The Langdale Caldera - Reassessment of the Side Pike Complex

Leader: Clive Boulter 7 July 2018

In shorts-weather a dozen members set off from Three Shire Stone to consider the demise of the Side Pike Complex concept. Initially the excursion route set the regional context by examining the earliest stratigraphy in the district from the Birker Fell Formation andesites and then upwards into the two components of the Whorneyside Formation: the lower Wet Side Edge Member (andesitic welded ignimbrite) and the upper bedded tuff (air fall deposits from a gigantic phreatoplinian eruption - ?the world's biggest?). We then moved into uncharted territory where, in the 1980s/1990s resurvey, the deposits in a 5 km^2 area could not be tied into the regional stratigraphy and the notion of the Side Pike Complex was born (Branney 1988). It was believed that the differences between this small area and its surrounds were created when flank failure of the volcanic edifice led to blocks, hundreds of metres to around a kilometre in size, sliding in from parts of the stratigraphy no longer exposed. The blocks in this megabreccia were considered exotic.

However, very detailed work on part of the established stratigraphy of the Scafell Caldera was extended to the excursion area with dramatic consequences for the stratigraphy of the Borrowdale Volcanic Group (BVG) and its volcanological model (Brown 2001). At excursion Locality 4, within the former Side Pike Complex, 5 m of strata are so distinctive that Brown (2001) could identify them as being part of the uppermost Seathwaite Fell Formation which is the sedimentary infill of the Scafell Caldera. In this few metres a welded ignimbrite is overlain by accretionary lapilli tuff, a pairing of rock types not uncommon in the BVG but to someone who has spent many weeks getting thoroughly acquainted with the sequence by doing bed by bed logging, their characteristics were unmistakable! Having got this reference point it was apparent that the underlying 20 or so metres of water-lain volcaniclastics are the equivalent of the Seathwaite Fell Formation which is typically hundreds of metres thick and at its maximum is 540 m. Below this there is a 70 m thick sheet of rhyolite before encountering the Whorneyside andesitic pyroclastics. Again, this is a massively reduced section compared to the Scafell Caldera section just a short distance away on Crinkle Crags because the rhyolite is the equivalent of the Airy's Bridge Formation rhyolitic ignimbrites which are typically close to 1000 m in thickness. These massively reduced thicknesses could have been caused by erosion of typical accumulations of Scafell Caldera deposits but they are more likely the result of limited deposition on topographic highs.

Subsequent work (Boulter *et al*. 2020) has identified the Scafell Caldera margin in this area so it is a case of restricted initial accumulations. These massive lateral differences explain why it was so hard initially to correlate these much-reduced units with their much thicker equivalents in the Scafell Caldera. Such changes over such a short distance are not uncommon in volcanic terrains but they make the job of mappers very difficult.

Implications of the Reassessment of the Side Pike Complex.

1. Because the stratigraphy is no longer exotic, Brown (2001) has recommended that the use of the term Side Pike Complex be discontinued even though the area has yet to be remapped in light of the new knowledge.

2. In the BGS resurvey, when the uncertain stratigraphy was projected through the Side Pike Complex onto Lingmoor Fell, an incorrect stratigraphic assignment was made from here eastwards. This led to a large area of the southern strip of the Borrowdale volcanics (British Geological Survey 1996) being wrongly assigned to the Seathwaite Fell Formation when it is much younger (Figure 1). The only published map that partially corrects this significant error is by Millward (2004). This new formation has been named the Tilberthwaite Formation but it does not appear on any published BGS maps even though it covers a large area. On Earthwise P916047 this new formation is shown as the Ambleside Basin Succession.

3. In the Coniston area the Tilberthwaite Formation, which was erroneously thought to be the Seathwaite Fell Formation, overlies, at an angular unconformity, major ignimbrite units such as the Lag Bank Formation and the Paddy End Member of the Lickle Formation; hence these lithostratigraphic units were placed much lower in the regional stratigraphy than they should have been (Figure 1).

4. Welded ignimbrites, younger than the Seathwaite Fell Formation, in what was the Side Pike Complex, probably were generated in a caldera-forming explosive eruption which means that earlier work did not identify the associated Langdale Caldera.

5. What seemed to be a good stratigraphic marker, the accretionary lapilli-rich horizon at the top of a thick sedimentary sequence, and just below the

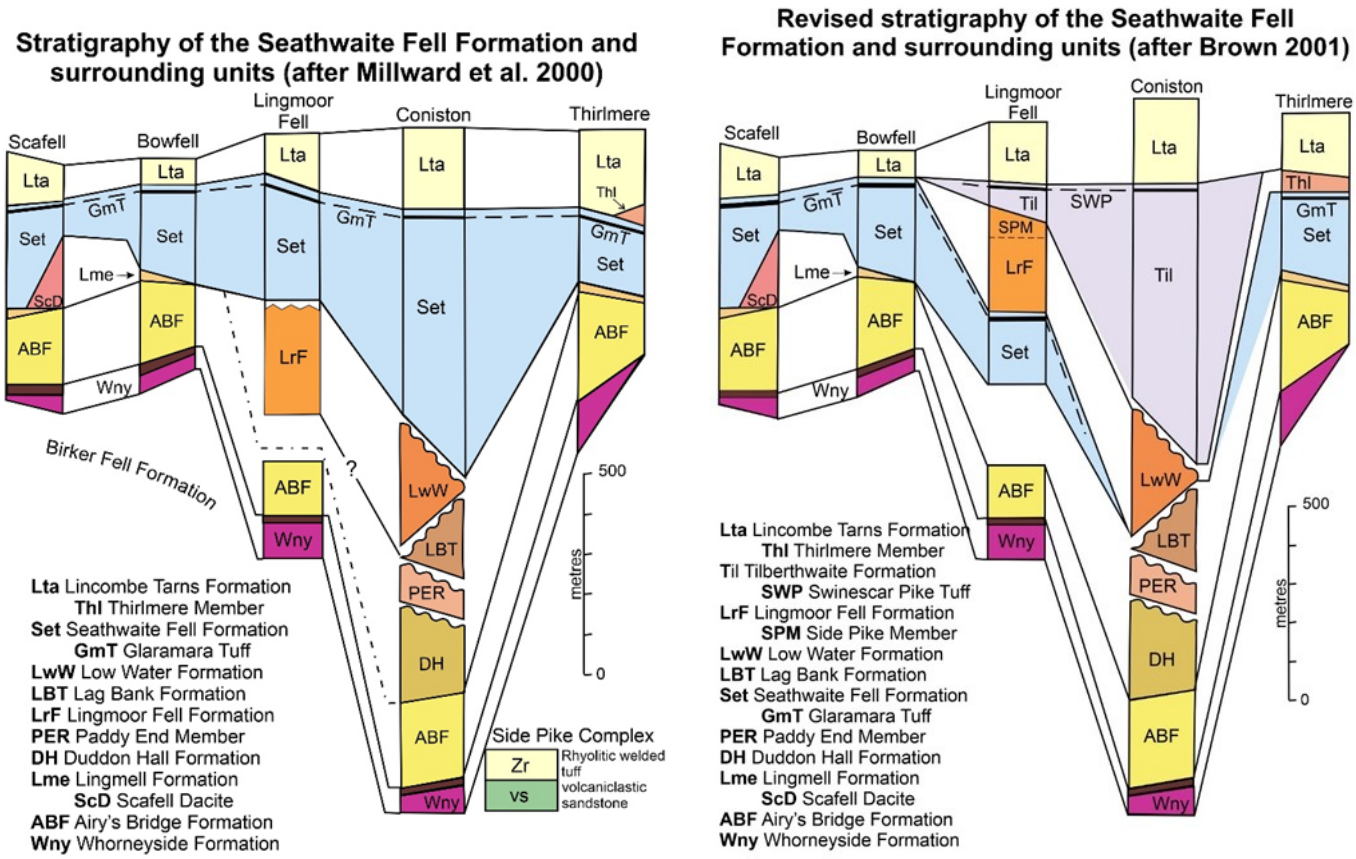


Figure 1 Comparison made by Brown (2001) of the correlations proposed in the Ambleside Memoir (Millward *et al*. 2000) and those made after recognition of Airy's Bridge Formation elements in the Side Pike Complex. The latter has been modified to remove some stratigraphic correlations that have not been generally accepted (Millward 2004). Section locations are as follows: Scafell NY 215 072; Bowfell NY 245 065; Lingmoor Fell NY 305 045; Coniston NY 290 990; Thirlmere NY 320 130; Side Pike Complex NY 285 045.

Lincomb Tarns Formation, is in reality two units of very different ages; the Glaramara Tuff is near the top of the Scafell Caldera sedimentary infill and the Swinescar Pike Tuff is near the top of the Tilberthwaite Formation, the sedimentary infill of the Langdale Caldera. Both tuff units probably represent deposits from very large tuff rings.

6. The regional implications are that a second silicic caldera (the Langdale Caldera) is present in the south Lake District and that the succession of ignimbrite eruption, probable caldera collapse, aqueous inundation, and sedimentary infill (as seen in the Scafell caldera), is repeated here by the eruption of the Lingmoor Fell, Lag Bank and Low Water Formation ignimbrites, followed by subsidence and sedimentary infill in the form of the Tilberthwaite Formation (Brown, 2001).

Locality 1 NY 27736 03273 Birker Fell Formation

This is a beautifully clean joint face exposing the top of an andesite sheet where a sedimentary network infills the gaps between feldspar-phyric andesite blocks. The locality prompts the standard question in much of the Birker Fell outcrop: is this the rubbly top of a lava flow where sediment was washed into the gaps between the andesite blocks or is it the top of a peperitic sill and unconsolidated sediment was injected into the andesite which fragmented on contact with the cool wet sediment? Lava flows and peperitic sills have the same sheet-like overall shape and, if you are unsure which of the two possibilities you are dealing with, then it is best to hedge your bets by saying it is an andesite sheet. At this locality the phenocrysts in the andesite give an almost granular texture which might be mistaken for a sedimentary texture. Also the sedimentary component stands proud and the andesite is recessive. If this is the top of an autobrecciated lava flow the reverse weathering response might be expected comparable to igneous fragments in the sedimentary matrix of debris flow deposits.

Diagrams in textbooks make the task of

discriminating between lava flows and high-level sills look simple but in practice it is a significant challenge. The tops of most lava flows are rubbly and brecciated and, if there is a time gap before the next flow, sediment can be washed between the broken pieces of lava producing a mixed sedimentary/igneous zone. For a high level intrusion the top contact will produce a similar sediment/igneous mixture. The igneous component is chilled by the cold wet sediments and fragments by cooling contraction granulation. Transfer of heat from the intrusion means that the pore fluid in the sediment wants to massively expand and the space created by the shrinking magma gives it somewhere to go! This all takes place in situ and the characteristic texture is jigsaw fits between igneous blocks. Contact metamorphism is typically restricted to millimetre thick zones because most of the energy of the intrusion goes in heating the sediment pore fluid.

Despite the conflicting messages from the locality the lack of jigsaw fit blocks tends to favour the andesite sheet being a lava flow.

Locality 2 NY 27721 03506 Wet Side Edge Member of the Whorneyside Formation

Andesitic welded ignimbrite with a weak welding fabric.

Locality 3 NY 27697 03564 Whorneyside Formation bedded tuff

Perfectly parallel-bedded airfall tuff from the massive andesitic phreatoplinian eruption that immediately pre-dated the rhyolitic Airy's Bridge component of the Scafell Caldera. Extensional features are widespread in this vicinity and impact sags are common. During piecemeal caldera collapse, blocks of this tuff were tilted. The headwalls of the slide blocks were extended and the toes developed compressional structures such as thrust faults. Conjugate normal faults created horst & graben patterns as can be seen at this locality.

Locality 4 NY 27992 04002 Black Wall "Member" and Glaramara Tuff at Long Crag

This is the most important locality in the region because distinctive units from the Seathwaite Fell



Figure 2 Pale weathering Glaramara Tuff overlying the diffuse-stratified ignimbrite of the Black Wall Member (Locality 4).

Formation could be recognised within the former Side Pike Complex. The crag is about 4.5 m high and the pale unit at the top is the Glaramara Tuff. The lower darker portion (Black Wall "Member") is a diffuse-stratified welded-ignimbrite that can be almost continuously traced from Seathwaite Fell via Scafell Pike to Coledale Head above Easedale Tarn. A feature of the ignimbrite is that the pumice clasts (fiamme) are mostly less than 2 cm long.

The Glaramara Tuff is the product of multiple eruptions in a very large tuff ring characterised by abundant accretionary lapilli. This and the Black Wall Member occur close to the top of the Seathwaite Fell Formation and are a definitive reference point for identifying stratigraphy in this challenging area formerly known as the Side Pike Complex. The Glaramara Tuff is rich in accretionary lapilli and the stratification plus the cross-stratification show that this unit was deposited from a low-concentration pyroclastic density current. Brown et al. (2007) have demonstrated that the Glaramara Tuff was produced by multiple explosions at an exceptionally large tuff ring.

Traversing south along Long Crag takes you through a continuous exposure of the massively reduced Seathwaite Fell Formation section. The well-developed bedding is mainly turbiditic in origin but none of the distinctive members seen in the Scafell Caldera can be identified. Some of the layers have reverse graded pumice fragments a few cm in size and one layer has 50 cm pumice clasts possibly from subaqueous eruptions.

Just below the Seathwaite Fell Formation is the hugely reduced equivalent of the Airy's Bridge Formation which here is a flow-folded rhyolite. The southerly traverse from Locality 4 went a little way into the Airy's Bridge correlate. The contact is at NY 28020 03845 where the rhyolite is flow banded and a little further south there is flow folding (NY 28037 03776) on a metric-scale. The lower contact of the rhyolite is a minor fault but the total thickness of this equivalent to the Scafell Caldera fill ignimbrites is only a few tens of metres partly explaining the problems of recognising regional stratigraphy in the former Side Pike Complex.

Immediately above Locality 4 Brown (2001) has described the Lingmoor Fell Formation which starts as a 20 m thick pebble/boulder sedimentary breccia (Unit 1) with an erosional base. The following 8 m (unit 2) of mainly parallel-bedded airfall tuffs, some of which has been aqueously reworked, is overlain by a distinctive rhyolitic welded- ignimbrite (Unit 3) which is about 30 m thick. The silicic ignimbrite is much repeated by faulting in this area and is seen on Side Pike itself. Unit 4 is another predominantly airfall unit seen at Locality 6. These four units have been termed the Side Pike Member by Brown (2001).



Figure 3 Glaramara Tuff – an ignimbrite with abundant multiply-rimmed accretionary lapilli and cross-stratification (Locality 4). 20p coin: 21.4 mm in diameter

Locality 5 NY 28079 04060 Unit 3 Side Pike Member, Lingmoor Fell Formation

This ignimbritic unit has several subdivisions not all of which were examined on the excursion. Much of it is a very distinctive strongly-welded ignimbrite and, in this dominant component, typically virtually all of

the fiammé are 1-2 cm long. Some sub-units of the ignimbrite have flattened pumice fragments 10 - 20 cm long forming up to 5% of the rock. Small lithic fragments are wrapped by the welding foliation giving an indication of the amount of flattening. The basal couple of metres of the ignimbrite are stratified with low angle cross stratification. This formed from a low density pyroclastic current that may have had a phreatic component to the explosivity. This can be seen at NY 28079 04060. The top of the ignimbrite is fissured as seen at NY 28169 04159.

Locality 6 NY 28215 04070 Unit 4 Side Pike Member, Lingmoor Fell Formation

The uppermost unit in the Lingmoor Fell Formation in this area is a mainly parallel-bedded set of airfall tuffs. Accretionary lapilli are distributed through the unit though only locally abundant. There is evidence of some fluvial reworking of the pyroclastics in parts of the unit. Tectonic cleavage of Acadian age is now apparent in some lithologies but it does not obscure original features.

Locality 7 NY 28382 04062 Boundary Lingmoor Fell/ Tilberthwaite Formations

This boundary is normally marked by the presence of a sedimentary breccia which contains fragments of many of the pyroclastics below this contact. At its most distinctive the breccia is dominated by large clasts of highly-welded ignimbrite as seen on Lingmoor Fell. At Locality 7 clasts of accretionary tuff are evident.

From here to the top of Bleaberry Knott (NY 28419 04062) turbidites of the Tilberthwaite Formation (e.g. at NY 28402 04083) show that depositional conditions have significantly changed from subaerial with fluvial reworking to lacustrine. A few metres before the summit cairn is the base of a dolerite sheet which locally is laced with sedimentary stringers showing it to be a peperitic sill.

Locality 8 NY 28541 04119 to 28512 04068 Soft-sedimentary deformation - Tilberthwaite Formation

Supporting evidence for the megabreccia nature of the Side Pike Complex came from the common development of soft-sedimentary deformation. Branney & Kokelaar (1994) inferred the presence of disaggregated chaotic material between megablocks and interpreted the deformation as being the result of competent megablocks driving into less competent ones. They described severe soft-state deformation and at Locality 8 considered it to be an example of “spectacular soft-state deformation”. This zone has soft-sedimentary faulting and metric scale folding, locally producing steep dips, but it is not particularly intense when compared to many of the sedimentary packages in the Borrowdale volcanics. The best example (NY 28682 04301) of this style of deformation is on the descent from Bleaberry Knott.

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