Side Pike

[NY 293 053]

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Introduction

Well-preserved subaerial pyroclastic successions in the ancient geological record are rare worldwide, largely because they are lost by erosion. The Side Pike GCR site contains possibly the best example in Britain of an ancient subaerial volcanic succession that exhibits in close association the three main categories of pyroclastic deposit: surge, flow and fallout deposits. It also records the three principal types of volcanic explosion, magmatic, phreatomagmatic and phreatic, and it also includes features that are interpreted to have resulted from a rootless explosion caused by the interaction of surface water with hot welded ignimbrite. Post-eruption volcaniclastic sedimentary deposits are represented by debris-flow breccias and aqueous volcaniclastic siltstones and sandstones, belonging to the Seathwaite Fell Formation.

Evidence for volcanotectonic faulting closely associated with caldera volcanism is also well preserved in this site. Large vertical syn-eruptive displacements are indicated by structures on fault planes and by abrupt thickness changes in pyroclastic and sedimentary units across the faults. The most intensely fractured part of the Scafell Caldera broke into blocks 10–1000 m in size; the resulting chaotic megabreccia covers an area of more than 5 km^2, and is known as the Side Pike Complex. Megabreccia is a characteristic feature of large calderas throughout the world (e.g. in the San Juan mountains, Colorado; Lipman, 1984), and represents caldera floor and/or wall rocks that fragmented as a result of caldera collapse. Side Pike forms a megablock, 500 m across, that lies near the eastern margin of the megabreccia.

The rocks of Side Pike were described first by Branney (1988a, 1988b, 1990b), and Branney and Kokelaar (1994a).

Description

Side Pike is a small glaciated peak on the south side of Great Langdale. Strata generally dip about 25° to the east and are intensely faulted (Figure 4.23). The lowest unit (the Lingmoor Tuff; A of Figure 4.24) is exposed on the south and west flanks and consists of fine tuff with thin parallel stratification, low-angle cross-stratification and abundant accretionary lapilli, many of which have several concentric laminations. It was deposited by ash fallout and from pyroclastic surges ((Figure 4.25)a). Above it lie approximately 6 m of pale-weathered silicic tuffs in which stratification becomes more diffuse and subtle with height. They grade up into a pink, massive eutaxitic lapilli-tuff, which is about 30 m thick and is interpreted as a welded ignimbrite (B of (Figure 4.24); (Figure 4.25)b). The size and degree of flattening of the fiamme change with height in the ignimbrite; the most flattened fiamme occur toward the centre. Locally [NY 2902 0516], most of the thickness of the welded ignimbrite has been brecciated into angular, jigsaw-fitting blocks, with interstitial fine silicic tuff. The breccia grades laterally into coherent, unbrecciated ignimbrite, and the brecciation clearly occurred *in situ.* Where coherent, the ignimbrite is overlain by a 20 cm-thick layer of cream-coloured, very fine (formerly vitric) tuff with abundant 1 cm-diameter accretionary lapilli (C of (Figure 4.24)). The tuff layer exhibits little stratification, and probably records suspension fallout of fine ash after the passage of the pyroclastic density current that deposited the underlying ignimbrite (Branney 1988a, 1988b). It is therefore a 'co-ignimbrite ash-fall' deposit.

The vitric ash at the top of the ignimbrite forms a prominent grassy ledge. Above this lie 1–2 m of cross-bedded, fine to coarse tuff (D of (Figure 4.24)), in which sorting, undulatory sand-wave cross-stratification and abundant accretionary lapilli indicate deposition from phreatomagmatic pyroclastic surges (Figure 4.25)c. The surge deposit is incised by the irregular base of a monolithological breccia (E of (Figure 4.24)) that contains angular blocks of eutaxitic lapilli-tuff, closely similar to the underlying in-situ welded ignimbrite. The breccia's geometry, poor sorting and lack of internal organization indicate emplacement from a debris flow.

A diverse succession of fallout deposits, ignimbrites and aqueously deposited bedded volcaniclastic sedimentary rocks (F of (Figure 4.24)) overlies the debris-flow breccia. The sedimentary rocks exhibit spectacular soft-state deformation structures, and are locally overturned (e.g. at [NY 2907 0537]). Such localized and intense deformation is characteristic of the Side Pike Complex. Two amygdaloidal andesite sheets with marginal autobreccias lie within the bedded succession (Figure 4.23).

Between the andesite sheets lies the Lingmoor Tuff, a thinly bedded fine tuff with abundant accretionary lapilli (Figure 4.23). The tuff is also exposed in the saddle between Side Pike and Lingmoor Fell, and on the eastern end of Lingmoor Fell [NY 2985 0510]. It reaches 10 m thick and includes ash-fall layers with accretionary lapilli, and thicker, massive ignimbrite layers with matrix-supported fiamme. The top of the tuff is cut by gullies filled with sediment that contains locally derived intraclasts of accretionary lapilli-bearing Lingmoor Tuff. This indicates post-eruption reworking, possibly by ephemeral streams.

Vertical and deformed fiamme occur in eutaxitic lapilli-tuffs in the immediate vicinity of NNE-trending faults in the saddle between Side Pike and Lingmoor Fell (Figure 4.23). For example, vertical fiamme occur in a welded silicic ignimbrite, more than 40 cm thick, and plastered on to the faulted face of a massive andesite at [NY 2938 0530]. Many of the fiamme are sub-parallel to the fault plane and indicate fault displacement while the ignimbrite was still hot and able to shear in a ductile manner (Branney and Kokelaar, 1994a). The thickness of the massive silicic ignimbrite underlying the Seathwaite Fell Formation on Lingmoor Fell and Side Pike varies dramatically in thickness across the faults, as does the thicknesses of lacustrine sedimentary rocks between the ignimbrite and the Lingmoor Tuff (see cross section in (Figure 4.23)).

Interpretation

The lowest part of the succession in the GCR site illustrates the distinction between the varieties of pyroclastic deposit and also the characteristic types of volcanic eruption. The silicic tuff (B of (Figure 4.24)) that grades up from stratified into massive ignimbrite records the prolonged passage of a pyroclastic density current in which the concentration of particles increased with time. The eruption was magmatic and the welding indicates a high temperature. Gentle fallout of fine ash from a dilute co-ignimbrite ash cloud left in the wake of the density current gave rise to the thin co-ignimbrite ash-fall layer on the top of the ignimbrite (C of (Figure 4.24)). Co-ignimbrite clouds are known to loft high into the atmosphere, and it is probable that the thin vitric ash layer once covered an area of several hundreds of square kilometres. During and after its deposition, the underlying hot ignimbrite was undergoing welding compaction during cooling. Shortly after the eruption, surface water, possibly a small water-course, penetrated down into the hot ignimbrite and caused a violent rootless phreatic (steam) explosion, blasting a crater into the ignimbrite and shattering parts into blocks. The pyroclastic surge deposit (D of (Figure 4.24)) may be derived from this explosion or from similar contemporary explosive eruptions. Blocks of ballistic ejecta around the rootless vent sloughed away as debris flows (lahars; E of (Figure 4.24)) and these were locally deposited into channels cut into the unconsolidated pyroclastic surge deposit. These events occurred in rapid succession because the unconsolidated, thin co-ignimbrite ash layer beneath must have been protected from erosion by rapid burial.

Further pyroclastic eruptions and aqueous reworking were followed by the phreatomagmatic eruption of the Lingmoor Tuff. This is important stratigraphically because it has been correlated widely around the western part of the Borrowdale Volcanic Group outcrop. It lies within the upper part of the Seathwaite Fell Formation. The facies association resembles that of the Neapolitan Yellow Tuff of the Campanian region of Italy, which was erupted from beneath the Bay of Naples (Scarpati *et al.,* 1993), and a broadly similar style of eruption is possible. Abrupt lateral facies variations across the NNE-trending volcanotectonic faults east of Side Pike indicate that the faults were active and influencing the local palaeogeography at the time of the eruption.

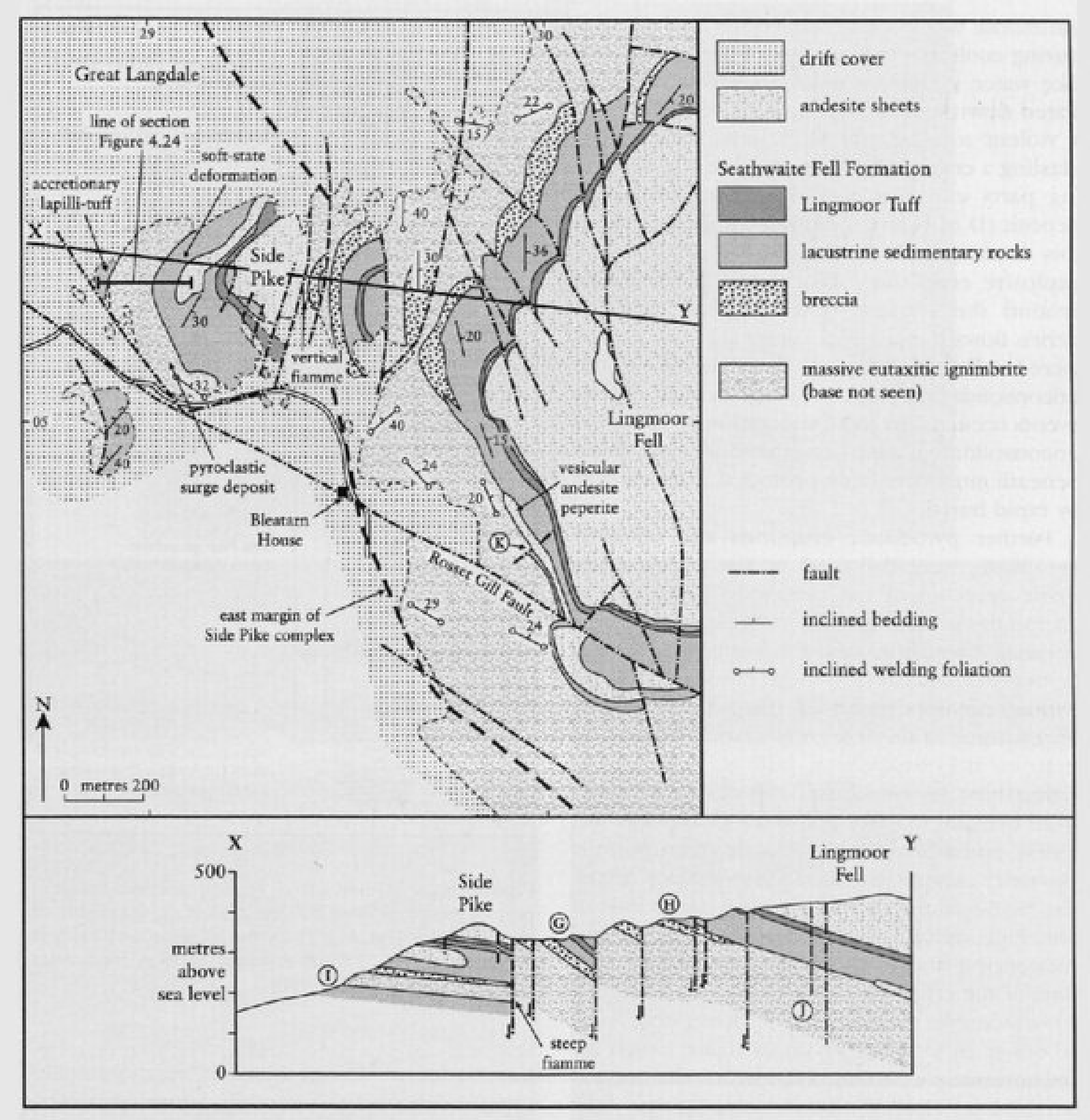
At Side Pike there is little evidence diagnostic of either an intrusive or an extrusive origin for the andesite sheets that occur within the bedded succession. However, their stratigraphical positions coincide with two andesite sheets on Lingmoor Fell (Figure 4.23) where there is evidence that the lower one is a high-level peperitic sill indicating intrusion into a wet substrate (see the Pets Quarry GCR site report for details of the mechanisms of intrusion). It cuts a contemporaneous volcanotectonic fault (K on (Figure 4.23)) and has fluidized and vesiculated suprajacent bedded sediment (Branney and Suthren, 1988). The critical top contact of the upper andesite sheet is not exposed.

The precise origin of the large-scale brecciation of the Side Pike Complex is not known. There appears to have been more than one phase of early fracturing, characterized by soft-state styles of deformation. The megablocks contain coherent to intensely deformed successions, some of which correlate with the Scafell caldera-floor and caldera-fill successions. However, several megablocks have 'exotic' volcanic sequences of unknown provenance, even though these may, in some cases, be correlated from one megablock to another (Branney, 1988b). The subaerial pyroclastic succession on Side Pike correlates with the successions seen in several other megablocks on Wrynose Fell, just to the SW, but this succession has not been recognized outside the Side Pike Complex; thus its precise stratigraphical position in the Borrowdale Volcanic Group remains uncertain. However, uppermost units in the Side Pike megablock are thought to correlate with the upper part of the Seathwaite Fell Formation, which is the record of a lake that filled the Scafell Caldera after it subsided (see Langdale Pikes GCR site).

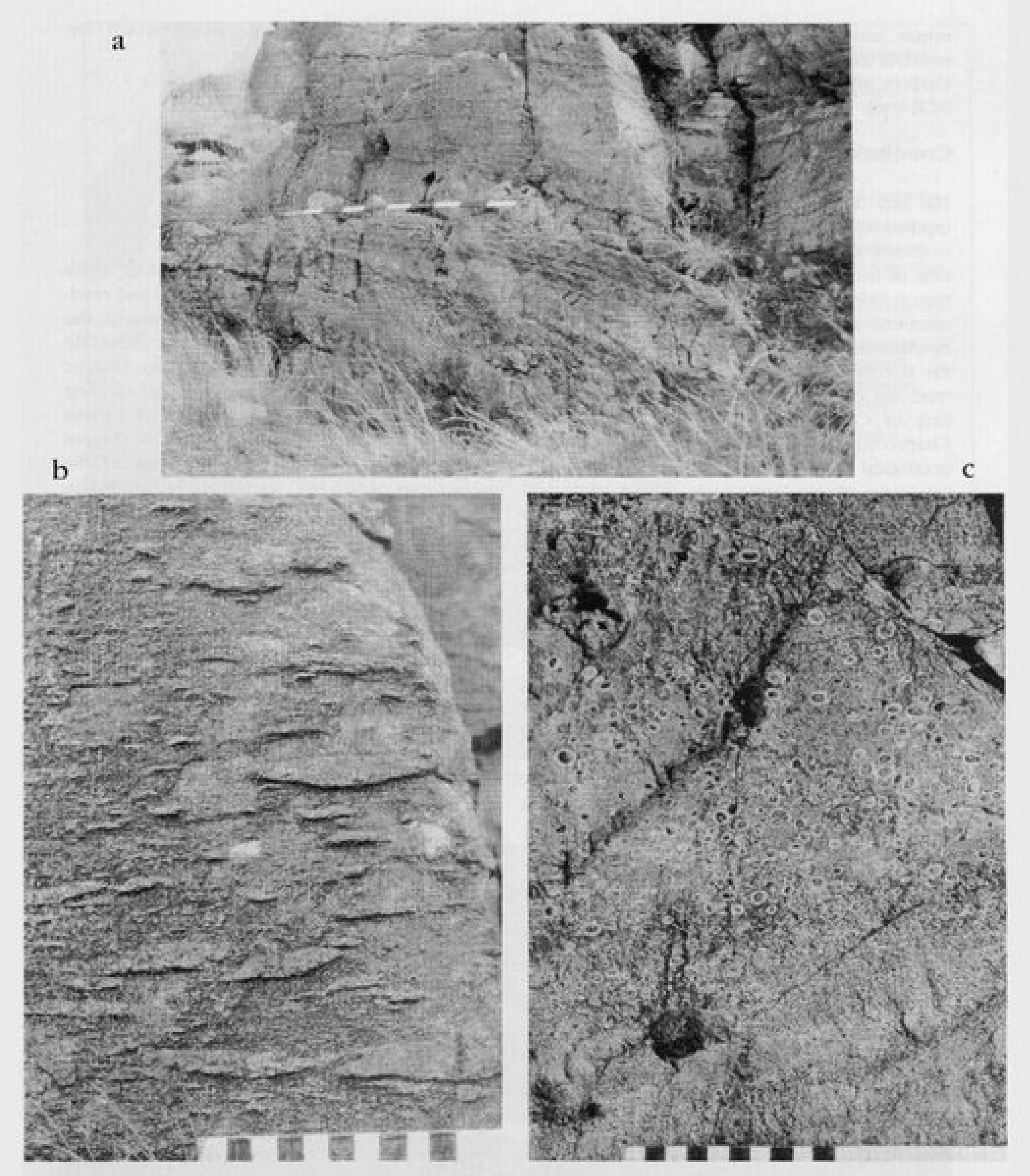
Conclusions

The Side Pike GCR site is part of a breccia that is exposed over more than 5 km^2. The breccia comprises enormous blocks and is associated with the formation of the Scafell Caldera. The facies association at Side Pike is diagnostic of a subaerial environment and its discovery was influential in determining the overall non-marine character of the Borrowdale Volcanic Group. This is in contrast, for example, with the island volcano setting of Caradoc rocks in North Wales (see Chapter 6). Side Pike is a rare site in the ancient geological record that exhibits the three main categories of pyroclastic rock: fallout, surge and flow deposits in close association. It also includes superb, rare examples of an ash-fall deposit associated with ignimbrite and the record of rootless steam explosions that occurred shortly after an ignimbrite eruption, while the ash deposits were still hot. Though secondary explosions of this type are well known at modern volcanoes, such as following the recent ignimbrite eruptions of Mount St Helens (USA) and Mount Pinatubo (Philippines), such clear evidence from Lower Palaeozoic rocks is rare. Side Pike also provides excellent evidence for differential ground subsidence along faults generated during volcanism which are now exposed in cross section.

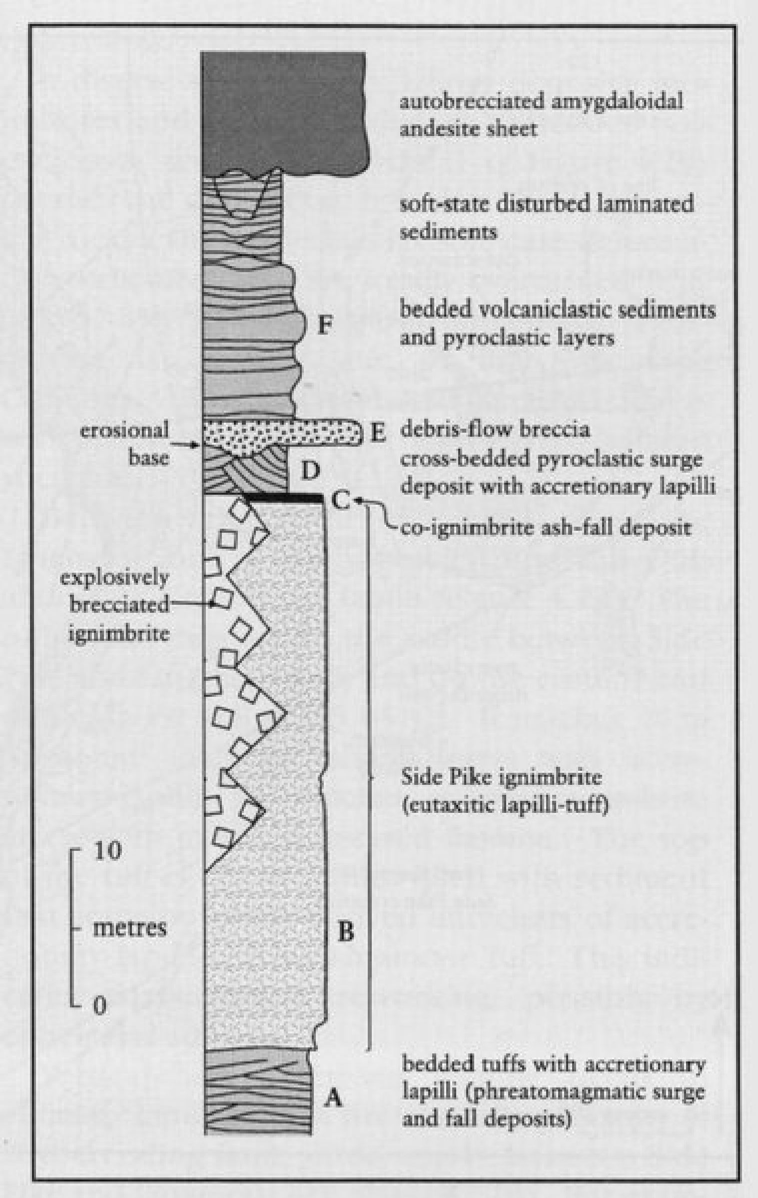
References



(Figure 4.23) Map and true scale cross section (X Y) of Side Pike, to show thickness changes across formerly eastward-downthrowing volcanotectonic faults, which have since been re-activated in the opposite sense. Note the change in thickness of lacustrine sedimentary rocks (between G and H) and of ignimbrite (between I and J), and the steep fabrics at two of the faults that record hot deformation of ignimbrite. A peperitic sill cuts a fault at K indicating that the fault pre-dates dewatering of the sediments. Localities G to K are described in the text. (Mapping by M. J. Branney and E. W Johnson.)



(Figure 4.25) Subaerial pyroclastic rocks at Side Pike, Langdale: (a) Cross-bedded phreatomagmatic fallout and surge deposits, which underlie the Side Pike ignimbrite. (b) Rhyodacitic welded ignimbrite (the Side Pike ignimbrite). (c) Accretionary lapilli-tuff in pyroclastic surge deposit that overlies the Side Pike ignimbrite. (Photos: M. J. Branney.)



(Figure 4.24) Generalized vertical section through part of the pyroclastic succession on the west side of Side Pike; see Figure 4.23 for the location and the text for explanation of units referred to as A to E After Branney (1988b and 1990b).