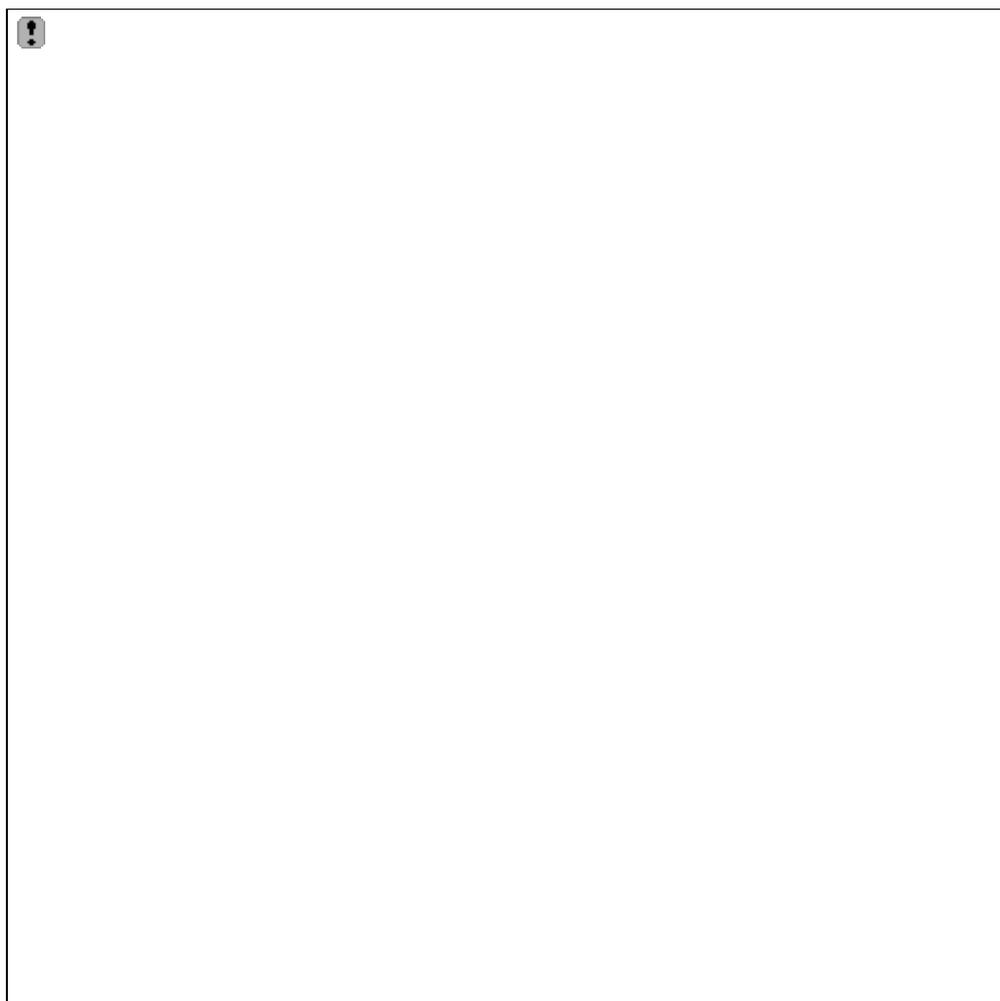


Figure 6.10: Map of the Porth Maen Melyn area, Pen Caer GCR site (after Kokelaar et al., 1984a).

The Strumble Head Volcanic Formation conformably overlies the Porth Maen Melyn Volcanic Formation, a contact well exposed in the steep cliffs on the north side of the bay. Immediately overlying the contact are classic pillowed basaltic lavas, individual pillows typically reaching up to 40 cm in diameter (Figure 6.11). Such lavas form the bulk of the succession exposed from Porth Maen Melyn northwards to Strumble Head and then eastwards to the extremity of the outcrop of the Strumble Head Volcanic Formation at Carnfathach. The pillowed flows commonly show well-developed inter-pillow breccias, while intercalations of isolated pillow breccias and hyaloclastites are sporadically developed. Locally, elongate, steeply inclined lava tubes are developed, as are classic necking structures. Intercalated with the pillowed lavas are massive, commonly lensoid lava sheets, as well as high-level intrusive basaltic sheets. Some intrusive sheets show pillowed forms at their base, while the thicker sheets commonly possess well-developed columnar jointing.



*Figure 6.11: Pillow lava from the Fishguard Volcanic Group, Strumble Head. The pillow in the centre of the photograph is 75 cm across (long axis). (Photo: R.E. Bevins.)*

The top of the chiefly basaltic Strumble Head Volcanic Formation and the base of the overlying chiefly silicic Goodwick Volcanic Formation is marked by a complex interdigitation of lavas and high-level intrusions (Figure 6.12). The various facies of a thick rhyolite flow or dome at the base of the Goodwick Volcanic Formation are excellently exposed on Penfathach. The lowermost facies, a breccia, comprises 4–5 cm-diameter clasts of flow-banded rhyolite showing little to no post-brecciation rotation. This passes upwards into rhyolites with excellent large- to small-scale flow-folding, and locally with well-developed columnar jointing. Locally, perlitic textures are preserved. Contact with the overlying autobrecciated carapace is gradational. To the east, basaltic tuffs are exposed at the foot of cliffs at Porth Maen. These tuffs are generally parallel-bedded, and show both normal and inverse grading. Clasts are typically 2–3 mm in diameter, reaching up to c. 1.5 cm. Offsets to bedding probably relate to soft sediment faulting. These tuffs are thought to be sediment-gravity flows slumping off the flanks of a submarine, possibly shallow-water volcano. Farther to the east, and up-section, coarse lithic-rich ash-flow tuffs are exposed. These are overlain by fine-grained silicic tuffaceous sedimentary rocks that have been intruded by a basic sill. This sill shows bulbous protrusions at its base, indicative of wet sediment–magma interactions. The top of a higher basic intrusion, exposed on Pen Anglas, has particularly well-developed columnar jointing, yet is pillowed at its top, again indicative of intrusion of magma into wet sediment (Figure 6.13).

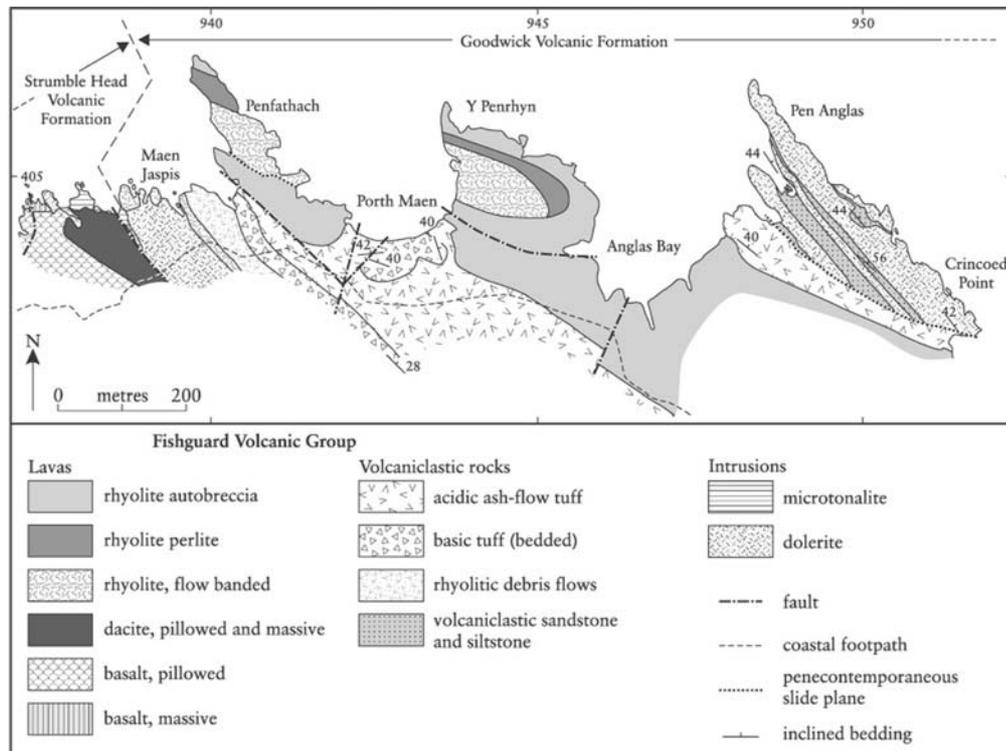
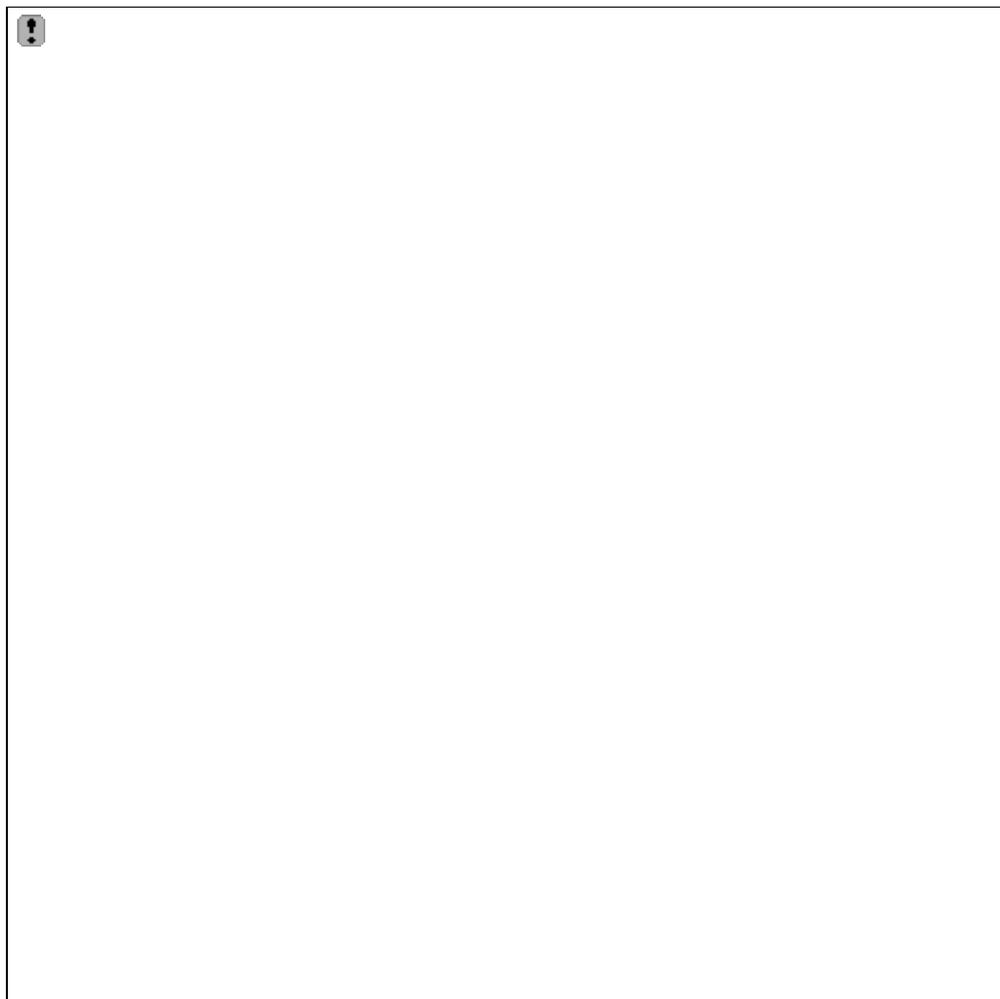


Figure 6.12: Map of the north-eastern part of the Pen Caer GCR site (after Kokelaar et al., 1984a).



*Figure 6.13: Magma-wet sediment relationships at the base of a high-level basic intrusion, Pen Anglas. Magma has injected and loaded down into unlithified tuffaceous sediment, while the wet sediment has locally flamed up into the magma. Lens cap for scale. (Photo: R.E. Bevins.)*

## Interpretation

This site demonstrates the complex facies developed in extrusive and high-level intrusive rocks associated with the generation and evolution of a submarine volcanic complex, with compositions ranging from basic through intermediate to silicic.

Classic pillowed and sheet-like forms are developed in the basic lavas, along with inter-pillow and isolated-pillow breccias. In critical sections, elongate, steeply dipping lava tubes can be seen. Unconsolidated tuffs, probably generated in relatively shallow-water environments, were reworked locally and led to the generation of bedded basaltic volcanoclastic sediments.

Some basic magmas failed to reach the seawater–sediment interface, and were intruded at a high level. At deeper levels in the sequence the intrusions are relatively thick, typically coarse-grained, and show sharp concordant contacts. At shallower levels, the intrusions are thinner, finer grained, even quenched, and show irregular, sometimes flamed or pillowed, contacts.

More silicic, dacitic, magmas produced a 40 m-thick flow that erupted onto the sea floor. Part of the exposure reveals a massive, central facies with an autobrecciated flow top; at the steep front of the flow, however, elongate flow tubes developed, associated with inter-pillow breccias. The flow appears to have been glassy throughout. Such flow features in dacitic lavas are extremely rare, making this site of international significance in terms of understanding eruptive igneous processes.

Silicic magmas were emplaced as extrusive domes on to the sea floor, with well-developed

autobrecciated carapaces and showing magnificent flow-folding phenomena. In addition, explosive eruptions produced deposits of ash, pumice, glass shards and lithic fragments; some deposits were derived from primary ash-flows, in other cases they represent the slumping of previously deposited debris on the unstable flanks of submarine volcanoes and domes.

Bevins (1982) investigated the geochemistry of the basaltic rocks of the Fishguard Volcanic Group. He reported that they show close similarities to N-type (normal) Mid-Ocean-Ridge Basalt (MORB), but were slightly enriched in the light rare earth elements and Th, coupled with a marked depletion in Nb. Such features are thought to reflect a minor subduction zone influence in their genesis and are characteristic of basalts erupted in back-arc or marginal basins. This is consistent with the Welsh Basin occupying a tectonic position at the margin of Gondwana during early Ordovician times, and with subduction of the Iapetus Ocean crust beneath the continental margin.

## Conclusions

This site provides excellent coastal exposures through a submarine volcanic pile, showing a range of extrusive and intrusive igneous phenomena. The products provide critical evidence for the nature of submarine volcanism and the processes involved in the development of a submarine volcanic complex. It is one of the classic sites in the British Isles for pillowed basaltic lavas and related tuffs and breccias. Of international note, however, are exposures through a dacite lava that shows a transition from a massive centre to a flow front with elongate flow tubes; such phenomena are extremely rare in lavas of such silicic composition. Also, the nature of the growth and development of rhyolitic domes on the sea floor is demonstrated, associated with the products of more explosive activity and the subsequent reworking of loose debris in the submarine environment. Finally, the geochemistry of the basalts indicates that the lavas were erupted in a marginal basin environment linked to subduction of Iapetus Ocean crust beneath Gondwana in Ordovician times.

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