PANDY

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OS Grid Reference: SJ195362, 199360and 197356

Introduction

The Pandy GCR site consists of three outcrop areas in the Ceiriog Valley near Pandy, Denbighshire, where three tuffs, belonging to the Cwm Clwyd, Swch Gorge and Pandy tuff formations, are well exposed. Two of these tuffs are products of explosive silicic volcanism, and comprise pumiceous ash-fall, ash-flow, and pyroclastic surge deposits, while the third is mainly composed of volcaniclastic sandstones, deposited at the coastal fringe of subaerial ash-flow tuffs. The tuffs clearly show a range of depositional processes. The three tuffs relate to activity at volcanic centres widely separated across North Wales, contemporaneous with the major caldera volcanism of Snowdonia (Howells *et al*., 1991; Bevins *et al*., 1992) (see, for example, the Snowdon Massif GCR site). The centres were apparently short-lived and produced discrete subaerial pyroclastic deposits within a predominantly marine succession, implying contemporaneous emergence in some way linked to the volcanism.

Research on the volcanic rocks in the Berwyn has occurred in two main phases. The first involved the mapping and preliminary description of the volcanic rocks. Ramsay (1866), in the Geological Survey Memoir, reported the continuity of ‘ash bands' along the northern flank of the Berwyn, while subsequently the outcrops and petrography of the igneous rocks were described in several papers in the early part of the 20th century, most notably by Cope and Lomas (1904) and Cope (1910, 1915). Cope (1910) included the first attempt to reconstruct volcanic events from the sequence of deposits. Groom and Lake (1908) presented a detailed account of the Glyn Ceiriog area that included perceptive descriptions of the pyroclastic deposits, recognizing that the flinty felsitic parts of the Pandy Tuff had a vitroclastic texture and were not intrusive as others had thought previously. They also noted the ‘bogen'-like texture of what is now recognized as a welded tuff. Resurvey by the Geological Survey of part of the eastern Berwyn area (Wedd *et al*., 1927, 1929) showed errors in the previous maps of the Swch Gorge and Pandy tuffs and established their true continuity along the northern flanks of the Berwyn. Subsequently, in the second phase of investigation, detailed studies of the pyroclastic beds focused on the depositional processes and environments (Brenchley, 1964, 1969, 1972).

The Pandy GCR site is critical to understanding the Caradoc volcanic history of the Berwyn area of North Wales. It is particularly important because the pyroclastic deposits exhibit magnificently many of the characteristic features of the explosive silicic volcanism that was widespread across North Wales. The significant localities are within a small area, the tuffs are well exposed and are relatively unaffected by deformation or metamorphism, so that they retain remarkably clear details of primary vitroclastic textures. Additionally the contacts between the Pandy Tuff and the marine sedimentary rocks above and below, and the internal relationships between the constituent welded and unwelded ash-flow tuffs, contribute to an understanding of the nature and origin of transiently emergent volcanic islands. The site therefore contributes to a broader view of silicic volcanism in the context of the Ordovician marginal basin of Wales (Kokelaar *et al*., 1984b).

Description

Strata of Caradoc age, including the three main tuff formations, crop out along the north flank of the Berwyn and are intersected by the Ceiriog Valley near Pandy, where the succession is well exposed on the valley sides (Figure 6.58). The Caradoc sedimentary strata that separate the tuff formations are predominantly silty mudstones with interbedded sandstones, interpreted as having formed in shallow subtidal environments in water depths of less than 25 m (Brenchley and Pickerill, 1980). The tuffs are probably all of Soudleyan age, though the Pandy Tuff could be Lower Longvillian (Brenchley, 1978).

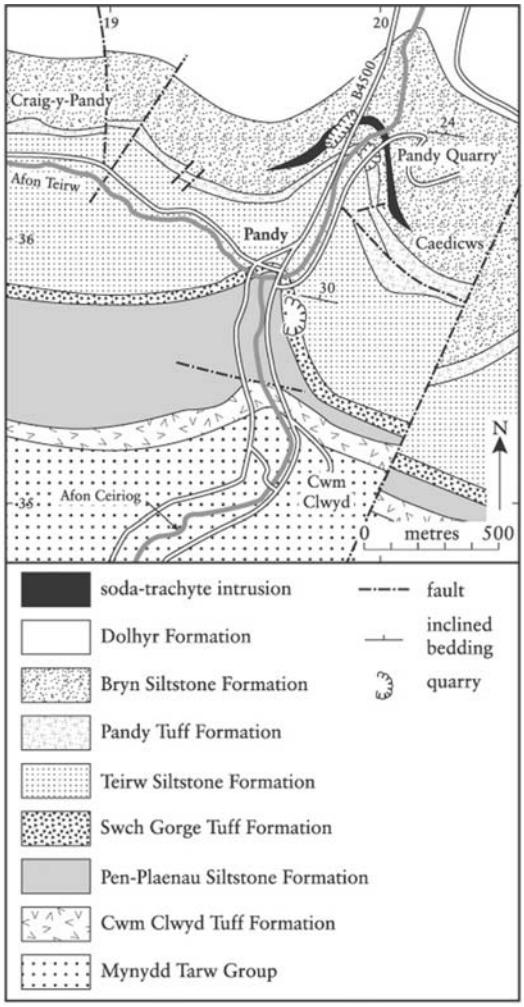

Figure 6.58: Map of the Pandy area.

The Cwm Clwyd Tuff is a sequence of bedded tuffs that are well exposed in crags on the eastern slopes of the Ceiriog Valley (Figure 6.58). It comprises alternations of thick-bedded lithic-crystal-pumice and thin-bedded pumiceous tuffs with partings typically 1–2 cm apart. The thick-bedded tuffs are tabular and may be massive, normally graded or, more rarely, inversely graded. Normal grading is most common in the coarser lithic lapilli-tuffs which show a reduction in grain size and increase in the amount of pumice towards their tops. The juvenile component of these tuffs is mainly pumice shreds and up to 12% quartz and 40% albite crystals, together with a variable content of accidental lithic clasts of pink rhyolite up to lapilli grade. The thin-bedded vitric tuffs are tabular, parallel-laminated or cross-laminated with dips of up to 10°. The vitric fraction in the tuffs is generally fine-grained tubular pumice, but bicuspate or tricuspate glass shards predominate in some beds. Accretionary lapilli occur in beds a few centimetres thick, interbedded within the sequence at several levels. The lapilli, which are flattened in the plane of the bedding, typically have a rim of fine vitric ash enclosing a pumice core. At the top of the sequence there is a massive unit of vitric-crystal tuff, 4 m thick, with irregular-shaped pumice lapilli weathered to form cavities. One laterally impersistent breccia containing blocks of tuff similar to the enclosing sequence is interpreted as a lahar deposit infilling a small channel and this, together with a few small channels containing a concentration of lithic clasts, is the only record of erosion and reworking of the tuffs.

The Swch Gorge Tuff, well exposed in quarries and crags on the eastern slopes of the Ceiriog Valley (Figure 6.58), comprises 40 m of volcaniclastic sandstones. The succession consists of thick-bedded, generally tabular sandstones up to 1 m thick that commonly appear massive although some show large-scale cross-stratification. There are thin shale partings between some beds, while large flakes of mudstone, some showing imbrication, are present in some of the sandstones. Desiccation cracks are known from a loose block. The sandstones are medium grained and are composed predominantly of feldspar and grains of volcanic rock with laths of

feldspar, suggesting that they are from a lava source and not derived from the ash-flow tuffs that form the thicker Swch Gorge Tuff sequence farther west (Brenchley, 1969). Rare graptolites have been recorded from within the Swch Gorge Tuff at Pandy (Groom and Lake, 1908) and a varied trilobite–brachiopod fauna occurs in the thinner-bedded sandstones at the top of the sequence (Brenchley, 1978).

The Pandy Tuff is exposed in crags on both the eastern and western slopes of the Ceiriog Valley and in quarries at Caedicws, Craig-y-Pandy and near Pandy (Figure 6.58), where a particularly flinty facies of the tuff was exploited for the production of china. The sequence through the Pandy Tuff is best exposed in the Pandy Quarry where it consists of 6 m of massive lithic-crystal-vitric tuff overlain by 21 m of massive vitric-pumice lapilli-tuffs that have unflattened pumice in the basal metre, show flattened pumice fiamme and a eutaxitic texture through the succeeding 8 m, and pass transitionally into a further 12 m of unwelded tuffs (Brenchley, 1964). In the top few metres of the tuff there is a marked increase in the abundance of uncompacted pumice clasts. The overlying sedimentary rocks lie in erosional hollows in the tuffs and contain a shallow-marine brachiopod–bryozoan–bivalve fauna (Harper and Brenchley, 1993). The quarries at Caedicws and Craig-y-Pandy show a similar sequence, but detail is partly obscured by large silicic nodules. Columnar-jointing of the welded ash-flow tuff is particularly well preserved at Caedicws.

In the crags laterally adjacent to the quarries and throughout most of the outcrop of the Pandy Tuff, welded tuffs are absent and the sequence consists of massive lithic-crystal-vitric tuffs, characteristically with coarse accidental lithic clasts at the base (coarse-tail grading) that range up to a few centimetres in diameter and protrude from the rock face. No internal divisions have been recognized within this development of the tuff, except in crags below the eastern end of Craig-y-Pandy where there is one horizon 6 m above the base where the clasts are concentrated to form a bed that thins laterally from 3 m to 4 cm over a distance of 12 m. The base of the Pandy Tuff is sharp but commonly irregular where the tuff has loaded into the underlying marine sediments, which locally contain detached blocks of the tuff several metres long. The marine mudstones extend upwards as tongues into the tuff, and sandstone beds are deformed into ball-and-pillow structures.

Interpretation

The site exhibits diverse pyroclastic deposits, formed by ash-fall and ash-flow processes representing accumulations related to separate volcanic centres in a generally marine, marginal basin setting. The Cwm Clwyd Tuff, with its predominance of fine pumice and beds of accretionary lapilli, records plinian or phreatoplinian eruptions that deposited more than 40 m of ash subaerially to a distance of at least 7 km from the volcanic centre. Beds have low-angle cross-stratification, in some instances occurring in stacked sets, implying deposition from currents. The low dip in most of the laminae and the variable direction of foreset dips suggest that the associated bedforms were low-amplitude, long-wavelength, sinuous dunes constructed by pyroclastic surges. The massive, thick-bedded lithic-crystal-pumice tuffs and the graded lithic-crystal-pumice lapilli-tuffs were interpreted as ash-fall tuffs by Brenchley (1972) because of their tabular nature and the vertical separation of the lithic clasts from the pumice in the graded beds. However, neither of these criteria is diagnostic and many of the beds could equally well have been deposited from pyroclastic surges. The range of bed types, including massive, inversely graded, graded and parallel-laminated or cross-laminated tuffs, could all be associated with downcurrent changes in the flow characteristics and depositional mechanisms of pyroclastic currents (Chough and Sohn, 1990). There is, however, a close relationship between ash-fall deposits and pyroclastic density currents, because ash columns may collapse (Cas and Wright, 1987) and evolve into different or varying concentrations and it is likely that the Cwm Clwyd Tuff records both ash-fall and pyroclastic surge deposits.

In contrast to the Cwm Clwyd Tuff, the Swch Gorge Tuff, in the Ceiriog Valley, is mainly reworked rather than primary. A high proportion of lithic grains of lava appear to have been derived from a source outside the immediate area, or from a local source that was entirely destroyed by erosion. Additionally there are a few thin interbedded marine mudstones. Laterally, towards the east, the volcaniclastic sandstones are interbedded with ash-flow tuffs and within 15 km the succession thickens and is wholly composed of ash-flow tuffs. The lateral association with welded ash-flow tuffs and the shallow subtidal sediments above and below

(Brenchley and Pickerill, 1980) place the volcaniclastic sediments in a shallow-marine context. This is supported by the brachiopod–trilobite fauna at the top of the tuff that belonged to a *Dinorthis* community living in estimated water depths of less than 10 m (Pickerill and Brenchley, 1979). The presence of flat mudstone clasts within the sandstones and the record of desiccation cracks suggest an intertidal setting. Some of the thick-bedded sandstones are cross-stratified, suggesting that dune bedforms were present, but other beds are either massive or planar laminated and some are separated by a mud parting. The welded ash-flow tuffs of the Swch Gorge Tuff probably formed islands of low relief (Brenchley, 1969) and the volcaniclastic sandstones in the Ceiriog Valley appear to represent an intertidal coastal fringe with dunes and sand flats intermittently covered by mud layers.

The Pandy Tuff represents a third type of pyroclastic accumulation, which is almost wholly composed of ash-flow tuffs. Throughout most of the length of its outcrop the tuff is a massive unwelded ash-flow tuff with a distinctive content of accidental lithic lapilli. The presence locally of a lenticular laharic deposit within the tuff suggests that it was formed from more than one flow. The deformation of the underlying substrate shows that the tuff was deposited on unconsolidated marine sediments. The absence of any signs of marine reworking suggests that if the pyroclastic flow deposited its contents in a marine environment, accretion above sea level was very rapid. Alternatively the sea floor may have been uplifted tectonically.

The welded ash-flow tuffs, confined to three separate short lengths of outcrop, form a single cooling unit and have a concentration of pumice at their top reflecting segregation during transport and eventual deposition from the waning current. Their lateral margins are not exposed, but it appears that the welded ash-flow tuffs abut against the unwelded ash-flow tuffs (Figure 6.59). They are interpreted as ash-flow deposits that infilled canyons incised into the non-welded ash.

Conclusions

The Pandy GCR site incorporates three contrasting manifestations of silicic volcanism in a shallow-marine setting towards the edge of the Ordovician marginal basin of Wales. Each volcanic formation is both underlain and overlain by shallow-marine sedimentary rocks, but two of the three tuffs were deposited subaerially, the third on the coastal fringe of a volcanic island. The Cwm Clwyd Tuff was formed from the products of explosive steam- and gas-charged (plinian/phreatoplinian) eruptions. Deposition was probably from pyroclastic flows and by ash-fall, but the relative frequency of the two depositional processes is uncertain. The Swch Gorge Tuff is formed of volcaniclastic sandstones deposited in an intertidal environment with shallow- marine dunes and sand flats, on the coastal fringe of a volcanic island. The Pandy Tuff is composed of ash-flow tuffs that appear to have accumulated fast enough in a marine environment to form a volcanic island or were deposited on a tectonically uplifted surface. The initial sheets of unwelded tuff were dissected by canyons that became the conduits for subsequent ash-flows which formed welded tuffs.

The importance of the site is that it exhibits particularly well some important aspects of Ordovician (Caradoc) silicic volcanism in a small, accessible and well-exposed area. The site is particularly relevant to an understanding of the genesis of transiently emergent volcanic accumulations in general, and contributes more particularly to an overall understanding of silicic volcanic processes in the Ordovician marginal basin of Wales.

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