PETS QUARRY

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Introduction

Pets Quarry lies 300 m west of Kirkstone Pass. The quarry is cut into volcaniclastic sedimentary rocks of the Seathwaite Fell Formation (Figure 4.12) and the currently active faces are changeable. The excellent exposures of the contact relationships of a high-level sill illustrate features diagnostic of an intrusive origin into wet sediment. The sedimentary rocks are of considerable interest in their own right, because they record catastrophic syn-eruptive lacustrine sedimentation of hydroclasts by sustained turbidity currents. The site has been described and interpreted by Branney (1988b) and Branney and Sparks (1990).

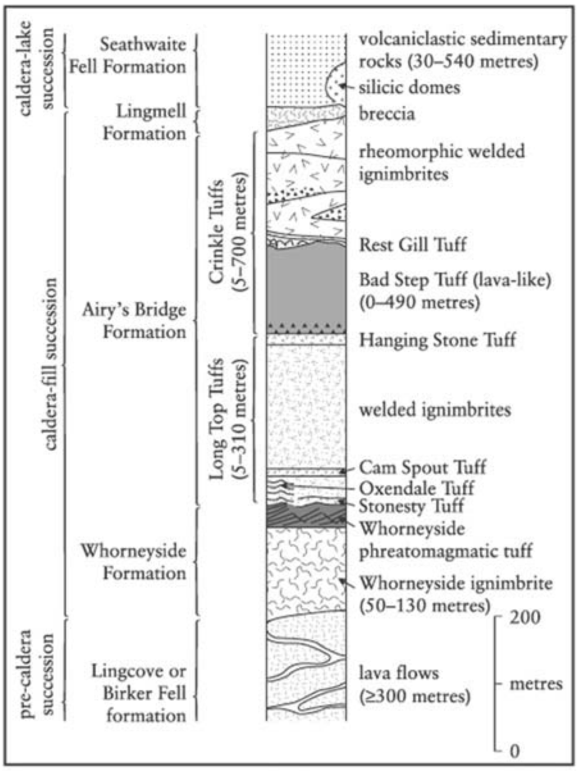

Figure 4.12: Generalized lithostratigraphy of the Scafell Caldera succession (after Branney and Kokelaar, 1994a).

The Borrowdale Volcanic Group (BVG) contains abundant sub-concordant igneous sheets throughout which, because they are readily distinguishable from volcaniclastic lithologies, have long been used as a basis for defining lithostratigraphical formations. However, it was established recently that sheets at many stratigraphical levels are intrusive (Branney and Suthren, 1988). The proportion of sills within the BVG remains unclear, but the recognition of sills that resemble blocky lavas has thrown into question the general practice of using the presence or absence of andesite sheets within local successions to define and to correlate lithostratigraphical units.

Early workers (e.g. Marr, 1916) compared andesite sheets in the BVG with modern autobrecciated lavas. Green (1913, 1915b) contended that many were sills, but subsequent workers (see Moseley and Millward, 1982 and references therein) concurred with the earlier interpretation, considering that the general concordance, brecciation, and lack of baking at upper contacts indicate an extrusive origin.

Recognition of high-level sills in the BVG (Branney and Suthren, 1988) followed work elsewhere (e.g. Kokelaar, 1982; Hanson and Schweickert, 1986), which had shown that sills intruded into wet sediment commonly do not bake the sedimentary host, for three reasons (Kokelaar, 1982). Firstly, steam generated at the magma contact insulates the host. Secondly, sediment immediately adjacent to the advancing margin of the intrusion is explosively disaggregated and excavated by steam, and is rapidly transported away along the magma–sediment contact in a fluidized state. And thirdly, an envelope of steam surrounding the invading magma can prevent the intrusion exerting directed stress on to the host to deform it. The removal of steam-fluidized sediment from the site of intrusion can give rise to strange contact geometries with an apparent ‘space problem'. Well-preserved or only slightly deformed bedding in the sedimentary rock is sharply truncated by sill contacts, indicating that substantial volumes of host sediment have been removed with little trace. Contact relationships may be complicated further by differential burial compaction of bedding around irregular sill margins. This can produce structures that resemble draped or mantle bedding, similar to that which characterizes fallout ash. Perhaps understandably, many such sills have been mistaken for lavas whose autobrecciated tops have been draped or infilled, and then buried by ash or sediment. The origin of many andesite sheets in the BVG whose upper contacts are not particularly well exposed remains equivocal. The non-genetic term ‘sheets' has been advocated for these (Branney and Suthren, 1988).

Description

The upper part of an irregularly shaped andesite sill is exposed in the quarry (Figure 4.28). The uppermost 8 m of the sill are brecciated; its base is not seen in the quarry, but is exposed a few metres below. Closely packed jigsaw-fit breccia grades upwards into an open framework-supported texture, and some of the uppermost blocks are apparently supported by sedimentary rock. At one place, loosely packed blocks form a 4 m-high vertical face at the top of the breccia. This is steeper than the repose angle, and it is unlikely that this could have been maintained without support of the sediment. However, there is no evidence that andesite debris from this body was reworked into the immediately adjacent sediments. Interstices in the breccia are occupied by andesitic sedimentary rock. In places this exhibits undisturbed lamination sub-parallel to the local dip. Elsewhere it comprises wispy discontinuous contorted laminations with soft-sediment shears and dislocations, or it is thoroughly homogenized. Bedding commonly abuts directly against the andesite blocks, though in many places there is a contact zone, 5 mm to 5 cm wide, of homogenized (formerly fluidized), pale, fine-grained sediment. Clouds of in-situ peperite, comprising locally spalled and quenched small hydroclasts set in homogenized sediment, occur adjacent to complex, highly irregular andesite block margins, particularly within zones of sediment between andesite blocks. Ellipsoidal chlorite amygdales up to 10 mm in diameter occur within the peperitic sedimentary matrix, and also occur in sediment that infills small vesicles in the andesite. There is ubiquitous penetration of fine-grained sediment into narrow fissures in the andesite and in the overlying sedimentary rocks. Many of the small vesicles in andesite adjacent to the fissures, or near the margins of the separated blocks, are completely filled with fine-grained sediment. However, vesicles in andesite away from the block margins contain no sediment.

Figure 4.28: Details of peperitic andesite intrusions in the Seathwaite Fell Formation at Pets Quarry, Kirkstone Pass. (a) Andesite blocks have intruded lacustrine volcaniclastic sands and silts (pale coloured); patches of angular hydroclasts surround some block margins and sediment has been injected into cracks between the blocks. (b) Breccia formed by reworking of hot peperite on the lake floor. Geopetal sand partially infills vesicles later filled with carbonate (white) and chlorite (black) in the large andesite block. White carbonate beneath the block preserves a cavity that probably formed when the hot block heated water in the sediment matrix after its emplacement in a debris flow. The coin is 22 mm across. (Photos: M. J. Branney.)

The host rocks are cleaved volcaniclastic siltstone, sandstone, and breccia, and bedding dips about 20° to the NE. Soft-state faults, and loading and dewatering structures are common. Some beds contain chloritic fiamme, whose shape indicates pre-cleavage burial compaction. Other beds contain angular blocks, up to 40 cm across, of vesicular andesite identical to those of the brecciated sill. The silty matrix of one bed contains vertical trails of carbonate-filled vesicles trails rising from andesite blocks, and carbonate-filled (steam?) geopetal cavities on the underside of andesite blocks.

Interpretation

The volcaniclastic rocks exposed in the quarry are correlated with the upper part of the Seathwaite Fell Formation, below the Glaramara Tuff (see Figure4.23 and the Side Pike GCR site report). Chloritic fiamme in some of the volcaniclastic sedimentary rocks are interpreted to record waterlogged pumice or scoria clasts that compacted in subaqueous sediment by burial during diagenesis (Branney and Sparks, 1990). They cannot have formed by welding, because the rock is lacustrine and sedimentary rather than pyroclastic, and it could not have been hotter than 100°C. The sedimentary lithofacies include high-density turbidites and debris-flow deposits. The turbidites do not exhibit Bouma sequences. This is because the turbidity currents were prolonged and high density rather than dilute, single-surge events dominated by waning flow, and so they deposited disordered sequences of divisions, including variously graded, massive or stratified layers and scour-and-fill structures (Branney and Suthren, 1988; Branney *et al*., 1990).

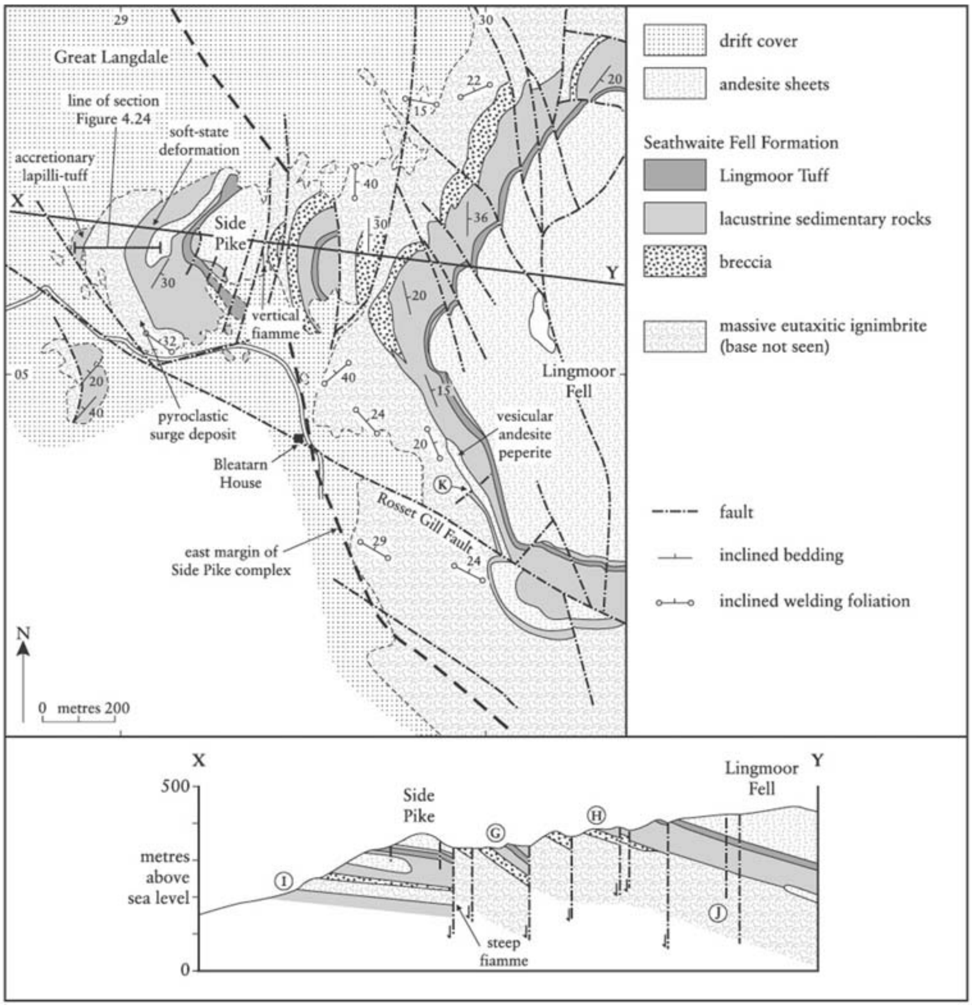

Figure 4.23: Map and true scale cross section (X–Y) of Side Pike, to show thickness changes across formerly eastward-downthrowing volcanotectonic faults, which have since been re-activated in the opposite sense. Note the change in thickness of lacustrine sedimentary rocks (between G and H) and of ignimbrite (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.)

The following features seen in the andesite are diagnostic of high-level intrusion into wet sediment (Branney and Suthren, 1988):

1. Localized vesiculation of sediment above the andesite sheet suggests that the overlying sediment was already present at the time of andesite emplacement and was heated by the andesite.

2. Matrix-support of some andesite blocks also indicates that the sediment above the sheet was in place before the andesite was introduced.

3. Localized clouds of peperite around block margins indicate that block margins were undergoing in-situ hydroclastic decrepitation.

4. Sporadic, pale, faintly laminated fine-grained sediment rims around some andesite blocks are inferred to be remnants of sediment left behind after removal of disaggregated sediment by steam fluidization.

5. A lack of evidence of sedimentary reworking of the in-situ peperite is consistent with

accumulation of the sediment before emplacement of the andesite.

6. Ubiquitous penetration of sediment into cracks indicates that the injected sediment was highly mobile, and probably water-fluidized and/or steam-fluidized.

7. Considering the volume of breccia, deformation that can be ascribed to sill emplacement is minimal. This suggests that sediment had been excavated by fluidization from sites now occupied by the andesite blocks.

Unequivocal criteria demonstrating intrusion, such as vesicles in the sedimentary rock, are not clearly visible where the upper intrusive contact of the sill in Pets Quarry is traced away from the fresh quarry face. It is also interesting that the diagnostic features do not occur everywhere along the contact. Movement of warm pore water through sediment is likely to have occurred as the intrusion cooled, and some of the host deformation may have been patchy post-emplacement dewatering and subsequent burial compaction. The andesite sill is autobrecciated in a similar manner to a block lava. This indicates that it had a similar rheology to a viscous block lava, and that it was in direct contact with only a steam carapace, so that the enclosing country rock was not able to exert significant mechanical constraint on the magma flow.

The sedimentary beds containing angular andesite blocks are also significant. The carbonate-filled geopetal cavities on the underside of blocks, and vesicles rising from their tops suggest that some of the andesite blocks remained sufficiently hot to vaporize the pore water of the debris-flow deposit after debris flow had ceased. The general facies association indicates that these beds were emplaced rapidly from unstable extrusive or unroofed parts of contemporaneous high-level sills that became emergent on the lake floor.

Conclusions

The Pets Quarry GCR site is perhaps the best and most accessible location in the Lake District that illustrates the processes of magma intrusion into near surface, wet sediment. Superb exposures show how sediment immediately adjacent to hot magma is mobilized by steam fluidization. Sediment only a little distance away from the contact is neither significantly heated nor disturbed, because a steam carapace around the invading magma effectively insulates the host, both mechanically and thermally, from the hot magma. The superficial similarity of this intrusion to a block-lava is instructive, and emphasizes the need for caution when interpreting the origin, and stratigraphical importance, of andesite sheets elsewhere.

The volcaniclastic sedimentary rocks show that sustained turbidity currents and debris flows may be generated during volcanic eruptions in lakes, and how the sedimentary facies produced in this way can be completely different from the much better-known sedimentary facies characteristic of non-volcanic turbidite settings. The site also exhibits pumice that has been flattened by low-temperature diagenesis and burial compaction. This closely resembles a lenticular type of disc (fiamme) formed in hot ignimbrite due to welding compaction (see also the Sour Milk Gill GCR site report). This alternative origin for such similar fragments is highly significant to the interpretation of volcaniclastic successions worldwide.

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