Exploring the Caldew Valley near Hesket Newmarket

Leader: Susan Beale 12 May 2018

The first locality was the bridge at Haltcliff Bridge (NY 368364), from where the route of the upper reaches of the River Caldew can be seen as it flows across the glacial deposits of Mungrisdale Common after leaving the massif of the northern fells. The party then walked from the Bridge to Haltcliff Mill where the main focus of attention was the 5th Limestone, which is here exposed in the river bank. The entrance to Swilly Hole, a two mile long cave network, was pointed out, hidden by vegetation. The river was too deep and fast flowing to allow close examination.This is the beginning of the change in character of the river valley from upland stream and glacial deposit terrain to a river cutting through limestone.

The party then drove to Hesket Newmarket and took the footpath northwards to join the River Caldew. En route the grassed-over spoil tips from a small 18th century coal mine were noted (NY 342387). The river at NY 342391 was dry, having completely lost its flow in the 3km stretch over limestone from Haltcliff Bridge. The party was able to inspect the river bed which here is very fine grained limestone with exposed corals, (Figure 1) and speculate on the palaeoenvironment.



Figure 1 *Siphonodendron ?junceum* from the bed of the River Caldew at NY 344391

Members returned to the path and passed through to the end of the woodland to descend again to the river a few hundred yards downstream where a thickly bedded limestone overlies a more rubbly limestone, the two separated by a thin shale at NY342394. (Figure 2)



Figure 2 Thin shale (in shadow) separating a thickly bedded limestone (above) from a more rubbly limestone (below) NY 342394.

Downstream from this point the river flows in a loop. The party crossed a field to rejoin the river where it has cut into a 40’ sandstone cliff consisting of massive sandstone beds cutting out thinner sandstones, which in turn overlie soft shale, below which limestone forms the (on this day dry) river bed. Some of the beds of thin sandstone were rich in planispirally-coiled gastropods.

Returning to the path to follow the river downstream the party reached the point where the River Caldew and the Cald Beck almost meet (NY341397). At this point members scrambled down the bank of the Caldew to inspect the river cliff which here shows a sequence of limestone overlain by sandstone and then shale, Figure 3.

Some members then elected to walk along the dry river-bed (others took the bankside path through the woods) to a large bend in the river where black shale

is seen to underlie the limestone. The presence of the impervious shale was further indicated by a deep pool on the bend. Although the shale was very crumby some samples of bryozoa (? F*enestella*) were recovered.

The party continued downstream to Riversmeet,(NY 343399) the confluence of the Cald Beck and the River Caldew. The Cald Beck which flows over impervious sediments, including glacial deposit, was flowing well whereas the River Caldew was a series of pools separated by dry river bed.

Following the Cald Beck upstream where it cuts through a limestone gorge, (Figure 4) and then across fields the party made their way to Caldbeck village from whence they were ferried back to Hesket Newmarket. En route it was observed that a sandstone outcropped in the banks of the Cald Beck. This may be the Hensingham Grit which is mapped as being down faulted here. Near the village the Beck was once more flowing through limestone and the outlines of the brachiopod *Productus sp.* was noted in the limestone under the footbridge by Caldbeck church (NY 326399) .

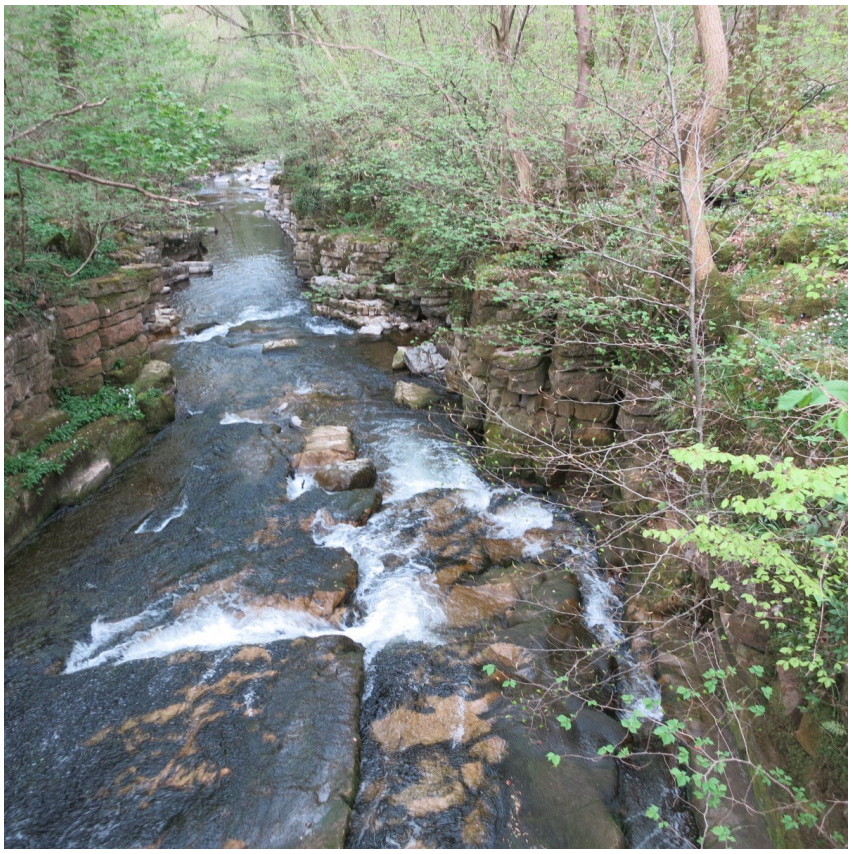


Figure 4 The Cald Beck flowing through a limestone gorge. View from the footbridge at NY 341398 looking downstream.



Figure 3 Section of bank of River Caldew at (NY 341397) (Light patches are sunlight)

Hidden Wonders of Iron Slag

Leader: Clive Boulter 9 June 2018

A small intrepid band of members headed north from Harrington Harbour in conditions that had one member wishing she had brought her swimming costume. The topic for the day was the physical volcanology of the slag from iron working. Studying slag has provided invaluable information for our understanding of some volcanological systems and around the coast of Cumbria we still have many opportunities to examine this style of effusive activity though remedial operations have meant some classic sites have been lost.

Iron oxide is reduced in a blast furnace to metallic iron. The furnace is charged with iron ore and coke, together with limestone as a flux to reduce the melting temperature. All of these are impure. Even the purest limestone has a few weight percent of impurities such as quartz, iron oxides, micas, and other minerals. Similarly rock forming minerals are present in iron ore. In the blast furnace the molten iron sinks to the bottom, and the impurities float, forming a silicate liquid which is equivalent to a natural magma but very different in composition. Most slag magmas are more akin to carbonatites than any calc-alkaline magma but there are interesting variants including Fe-rich compositions with komatiitic (spinifex) textures.



Figure 1 A large cavity in a pudding – lava stalactites hang vertically from the roof.

Locality 1 NX 98743 25915 Pipe vesicles & lava dribbles

The slag that formed this large block (skull/pudding) was poured into a railway-mounted ladle and held until it was almost all solidified before tipping. Intact tipped blocks of slag are known as puddings in south Cumbria and skulls in the north. The top surface of the skull has a ropy pahoehoe surface structure (similar to Figure 2, Locality 3) indicative of a very fluidal, low viscosity, flow of liquid slag. The outer surface of the flow becomes chilled and solid but, in the case of pahoehoe, the crust is initially thin and flexible, deforming into wrinkles when it is impeded whilst the lava beneath is still moving. The uncertainty here is when did the pahoehoe form? Was it formed whilst appreciable amounts of liquid slag were present or does it represent small amounts of still-molten slag that escaped at the time of tipping – a dribble? Dribbles are very common in slag deposits on the Cumbrian coast.

Loose blocks of slag with pipe vesicles are found at this locality, immediately seaward of the skull block, at the head of the beach. In nature pipe vesicles are found perpendicular to the margins of a variety of features including lava flows and pillows.

Locality 2 Traverse from NX 98707 26060 to NX 98708 26132

Here an old railway embankment has been constructed from tipped slag. In early iron working operations only manually charged blast furnaces were used which, because of their lower temperatures, produced viscous slag that could be transported by rail in slag boxes sealed to waggon bogies by fireclay. At the slag tip, the box sides were lifted off and the solid block of slag could be tipped. Box shape evolved from octagonal through rectangular to circular and this is reflected in the morphology of the tipped material. Clearly the aim was not to have too much liquid in the box at the time of tipping. The nature of the slag deposits reflects varying lengths of cooling. Advanced cooling led to abundant fractures because the slag contracted as it cooled; such materials would break into many small pieces when tipped. Shorter cooling periods with less pervasive fracturing left intact blocks (puddings/skulls).



Figure 2 Twisted ropy pahoehoe (20p coin for scale) at Locality 3.

Several puddings containing liquid appear to have cracked open a bit on tipping and not moved further since they were tipped. The evidence for this interpretation is preserved as vertically-hanging lava stalactites, from residual liquid in the puddings, on the roofs of the cavities . Up to 3 similar cavities are seen in a stacked sequence at the top of many large pahoehoe lava flows and they were crucial in the realisation that these enormous flows were emplaced by inflation (the SWELL hypothesis, Self et al. (1998)).

Judging by the size of the cavity shown in Figure 1, this pudding seems to have arrived at the tip with quite a bit of liquid present. The cavity has a surround of vesicles and the present-day top has lava stalactites formed as the last of the liquid drained. The movement of vesicles will have been arrested at the inward-migrating solidification front and the relationships seen in various complete puddings indicate complex cooling patterns. Many puddings/ skulls were formed by discrete slag pouring events at variable time intervals. Some patterns in individual "flow" events are simple and mimic what you see in lava flows but others are much more complex.

Locality 3 NX 98749 26320

A fine example of twisted ropy pahoehoe is found at this locality though the most impressive examples in Cumbria are to be found at the end of Askam Pier, in south Cumbria where there are flow fields of pahoehoe lava.

At Askam Pier it would appear that most of the slag ladles were delivered to the tipping location either totally molten or with very little solid. The pier was built up by multiple thin flows rarely thicker than ten cm. Rather than the sectional views provided by the main slag tip at Workington, Askam allows you to walk over the tops of sheets of lava poured onto nearly horizontal surfaces (Figure 3).

Discovered on the Day

Spinifex texture (bladed olivine crystals) is common at Workington. This texture has rarely formed in nature since the Archaean where it is the defining characteristic of komatiitic lava flows. In komatiites the equivalent crystals are Mg-olivine but in the slag environment they are Fe-olivine. Walking north from Locality 2 the natural line is along the sandy strip of beach between the tipped slag and the head of the beach. On the seaward side of this strip, about 25m south of Locality 3, an excellent



Figure 3 Twisted ropy pahoehoe at the end of Askam Pier as part of a pahoehoe flow field.

block of spinifex-textured slag can be seen. Bladed spinifex is well developed and random spinifex (Figure 4) is exposed in 3D (possibly grown into a cavity).

At NX 98727 26289 there is a fine example of spinifex texture but this can be covered by sand following storms. If this has happened there is plenty of the same feature to be seen from NX 98715 26575 to NX 98661 26847.

Locality 4 NX 98756 26533 Volcanic Glass

Volcanic glass is scattered all along the excursion route but this pudding gives us the chance to see the original setting that produced this chilled/quenched magma. Within lava flows cooling rates are typically around one degree Celsius per hour whereas quenching involves rates 100s to 1000s times more rapid. Slag box material commonly has glass around the pudding margins whilst in the skulls glass is mainly from the portion in contact with the ladle base. Conchoidal fracturing, which is very characteristic of volcanic glass, is a striking feature at this locality. Some surgeons consider this fracture style produces a cutting edge better than steel! Some glass seen on the traverse has a greenish tinge probably from traces of other elements.

Locality 5 NX 98729 26664 Thin pahoehoe lava flows (you need a hard hat to examine this locality safely)

Very thin lava flows form most of the slag tip, as seen in Figure 6 below. Many of the flows are around 5 to 10 cm thick and have two to three internal subdivisions. The white components have pahoehoe structures on their upper surfaces which means they represent the top of these flows. Because the cliff face presents lava sections, the pahoehoe top surfaces are rarely exposed but some steps in the weathered face give limited opportunities to examine the ropy structure.

Many of the lava flows have a glassy bottom layer and a white upper layer. Some flows have a three-fold structure with a rusty (Fe-rich) layer in between the white and glassy parts.

There is a pronounced topography on the white tops of some flows which may have been hornitos/driblet spires where a weakness in the lava crust allows magma and volatiles to escape. Small fingers of the



Figure 4 Random spinifex texture showing bladed olivine crystals (25 m south of Locality 3).

brown component of some flows penetrate upwards into the white pahoehoe part showing the linkage in time between the two.

A Miscellany of Features to Look Out For Along the Traverse

If iron is tapped along with the slag, its density means it will sink to the bottom of the box/ladle and this provides a way-up criterion for puddings/skulls with iron in them that have tumbled down a slag bank and partially broke up. If tapping was done at discrete intervals the patterns may be complex.

The relationship between the margins of rock fragments and cooling joints provides crucial volcanological information. Some cracked open skulls from Workington have a good radial pattern of cooling joints mimicking patterns seen in lava balls detached from lava flows that broke open on coming to rest (e.g. Teide's Eggs on Tenerife). Similar patterns in pyroclasts in low-temperature ignimbrites (prismatic jointed blocks) identify fragments of the magma responsible for the explosive behaviour. Delicate blisters approximately one centimetre in size are preserved on some surfaces.



Figure 5 At 22 cm these are the longest bladed olivine crystals of spinifex textured slag seen at Workington. It is probable that this sample is often covered in sand (20p coin for scale).

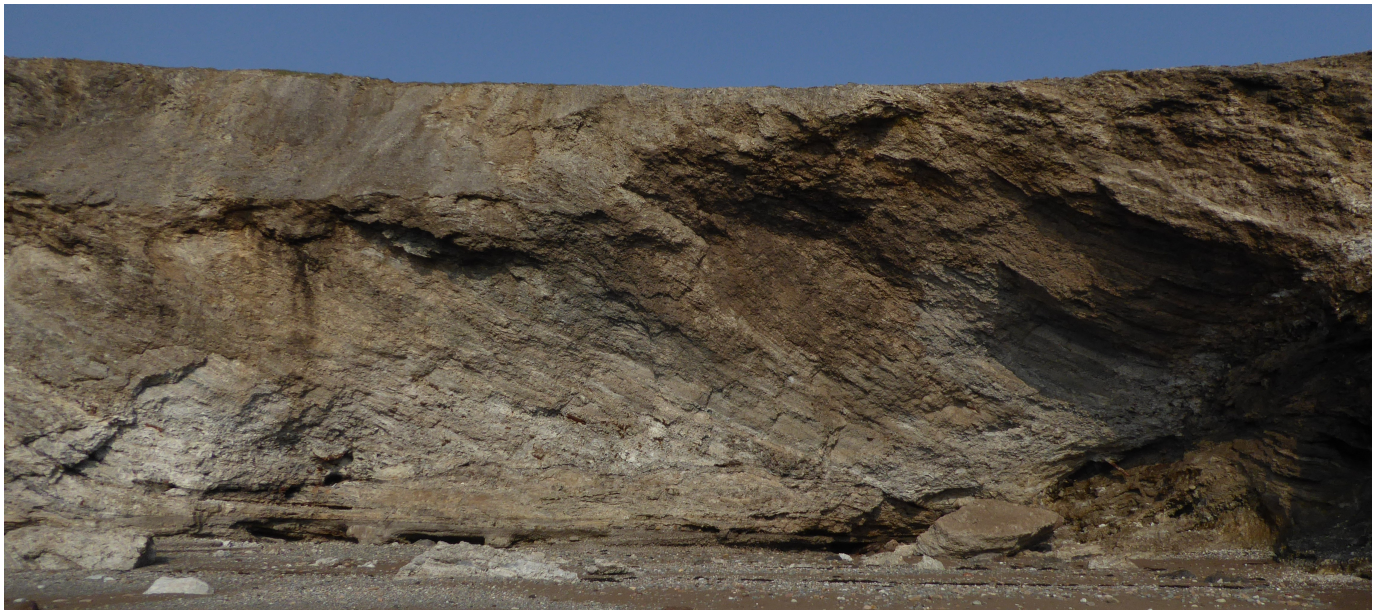


Figure 6 Cross-stratification created by multiple thin pahoehoe lavas from tipped slag. Cliff height approx. 10 metres.

References:

Self, S., Keszthelyi, L., and Thordarson, Th. (1998) The Importance of Pahoehoe, *Annual Reviews of Earth and Planetary Science,* vol. 26, 81-110.

The Geological Landscape around Low Rigg

Leader: John Rodgers 20 June 2018

This was an evening meeting during which members were asked to consider the geological and environmental features that could be observed on a walk across Low Rigg, and whether it would be worth producing an explanatory pamphlet for visitors to the area.



The Low Rigg microgranite intrusion with the Caldbeck Fells behind, viewed from the north end of High Rigg

The group of 15 met at the road junction on the minor road south of the A66 at NY 305 240 (a safe place to leave several vehicles). We then took the lane to the marked path which traverses south across Low Rigg towards the Youth Residential Centre. Low Rigg is an elongate dome of about 1 km ² composed of Threlkeld microgranite and separated from the main laccolith to the east by St.John's in the Vale. This is a fault-line valley formed by erosion along the major structure of the Coniston Fault that extends in a N-S direction right through the central Lake District. The fault line to the north appears to stop at around the A66 but it was suggested that the deeply eroded valley of Glenderaterra Beck, between Lonscale Fell and Blencathra may be a continuation that has been offset several hundred metres to the west by sinistral strike-slip displacement along the Causey Pike Fault.

From a vantage point near a small disused quarry the view to the north is dominated by the south face of Blencathra with the faceted slopes of Gategill, Hall's and Doddick Fells separated by deeply-incised V-shaped valleys. There was discussion as to whether these triangular faces represent truncated spurs of

Blencathra, sliced off by great easterly moving glacier (s) that originated from a central Lakeland icecap. Looking to the east, the twin rounded hills of Great and Little Mell Fell are erosional remnants of Mell Fell Conglomerate, laid down as thick gravels washed down from the much higher mountains that formed some 400m.y. ago. Immediately to the east is the dome-like mass of Threlkeld Knotts, which is now recognised as a massive landslip from the rock slope failure on the north face of Clough Head. The northern part of the Knotts is composed of microgranite and has been extensively quarried around the lower margins of the intrusion, mainly for aggregate, but some of the local buildings consist of dressed stone which tends to weather to a pale pink on exposed surfaces. (A more detailed account of Threlkeld Knotts appears in a later field trip report from July 2019).

The relatively low-lying ground surrounding the two microgranite outcrops is underlain by dark cleaved mudstones of the Skiddaw Group. However, to the south there is an obvious increase in slope gradient as the basal boundary of the Borrowdale Volcanic Group is crossed and Low Rigg gives way to the ridge of High Rigg. The eastern side of the latter clearly displays stepped (trap) topography in the form of interbedded tuffs and andesite lavas (although some of the layers may be sills).

Other notable landscape features visible from Low Rigg and worthy of discussion are the landslips on the south side of Latrigg to the north-west, an indication of the potential instability of the fellside slope above the River Greta. It was also pointed out that the elevation of the Caldbeck Fells massif to the north, mainly composed of more easily eroded Skiddaw Group, is probably due to the presence of underlying Skiddaw Granite.

A final discussion resulted in general agreement that there was much of geological interest to be seen from the Low Rigg location, but any pamphlet or guide would need illustration with diagrams, pictures and a map and would involve a significant amount of time being spent on its production.

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

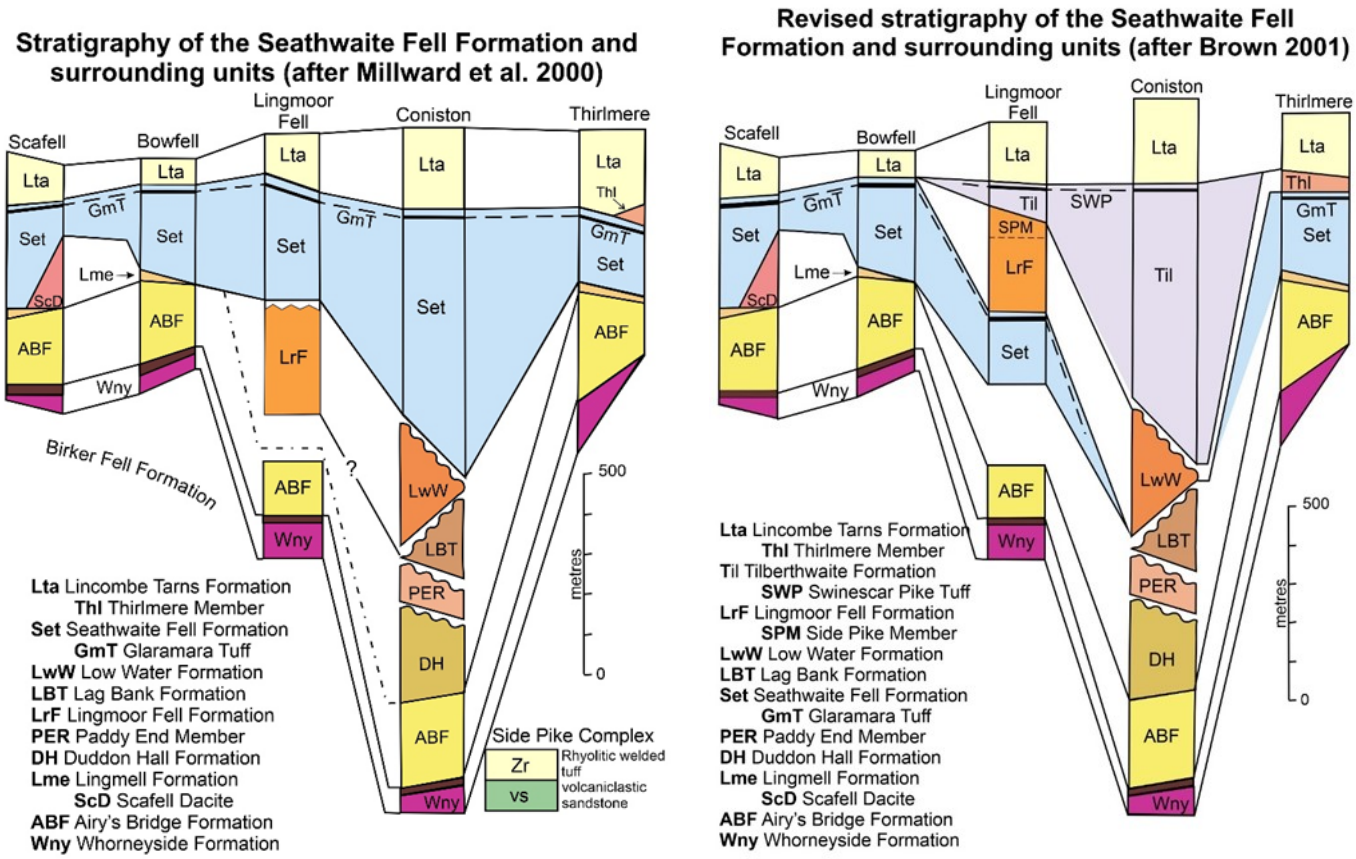


Figure 1 Comparison made by Brown (2001) of the correlations proposed in the Ambleside Memoir (Millward *et al*. 2000) and those made after recognition of Airy's Bridge Formation elements in the Side Pike Complex. The latter has been modified to remove some stratigraphic correlations that have not been 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.

References.

Boulter, C.A., Haselden, D., & Woodward, B., (2020). A Buried Caldera-Collapse Topography, Scafell Caldera, Former Side Pike Complex, Borrowdale Volcanic Group. *The Cumberland Geologist*, No 1, 2-8.

Branney, M. J., (1988). Subaerial explosive volcanism, intrusion, sedimentation, and collapse, in the Borrowdale Volcanic Group, SW Langdale, English Lake District. *PhD Thesis, University of Sheffield.*

Branney, M. J., & Kokelaar, B. P. (1994). Volcanotectonic faulting, soft-state deformation, and rheomorphism of tuffs, during development of a piecemeal caldera, English Lake District. *Geological Society of America Bulletin*, vol. 106, 507-530.

British Geological Survey, (1996). Ambleside. England and Wales Sheet 38. 1:50,000. *British Geological Survey,* Keyworth, Nottingham.

Brown, R. J. (2001). Eruption History and Depositional Processes of the Poris Ignimbrite of Tenerife and the Glaramara Tuff of the English Lake District. *PhD Thesis, University of Leicester*. (https://lra.le.ac.uk/handle/2381/7825).

Brown, R. J., Kokelaar, B. P., & Branney, M. J. (2007). Widespread transport of pyroclastic density currents from a large silicic tuff ring: the Glaramara tuff, Scafell caldera, English Lake District, UK. *Sedimentology*, vol. 54, 1163–1189.

Millward, D., et al. (2000) Geology of the Ambleside district. *Memoir of the British Geological Survey, England and Wales, Sheet 38.*

Millward, D. (2004). The Caradoc volcanoes of the English Lake District. *Proceedings of the Yorkshire Geological Society*, vol. 55, 73-105.

Glaciation of Borrowdale

Leader: Prof Mike Hambrey 21 July 2018

We met outside Rosthwaite Village Hall where the background to the Lake District glaciation was explained. The peak of the glaciation was some 30,000 years ago when the Lake District had its own ice cap within the overall ice sheet. In the following 15,000 years the glaciers exploited the previous radial drainage system, steepening the sides and forming basins which later became lakes. The ice probably all disappeared before returning briefly at the valley-heads around 12,000 years ago. Rosthwaite village sits on a roche moutonnée, called The How (NY 258146). Nearby are 3 ridges of glacial debris which are the end-moraines of a glacier entering Borrowdale from Stonethwaite and Langstrath. The flat plain to the north represents the floor of a lake (Figure 1).

On the way to the River Derwent we examined the Rosthwaite Moraines which, according to inconsistent dating, seem to be over 15,000 years old. We noted that the stone walls were composed of subrounded boulders that had been transported at the base of the glacier (Figure 2).

On a bend in the river (NY 254140), on the way to Seatoller, the river has eroded the outermost of the three Rosthwaite moraines to reveal a poorly sorted texture typical of a deposit from basal glacier ice (Figure 3).

Nearby are potholes produced by the turbulent glacier melt water. Potholes are a common feature in subglacial channels where the water is under pressure.

After walking up the hillside above Seatoller to Little Gatescarthdale (NY 232137) the effects of the glacial deposition during the Younger Dryas were pointed out. It is thought that the landforms represent ‘dynamic retreat’ i.e. that the ice was still flowing forward and dropping material. This is similar to the processes observed in Svalbard in the Norwegian Arctic, where low-angle fractures in the glacier bring



Figure 1. Borrowdale viewed from King’s How. The route of our excursion traversed the hillside on the right. Off the picture to the left is the Stonethwaite valley; its glacier produced the moraines at Rosthwaite, which is mid-left on the valley floor. Beyond is Glaramara and the hanging valley of Coombe Gill. Further to the right Scafell Pike is visible in the background, below which is Seathwaite at the head of Borrowdale. Great Gable is the rounded summit mid-right. Little Gatesgarthdale is “round the corner” to the right.



Figure 2. Subrounded glacial boulders in a wall in front of a Rosthwaite moraine

debris to the surface before being deposited. The resulting landforms are push- or thrust-moraines.

Then we took the high-level path on the west side of Borrowdale towards Castle Crag.

Diamicton (NY 243154), which by definition is a sediment with a wide range of clast shapes and sizes, was observed at the side of the path. It was discussed that to establish the process of deposition the grain size, the percentages of silt-plus-clay, sand and of gravel needed to be considered, together with the character of bedding, clast shape and orientation of the long axis of clasts (Figure 4). The attributes at this locality allowed us to interpret that this was a basal glacial sediment (or more strictly a "subglacial traction till").

We then looked at the bigger picture to where we were in the morning. The flat area was a proglacial lake dammed by a moraine by the Jaws of Borrowdale (Castle Crag and King's How). The notch to the west of Castle Crag may have been an outlet for the meltwater (Figure 5).



Figure 3. Basal glacial debris in Rosthwaite moraine. (above)



Figure 4. Discussing the origin of diamicton, and interpreting it as of subglacial origin. (left)



Figure 5. Walking towards Castle Crag, with King's How centre-right, and with Jaws of Borrowdale between, and notch to left of Castle Crag.

On the path there were grooves and striations on glacier-smoothed rock outcrops and 'p' forms i.e. plastically moulded depressions formed by high pressure meltwaters.

Half-way up Castle Crag (NY 250159) we stopped and looked towards Borrowdale to note that the volcanic rocks upstream of the glacier looked 'plucked' whereas if we looked downstream they would look smooth and abraded – representing distinct forms of glacial erosion.

From the top of Castle Crag (NY 249159) there is a good view across Derwentwater to Skiddaw and Blencathra (Figure 6). Derwentwater is in a rock basin scoured out by a glacier, with Skiddaw Group to the west and Borrowdale Volcanic Group to the east, while a strike-slip fault occurs down the east side. There are several smooth mounds and islands in the lake near Keswick, which are all drumlins

We then continued to Grange (NY 253175) to examine the roche moutonnée under the bridge which also showed glacial striations and 'p' forms. Mike was thanked for a fascinating walk.



Figure 6. Looking north from Castle Crag across Derwentwater to Skiddaw and Blencathra.

Leader: John Rodgers 4 August 2018

The valley of Scordale is deeply incised into the southwest facing Pennine escarpment and has a long history of lead mining. The aim of this excursion was to walk up the track beside Scordale Beck as far as the old levels, taking advantage of one of the few non-firing days on the MOD Ranges in this area, and to observe the geological features of the valley sides, the traces of mining activity and an outcrop of the Whin Sill. A bonus at the far end of Scordale was the opportunity to collect samples of yellow fluorite which is relatively rare outside this area.

A group of 21 met on the track just beyond Hilton village Town Head (NY 736 208) and took the bridleway on the southeast side of the beck. The first kilometre is underlain by the Lower Palaeozoic rocks that are part of the southern extremity of the Cross Fell Inlier, upthrown by movements along the complex Pennine Fault system. There was little evidence on the surface of these formations and much of the valley bottom is covered by “made ground” largely resulting from scree and landslips. However, the upper valley sides had excellent exposures of Lower Carboniferous Melmerby Scar Limestone Formation, forming near horizontal beds with characteristic vertical jointing. Erosion and rockfall have produced isolated pillars and tower-like structures, particularly on the north-west side.

A brief description of the mining activity was given en-route, and locations of former processing buildings were pointed out, including crushing and smelting plants. A noteworthy feature of the landscape are the hushes – erosion channels down the valley sides that were created after release of dammed water, the aim being to expose any underlying mineral veins. An infamous example of this is Lowfield Hush (named on the 1:25000 OS sheet), best seen from the point NY 755 216 which allows a view up the channel that cuts diagonally across the lower slope of the main valley. The practice of hushing led to significant pollution of the streams and rivers in the drainage basin and it is believed that an extraordinarily large one from Lowfield Hush led to the practice being outlawed in 1811. In the decades that followed the London Lead Co. operated the mines and invested in the local community around Hilton, creating a clean water supply and building a school. However, by the late 1870s the price of lead had dropped dramatically and mining ceased for a number of years. Activity resumed around the end of the century, but now it was barytes and witherite (valuable sources of barium) that were extracted. This continued intermittently in the early 1900s. In 1963 the remaining buildings were demolished and all but one of the adits were closed off by the MOD.

The party arrived at the end of the track and this made a good stop for lunch after which members were given time to explore the immediate area. A determined search in the stream bed led to numerous samples of cubic crystals of yellow fluorite. It was explained that fluorite and the barium minerals commonly accompany the lead mineral galena but tend to occur separately having been precipitated from hydrothermal solutions at different temperatures.

Most of the members were able to scramble up to the waterfall a little further up the valley, where an outcrop of the Whin Sill provided the resistant band. Samples extracted from the upper surface clearly showed a very fine grain size which contrasted with the coarser dolerite a couple of metres below, and thus demonstrating the chilled margin effect. Thankfully, the weather remained sunny and dry for the return walk down the valley, finishing around 3.30pm.



CGS members exploring the outcrops of the Whin Sill at the upper end of Scordale. (The main exposure is left of centre).

Leader: Sylvia Woodhead 5 September 2018

Members and visitors met in Sandwith village (NX 965 147), and shared cars for the drive up the private road to park outside Birkhams quarry on St Bees Head (NX 955 164). The area is geologically important; the quarry, headland and beach cliffs form a Site of Special Scientific Interest (St Bees Head SSSI), and there are 5 Geological Conservation Review sites (GCR). St Bees Head is composed of the St Bees Sandstone Formation, the lower formation of the Sherwood Sandstone Group. To the north lie the Carboniferous rocks of the former West Cumbria coalfield.

Birkhams Quarry and St Bees Head have been visited many times in the past by CGS members, and excursion reports have appeared in all three CGS Excursion Guides, in 1982 and 1992 by Tom Shipp & in 2008 by David Kelly.

The Quarry was designated a Local Geological site (LGS 4_030) in 1994, because it exhibits a wide range of sedimentary structures; parallel lamination, planar and trough bedding, and leached layers in the St Bees Sandstone. This was deposited by a large ephemeral river, the Budleighensis River, which flowed north, in braided channels over a desert area. The sandstone layers are often thickly bedded and sparsely jointed, with erosive bases indicated by rip-up mud clasts. Further examples of ripple marks and other sedimentary structures may be seen in the loose blocks. There was much discussion on the origin of the bleached layers.

Sylvia explained that Cumbria GeoConservation (CGC) had become involved with the quarry in 2015, when responding to a Cumbria County Council (CCC) planning application to extend quarrying until 2030. CGC had suggested some planning constraints; geological interpretation, access to rock faces, and visits for geologists, all of which have been adopted. Two interpretation boards have been designed, the one covering geology by Dr Elizabeth Pickett, in consultation with Marshall Stancliffe (MS), the quarry owners, agents Stephenson Halliday, CCC and the National Trust. CGC now attends the annual quarry monitoring meeting. Each information board is mounted on stone blocks from the quarry, which were chosen by CGC and transported to Locharbriggs quarry near Dumfries to have an angled face cut. The mounted boards were 'unveiled' in 2016 by Mervyn Dodd, who had drawn up the original LGS designation. The boards are now seen by the thousands of walkers who pass along the Coast to Coast path each year.



Working quarry face Birkhams Quarry

After examining the interpretation boards and finding examples of the sedimentary structures mentioned, members entered the quarry, where they were welcomed by Steve Boam, quarry manager. Steve explained that the quarry had been worked for many years, and is now operated by MS. It is worked in winter only, from September to March to reduce disturbance to nesting peregrines and the C2C walkers. The stone is now extracted on a contract basis when required. Steve explained that the stone, a finite resource, provides high quality (and expensive) building stone. A 12 tonne block would sell for over £1000. It is extracted carefully to reduce wastage. The current working area has very thickly bedded uniform sandstone, which is much sought after. It is extracted using the natural joints, though thicker beds need to be drilled and loosened using black powder. The leached layers help ease out the blocks. MS now concentrate on providing good high quality building stone for specific projects. Recent projects have been in Rotherham, Chester bus station and Monmouth School extension. Further quarry visits can be organised on request to MS. Members thanked Steve



Ripple marks in Birkhams Quarry

Boam for a most interesting visit and applauded the vision to utilise the stone in the best possible way.

St Bees

Members now transferred to St Bees beach, taking lunch on the rocks below St Bees Head, where further sedimentary structures could be seen in the St Bees Sandstone. After lunch, the layers of glacial drift resting directly on the sandstone bedrock were examined. The LGS designation (LGS 4_009) identified two tills formed in glacial re-advances. The Lowca Till Member, a well consolidated coarse lodgement till with locally derived clasts suggesting a northerly derivation, is identified as Late Devensian and occurs at the foot of St Bees Head. This is separated by contorted outwash sands and gravels (St Bees Sand and Gravel Member), thought to be the product of high energy meltwater flow. An overlying fine grained till (St Bees Till Member) is almost pebble-free sand and silt grade with marine fossils, identified as the Gosforth Oscillation.

The afternoon visit was to the golf course cliffs (NX 954 118 to NX 969 107), also an SSSI, GCR site and LGS 4_009, for their importance in interpreting late Devensian glacial events, and late glacial environmental conditions. The cliffs are a key site for showing evidence of the Windermere interstadial and Loch Lomond stadial events. They have been variously interpreted at different times, and have been the subject of some recent research (Lee & Phillips 2013).

During the last Ice Age the St Bees area was glaciated by radial ice from the Lake District (Ennerdale) and by unstable, surging and fast moving Irish Sea ice, from the Solway. To the north the 'St Bees valley', a former lake now peat filled, is blocked by glacial deposits. The St Bees 'golf course'cliff section has been identified as a push moraine, with folded and faulted glacifluvial and glacigenic sediments thrust to the south west as a thick ice wedge. The folds are very clearly displayed in the St Bees Sand and Gravel Member (Williams et al 2001).

In the low cliffs at the south end of the Promenade (NX 962 116) folding and deformation of the St Bees Sand and Gravel Member are clearly seen. Williams et al estimate a 22% shortening of the sediments due to glacitectonics. Deformation occurs as the ice overrides or pushes into pre-existing sediments. This deformation is recognised as being similar in nature, though much smaller in scale, to thrust belts in continental collision, producing thrust structures and nappes. Evidence for an upwardly displaced ice wedge could be seen in these small cliffs. Lee & Phillips (2013) note that these deformation structures exert a dominant control on the development and style of landslide.

A large BVG erratic at NX 962 117 was examined & found to be a peperite. Erratic pebbles possibly originating from Criffel were identified. The high till



Sylvia and Fred at St Bees looking at the folding and deformation



Glaciotectonics St Bees

cliffs were examined for evidence of ice wedge deformation. There was much discussion about conditions at the end of the Ice Age, and how the ice pushed and distorted the previous glacial deposits which it overrode.

A search on the lower beach for the submerged forest was unsuccessful on this occasion. During a Westmorland Geological Society visit on 11 September 2019, the submerged forest was found to be exposed opposite the southern end of the promenade among boulders at the shingle-sand boundary (NX 961 117). A soft layer of dark peat about 15 cms thick was exposed. Clear tree roots could be seen, which might have been pine, and possibly the boles of large trees. The forest has been dated as 8-9000 years old, i.e. during the Boreal Zone. This showed that the coastline was once much further out, and that the area now St Bees Bay was dry land where forests grew, and people may have settled. As the climate changed these were flooded as the sea level rose in the Flandrian marine transgression. Members walked back along the beach, re-assessing the structures revealed in the cliffs.

References

Britice Map v2.0 (2017)

Lee, J.R. & Phillips, E.P. (2013) Glacitectonics- a key approach to examining ice dynamics, substrate rheology and ice-bed coupling *Proceedings of the Geologists Association* 124 731-737

Kelly, D. (2008) St Bees, in Beale, S & Dodd M (eds) *Exploring Lakeland: Rocks and Landscapes* The Cumberland Geological Society 110-117

Shipp, T. (1992) The Permo-Trias of St Bees Headland in Dodd, M (ed) *Lakeland Rocks and Landscape: a Field Guide* Cumberland Geological Society 62-68

Shipp, T. (1982) St Bees Headland in *The Lake District Cumberland Geological Society* 86-92

Stone P et al (2010) *Northern England, British Regional Geology* British Geological Survey

Williams, D. P. J. Brabham, G. P. Eaton and Harris C. (2001). Late Devensian glaciotectonic deformation at St Bees, Cumbria: a critical wedge model*, Journal of the Geological Society*, 158, 125-135, 1 January 2001

Harter Fell, Dunnerdale.

Leader: Clive Boulter 18 May 2019

This excursion is an adaptation of Itinerary 11 by Millward in the Geologists' Association Guide (1990). It is entirely within the Birker Fell Formation which dominates the lowermost part of the Borrowdale Volcanic Group. The unit is up to 2700 m thick and about 60% is andesite lava flows (including sills) but it also contains basalt, basaltic andesite, and dacite lava flows as well as pyroclastics (ignimbrites and airfall tuff) and reworked material (fluviatile and lacustrine). This assemblage formed a low-profile plateau volcanic field mainly fed by fissure eruptions. The andesite lava flows are normally tens of metres thick but individual flows can be 200 m. Most flows can be traced for no more than five kilometres. The typical flow has blocky autobrecciated margins and on the upper flow surface the cavities between fragments became infilled with sediment either washed in as reworked pyroclastics or settled in from air-fall pyroclastic events. An overall extensional tectonic setting is the only way such a thick pile of subaerial volcanic material can accumulate and be preserved. Convergent tectonics, such as subduction at a continental margin, readily provide such opportunities as most arc systems are in tension (slab roll-back).

The focus for the field meeting is two prominent felsic marker horizons within this otherwise monotonous pile of andesites and derived materials. Locally in contact but otherwise separated by a few tens of metres of bedded volcaniclastics, the Little Stand Tuff Member (LST) and the Great Whinscale Dacite Member (GWD) can be traced laterally for 16 and 13 km respectively. The LST is a rhyodacite ignimbrite and in almost every exposure it is readily identified by the presence of lithophysae which are spherulites that have a central vug. As is the case for spherulites, lithophysae are characteristic of high-temperature devitrification of coherent silicic glass and are found in formerly glassy lavas and welded pyroclastic deposits. They begin to grow at an early stage in the cooling history, when the hot glass is still able to deform plastically and involve nucleation of spherulites on small vesicles. As spherulitic crystallization proceeds, the vesicles are expanded by the exsolving volatiles. The vugs vary from circular to star shaped and may remain open, or be lined, or filled with minerals such as agate or chalcedony. Lithophysae range up to larger diameters than spherulites, reaching a few tens of centimetres across (McPhie et al., 1993).

Locality 1 Brandy Crag SD 2256 9893 (eastern end).

The upper autobrecciated couple of metres of the andesite lava flow has cavities between clasts infilled with white-weathering airfall tuff/reworked tuff. Above and below the LST there is well-bedded probably water-lain volcaniclastics. The characteristic nodular nature (lithophysae) of the LST is not very

Locality 1 Brandy Crag – marker horizons within the Birker Fell Formation [photo taken from SD 22490 98812]



Great Whinscale Dacite – dacitic lava erupted at high temperatures.

Between the GWD and the LST is an andesitic, bedded mixture of pyroclastics and fluvial reworked pyroclastics.

Andesite lava flow – the upper couple of metres is autobrecciated, cavities between clasts infilled with airfall tuff/reworked tuff.

prominent here. Also the flattened pumice fabric is weak and not very evident. Both these features can be clearly seen near the summit of Harter Fell.

There is an andesitic ignimbrite a few metres above the LST. It is a very distinctive unit because it contains large fiammé around 10 cm long and the whole unit is a little over three metres thick.

The base of the GWD is at a colour contrast – lighter GWD above (felsic) and darker unit below (andesitic). The basal couple of metres of the GWD is autobrecciated and above that it is flow banded. The bulk of the GWD is flow jointed and the upper few metres can be amygdaloidal. Isoclinal folds of flow-banding are seen in the lower part of the GWD above the lowermost autobrecciated zone. Many of the clasts in this breccia have disrupted flow banding or flow folds.

Locality 2 Fault with slickenlines and slickenside SD 22542 99203

The exposed fault in this gully dips 58^{o} towards the SE and strikes 226-046^{o}. The slickenlines plunge 52^{o} → 098 (pitch 68^{o} from 046 on the fault surface). The sense of movement cannot be securely determined. This exposed minor fault is not along the gully and the fault that controls this topographic feature is not exposed though there is plenty of vein quartz in the scree including some moderate sized blocks.

Locality 3A Autobrecciated base of the GWD SD 21956 99823.

This locality allows more comfortable examination of the basal autobrecciated zone in the GWD than is possible at Brandy Crag. The blocks are typically 15 – 20 cm in diameter and the contact with the underlying bedded volcaniclastics is clearly visible.

If you peer over the top of this mini crag you will see, very close by, a small rectangular tarn which is a key geographical reference point. Just a few metres west of locality 3A, towards the small tarn, is a good eexample of fluviatile reworking of primary pyroclastics. Very rarely on Harter Fell is there



Figure 2 Locality 3A – basal autobrecciated zone of the GWD.

e

evidence for deposition in lakes (grading and elutriation channels) but there are examples around Locality 3.

In the general area above the rectangular tarn there are good exposures of GWD. Both the GWD and the LST are distinctive in their own right. Together they make an excellent marker horizon in the Birker Fell Formation in what would otherwise be a sequence perhaps overwhelmed by correlation challenges. These two units are found approx. 1200 metres above the base of the formation. Unusually laterally extensive, the GWD can be mapped over a distance of 13 km. Such a viscous magma can only flow so readily if it was erupted at high temperatures. The bulk of the GWD is typified by the prominent flow joints (Figure 3) which are so distinctive they can be recognised in well-travelled erratics.



Figure 3 Strongly developed flow-joints in GWD

Locality 3B Little Stand Tuff SD 21880 99869.

A complete section through this unit is easily accessible here highlighting the unit's distinctive nodular appearance. Also present is the weak eutaxitic fabric (alignment of flattened pumice fragments) that prove the ignimbritic origins of the unit. The in-situ crag exposure shows the overall distribution of lithophysae (mostly 4 to 6 cm).

The in-situ exposure is north facing, damp, and has an organic coating. Better opportunities to examine lithophysae in detail are provided by joint faces on fallen blocks. On a fresh surface the 4-6 cm nodules weather positively whereas on joints, sectional views are seen.

Locality 3C Impact sag SD 21837 99857

For the bedded units between lava flows, and for the obvious pyroclastics, it can be quite a challenge to determine how they were deposited. In this fallen block it is clear that a rectangular pyroclast approx. 16 cm long has impacted stratified airfall deposits. The clast is picked out in faint green by selective epidotisation.



Figure 4 Lithophysae (~4 cm diameter) at Locality 3B in the Little Stand Tuff showing trilete central vugs.



Figure 5 Folded flow-banding in an andesite lava flow (field of view ~3 m).

Locality 4 Isoclinally folded flow-banding in andesite lava flow, Birker Fell Formation. SD 21733 99619.

The layering known as flow banding can result from just a few percent variations in the amount of tiny crystals (microlites) and/or tiny vesicles. During magma ascent, and whilst it flows over the Earth's surface, repeated episodes of fracturing, healing, and attenuation in the flow stretch out pockets of different texture to create banding. Flow banding was once thought to be created by segregation of phenocrysts and microlites during magma flow. On close inspection the bands are seen to have ragged margins. Flow banding is normally weakly defined but can be emphasised by weathering to be nearly as well developed as bedding in sedimentary rocks.

Close to Locality 4 at SD 21727 99666 a thin layer (<20 cm) of small accretionary lapilli (smooth areas) overlies autobreccia at the top of the flow-banded GWD (also amygdaloidal).

Locality 5 Harter Fell Summit SD 21850 99726

The summit consists of an autobrecciated top to an andesite lava flow with laminated sediment infilling cavities between blocks. By tracing such horizons the British Geological Survey has mapped several lava flows around the summit (see GA Guide, 1990).

As ever, careful observations are required to be sure that an effusive origin has been determined rather than an intrusive peperitic contact.

References:

G A Guide (1990) Geologists' Association Guide, Geology of the Lake District 1990.

McPhie et al. (1993). Volcanic Textures, *University of Tasmania, Centre for Ore Deposit and Exploration Studies.*

Skiddaw Group Structures in Wythop Woods

Leader: John Rodgers 3 July 2019



The group enjoying evening sunshine above Wythop Woods

This was an evening excursion based on the information given in Phil Davies' recently published book "Geology in the Lake District National Park". His Geosite N4 section, entitled 'The secrets of Wythop Woods Tectonic features and intrusions in the Kirkstile Formation', provided a most useful guide to interesting exposures in Wythop Woods and the open fellside to the west.

The group of 18 met at 6pm at the Woodend Brow car park (NY 218 275) and then shared transport along the old disused road, stopping after about 400m to examine a road cutting section which displayed both folding and faulting in the sandstone and siltstone beds. We then drove further along the road and left vehicles at Beck Wythop before taking the bridleway for c. 300m to another well-exposed section on the west side of the path (NY 213 287). Here members were invited to find a variety of features in the highly contorted bedding, including small faults, quartz veins and a prominent thrust plane. After spending about 30 minutes discussing this section we continued on the track up to the edge of the woods and then roughly westward across open fields to the disused quarry just west of Lowthwaite Side (NY 204 293). The quarry was probably worked for the hard andesite that forms a sill in the lower part, overlain by about a metre of Kirkstile Formation sediments. A small dip-slip fault can be traced in the outcrop clearly displacing the boundary between the two rock types, with a slickensided surface indicating the movement direction.

There is another locality in this area described in Phil Davies' book but on this occasion there was insufficient time to reach it. The group retraced their steps back to the vehicles, noting en route a variety of large erratic boulders (mainly volcanics from the Borrowdale Volcanic Group to the south) and the fine views across Bassenthwaite to Skiddaw on a warm, dry and sunny evening.

References:

Davies, T. P., (2018) *Geology in the Lake District National Park.* Otley Steps

Threlkeld Knotts-Lavas, Laccolith and Landslips

Leader John Rodgers 10 July 2019

This was a trip that was originally planned for the afternoon of 12 June but bad weather forced its postponement. A group of 15 met at the road junction 500m SW of Burns Farm (NY 304 240) for car sharing to a small layby in the lane at NY 314 231, just south of Wanthwaite Mill. We then proceeded on foot to the main road (B5322) and a short way along to the start of the Old Coach Road public way. We then followed this track for about 700m before turning up onto the fellside and eventually after a further 500m locating an obvious path up towards Threlkeld Knotts.

The aim of the excursion was to examine and explain the topography of Threlkeld Knotts. Until quite recently the dome-like form seen from the north was interpreted as a laccolithic intrusion of microgranite, modified by glacial erosion. (Field evidence and geophysical surveying indicate that the original form of the intrusion was indeed a laccolith emplaced around 450 m.y. ago). However, further research using ground-penetrating radar has shown the sub-surface nature of the upper part of the Knotts to be consistent with the idea of a massive landslide. Direct observation of the morphology and lithology of the upper part of the Knotts immediately below the scarp face of Red Screes enables appreciation of this interpretation.

En-route up the track an outcrop of dark grey slaty rocks was described as part of the underlying Buttermere Formation of the Skiddaw Group. This was overlain by microgranite, a pale-grey fine-grained porphyry with infrequent phenocrysts of quartz and cream feldspar. At the top of the track lies a large depression with a prominent E-W ridge on the north side and the steep scarp face of Red Screes on the south side. The ground is littered with large angular boulders (up to 2m across) that have fallen from the adjacent slope and consist of microgranite and various volcanic rocks from the overlying lowest formations of the Borrowdale Volcanic Group (BVG) Birker Fell Formation. Some of the boulders displayed excellent examples of flow- brecciated andesitic lavas, the recessed surface clearly picked out by differential weathering. The group then ascended the steep ridge to the north where a zone of rusty weathering, dark fine-grained lavas were found to be extensively filled with a network of pyrite veins, (NY 330 230). This ridge is now interpreted as the upper part of a great rotational landslip with the volcanic rocks now forming a transverse antiscarp. An emplacement model of the sequence of events is shown in Figure 1. Other linear depressions, both transverse (E-W) and longitudinal (N-S), over the surface of the Knotts coincide with subsurface discontinuities that have been revealed in the profiles produced from ground penetrating radar. Threlkeld Knotts is now regarded as a major landslip, estimated as 40 million cubic metres

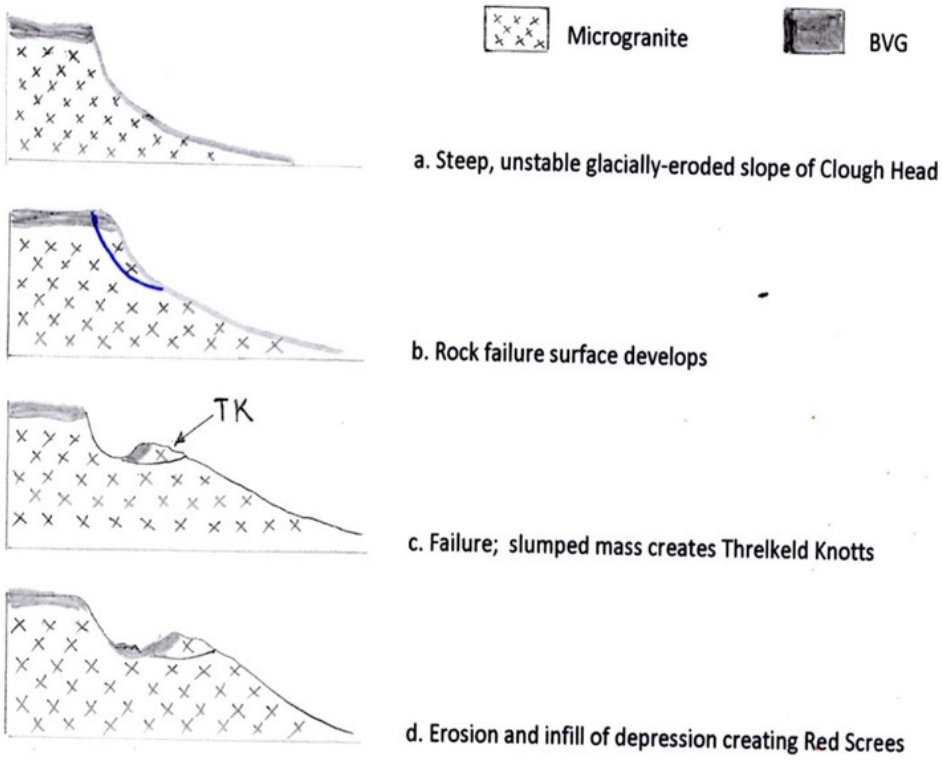


Figure 1. A model of how Threlkeld Knotts developed.



Figure 2 View of Clough Head and Threlkeld Knotts from the north.

in volume and composed of a moderately disaggregated mass of microgranite and volcanic rock. The rock slope failure is thought to have originated up on Clough Head, possibly along a line that was c. 100m behind the post-glacial cliff edge, which itself would have been an unstable surface following de-glaciation.

Advantage was taken of the elevated viewpoint to demonstrate many of the other landscape features in the surrounding area including the south face of Blencathra, the Coniston Fault line along the valley of St. John's in the Vale, the stepped (trap) topography of the BVG rocks of High Rigg and the microgranite mass of Low Rigg which has been separated from the Knotts intrusion by erosion along St. John's in the Vale. The existence of two much smaller and previously recognised rock slope failures on either side of Threlkeld Knotts was also mentioned, with a comment on how surprising it is that the landslip origin of the Knotts itself was not fully researched until relatively recently. It is now considered as one of the largest in the country and emphasises the importance of re-evaluating landscapes partly because of the need to assess the possibility of future landslip events.

Nenthead

Leader Rosemary Vidler 13 July 2019

On a pleasant July day, a large group met at Nenthead mines near Alston to view the surface geology around the Nenthead mine site and underground in Carrs Mine.



Figure 1 Laminated mudstones covered by glacial till (image ©D Powell)

The Alston Moor area is part of the North Pennine Orefield which is fault bounded and underlain by the Devonian Weardale Granite (399.3+/- .7 Ma). It is dominated by Carboniferous rocks of marine limestones and siltstones and coastal sandstones passing into fluvial sandstones and some coal seams forming sequences referred to as Yoredale cyclothems. These strata are generally flat lying, dipping gently to the east and dissected by networks of mineralised faults. Twenty-two cyclothems are recognized in the North Pennines but not all are present in all areas. In the Alston Moor area eleven can be identified.

Dome-shaped mineralization follows the form of the underlying Weardale Granite whose uplift fractured the limestone allowing mineral deposition from hyper-saline solutions at temperatures between 200 - 70° C. It is thought mineralisation was initiated by the cooling of the Whin Sill (c295 Ma) with some interaction with the Weardale Granite and this may have continued into the early Permian.

There are different zones of mineralisation with a central zone dominated by fluorite and an outer by barium along with lead, zinc and other minerals including varying amounts of silver in the lead. These minerals have been exploited for nearly a 1000 years.

Much of the solid geology is covered by glacial till and mine spoil with exposures mostly confined to the banks of the River Nent. We followed the river upstream to look at the shales and limestones of some of the cyclothems exposed there. At the first location on the right-hand bank (looking upstream) we could see glacial till of cobble sized blocks in a sandy/silty matrix overlying laminated mudstones (Figure 1). Water levels were low allowing us to walk over the riverbed to examine these more closely.

Moving further up the river to opposite the Carrs Mine Shop on the right-hand side there is a hard, grey limestone, about a metre thick with shales above and below. This is the Iron Post limestone which is named for its hardness and not for any iron content. On examination crinoid fragments were observed and brachiopods have been found here.



Figure 2 Base of Great Limestone with fossil band (image © D Powell)

Carefully following the river further upstream on the left-hand side as we approached the waterfall, we examined the base of the Great Limestone which lies above the Iron Post limestone. At this particular point there is a layer of black carbonaceous material which is the top of the shale beds of the Iron Post cyclothem. In the base of the Great Limestone (Figure 2) is a band of mats of the sponge *Chaetes* and the colonial coral *Siphonodendron* which are in life positions and are an important and extensive stratigraphical marker across the area.



Figure 3 Poorly exposed sandstone above Great Limestone (image © D Powell)

Approaching the waterfall and the rear exit from Carrs Mine we could see the limestone was a pale brown colour were it has been mineralised to a hard ankerite rich rock and many examples of galena could be found in the surrounding rocks and river bed.

Following the track up past the entrance to Smallcleugh mine we continued up the river to another small waterfall of a medium grey bioclastic limestone weathered to an orange brown with well-developed rectilinear joints and abundant crinoid fragments. This is the base of the Little Limestone, the cyclothem above the Great Limestone.

Continuing up the river below the old compressor house small poorly exposed outcrops of sandstone were seen on the steep banks and the more intrepid of us scrambled up to confirmed that crinoid fragments are present (Figure 3).

Returning back down to the Smelt Mill buildings we had lunch. As only small groups could go into the mine we divided up with some going into the mine and the other groups visiting Brewery Shaft and mineral hunting in the river before going into the mine.

Entering the mine (Figure 4) we could see how the miners had used local sandstone rather than scarce wood to form arching to support the roof. Once through this we could see the layers of relatively ‘soft’ shales the miners more easily worked through before reaching the harder limestone where mineral ore could be found. Much of the galena was found in horizontal ‘flats’ where the hot mineral fluids had been forced sideways from a vertical feeder channel.



Figure 4 Group entering Carrs Mine (image © D Powell)

Further on a fault between the shales and the limestone caused by down throw formed a mineral vein which the miners exploited (Figure 5).

As well as seeing the geology underground we were also shown how the minerals were extracted firstly using black powder and hand drilling (ca 1850s) and later using



Figure 5 Underground fault dipping to the right (image © P Winskill)

more modern methods such as compressed air rock drills and dynamite (ca 1900s).

With the introduction of compressed air drills there was a need to provide compressed air to power them. One way this was done was to sink the 100 metre deep Brewery Shaft (Figure 6) down which water was dropped and the compressed air extracted at the bottom. Looking down this feat of engineering with much of the pipework still in situ was a fitting end to our visit to Nenthead.



Figure 6 Looking down Brewery Shaft. (Image © D Powell)

Bibliography

Bulman R (2004) *The Geology of Alston Moor,* North Pennines Heritage Trust

Brian Young *Nenthead: Geology and Mineralogy,* NMCS

Shapfell Quarry, Hardendale: past, present and future

Leader Sylvia Woodhead 17 August 2019

A large party assembled at the minor road corner 'Castlehouse Scar' NY 590 146, for a visit to Shapfell Quarry, Hardendale. The visit was hosted by Tata Steel: the General Manager and Operations Manager gave up their Saturday morning to show us round the quarry. In 1962 the quarry was opened for good quality limestone for the Scottish steel industry. Active blasting ceased in 2009, and the quarry is now being restored. The restoration is planned to run for 18 years, in 3 phases, and includes a scheme for geological interpretation which formed the focus of the visit.



Figure 1 View to NE corner of Shapfell quarry

The quarry was opened for significant extraction in 1962 by Colvilles of Glasgow, to provide crushed limestone for the Scottish steel industry. The limestone has a high $CaCO_3$ content, with low sulphur and phosphorus, which also makes it suitable for calcination to high quality lime, and in 1972 the first three of Shapfell's four lime kilns were built, with the fourth added in 1990. The plant makes approximately one-fifth of the UK's lime. The stone was taken from the quarry by a private haul road over the M6 to the Shapfell works site where it was crushed prior to calcination, with the fines or 'slimes' from the crushing plant being returned to the quarry as backfill. Water was pumped into settling ponds.

The land on Hardendale Nab was formerly agricultural grazing land. In 1996 when the then extant restoration plan was approved it was assumed that the quarry would be infilled to return the land for agriculture, and that the rock faces would be obscured by landscaping. An area of Hardendale Nab has been restored.

In 1967 Colvilles were taken over by British Steel, who merged with the Dutch steelmaker Hoogovens to form Corus in 1999. In 2007 Corus and the quarry were purchased by Tata Steel of India. By 2009 the majority of the quarry's consented reserves had been exhausted, and the quarry was mothballed whilst an application to further deepen the quarry was determined. This application however was subsequently withdrawn by Tata Steel due to concerns that pumping below the water table for a significant period may be ecologically harmful, and instead an enhanced restoration application was submitted.

In 2009 active drilling and shot blasting at the quarry ceased, and it filled with water once the pumps were switched off. The works now uses limestone from Hanson's Shap Beck Quarry, north of Shap NY 554 182 and from Tarmac in Derbyshire, the latter brought by rail. The quarry void continues to be restored with slimes, which comprise mainly fine limestone particles with some clay that arise as washings from the washing plant.

In 2018 a new application was granted to extend the restoration and time scale to 18 years, in 3 phases. There was extensive public consultation. Cumbria GeoConservation (CGC) submitted a response requesting that the rock faces are not obscured by planting, that the geological heritage of the quarry is recognised, and that accompanied visits for geological groups can be made available by appointment.

In 2019 the application was approved, with a planning condition requiring a scheme for geological interpretation. The new restoration plan will return the land to the landowner in a 'suitably restored condition'. Around 37 hectares will be restored for agriculture and ecology, but the 30 ha of water will remain. CGC is now in discussion with Tata Steel & planning officers of Cumbria County Council over the details of geological interpretation. The scheme

includes at least 2 geological interpretation panels; and agreement of their design, mounting and siting.

One panel may be located at the meeting place, NY 590 146, 'Sandpot Hole' on the OS map, with this panel describing the background to the past, present & future of the quarry, with an explanation of the restoration plan and reference to a geological trail around the quarry exterior.



Figure 2 CGS members on the 'bedding plane' area

To access the quarry interior, following from previous visits by CGC, Tata Steel have installed a locked gate at NY 585 142 in the quarry boundary fence. At NY 589 146 a small area of limestone pavement with some erratic blocks of Shap granite was examined. As the gate was approached, the first views into the quarry were obtained (figure 1). A large limestone block near the gate is the proposed site for a further panel, this time to focus on the geology.

The view into the quarry is impressive, a large body of water and distant views of the strike face of the Lower Carboniferous Knipe Scar Limestone (KNL) Formation (described by the BGS as rhythmically bedded wackestones with thin interbeds of mudstone and siltstone, with a regional thickness of around 100m). In the quarry the KNL appears pale grey, blocky and well jointed. The strata dip to the east at approximately 5-10°.

Through the gate Tata Steel have begun an indicative path of crushed stone, into the quarry void. On the descent into the quarry members were distracted by fossils in loose blocks, which also included examples of sandstone, possibly the Wintertarn Sandstone Formation (WTRS) of the Yoredale/ Alston Group, which overlies the KNL.

In the northwest corner an inclined bedding plane exposed by quarrying shows good cross sections of fossil corals (figure 2). This area is intended to be on the internal quarry geology trail that will be created as part of the final restoration phase. Large blocks of limestone, to be called the Rock Park, also show good fossils (figure 3). In addition to a second geology interpretation board, further interpretation of the fossils is planned.

The party were then taken to the *piece de resistance,* amazing gour pools, deposits of tufa, (figure 4) (described in detail in a separate article in this publication). All agreed these features were of outstanding quality. On leaving the quarry the



Figure 3 View to 'rock park' area

Managers were thanked for their time. Members took lunch under the limestone cliffs of the original quarry of Hardendale Nab, NY 580 140. After lunch the Coast to Coast path was joined, past the former entrance to the quarry. Along the southern boundary of the quarry a small boulder identified a possible site for a copy of the general geology interpretation board planned for Sandpot Hole.



Figure 4 Gour pools in Shapfell quarry

Members continued around the eastern edge of the quarry, noting viewpoints into the quarry, small patches of limestone pavement, small sinkholes, and occasional Shap Granite erratics. A pause at the stone wall at NY 593 143 demonstrated different rock types, limestone and sandstones, with abundant fossils, before returning to where the cars were parked.

A Visit to Whitehaven Harbour for a Building Stones Walk

Leader Margaret Bennett 29 August 2019

An intrepid group of Society members met in the car park to the north of Whitehaven's North Pier. The lovely weather had ended 2 days earlier and we had high winds but no rain to contend with. As the tide was out we escaped spray from the waves pounding the piers.

We began by walking along the North Pier to the old lighthouse (disused) at the end. The North Pier is one of the oldest parts of the harbour and the Carboniferous and Permian Sandstones it is constructed with exhibit signs of severe weathering. Many of the flagstones show bedforms and some have inclusions of a much darker rock, softer than the surrounding stone but with a very hard margin.

We returned to the start of the pier and took advantage of the harbour bridge being down to cross to the Old Quay. Here again we saw sandstone bedding structures. A building on the Old Quay has a plaque dating it to 'about' 1730 so that area must be at least that old.

A section of the quay where it joins the road has been paved with large rounded cobbles and the members were interested in the range of rock types that had been used.

From there we turned onto the West Pier. Several large blocks of Shap Granite have been used to prevent motorised access. One block has an interesting inclusion (xenolith?) exhibiting what appear to be chilled margins. One on the top of the block is black but a lower one is greenish yellow.

We followed the West Pier to the end and climbed up the steps to the new lighthouse. There are some deeply eroded stones in the wall which we sheltered behind.

The return walk along the top of the pier was abandoned due to the high wind.

Leader: Noel Pearson 8 September 2019

Within the geological structure that is the Stainmore Trough is a topographic feature, a trough some 6km from north to south. It is floored by mid-Carboniferous sediments that abut, with increasing dip, against older more competent lower Carboniferous limestones. This is the Stainmore Monocline. Its eastern boundary is defined, from south to north, by the Argill Fault (or Dent Line) and the Augill and Barnarm Faults. The Monocline, a result of Variscan NW-SE compression is cut by these later faults. It is east facing in the south and trends anticlockwise as the Dent and Pennine Lines intersect. The excursion visited three locations north of the A66 where these structural patterns can be seen, as shown in Figure 1.

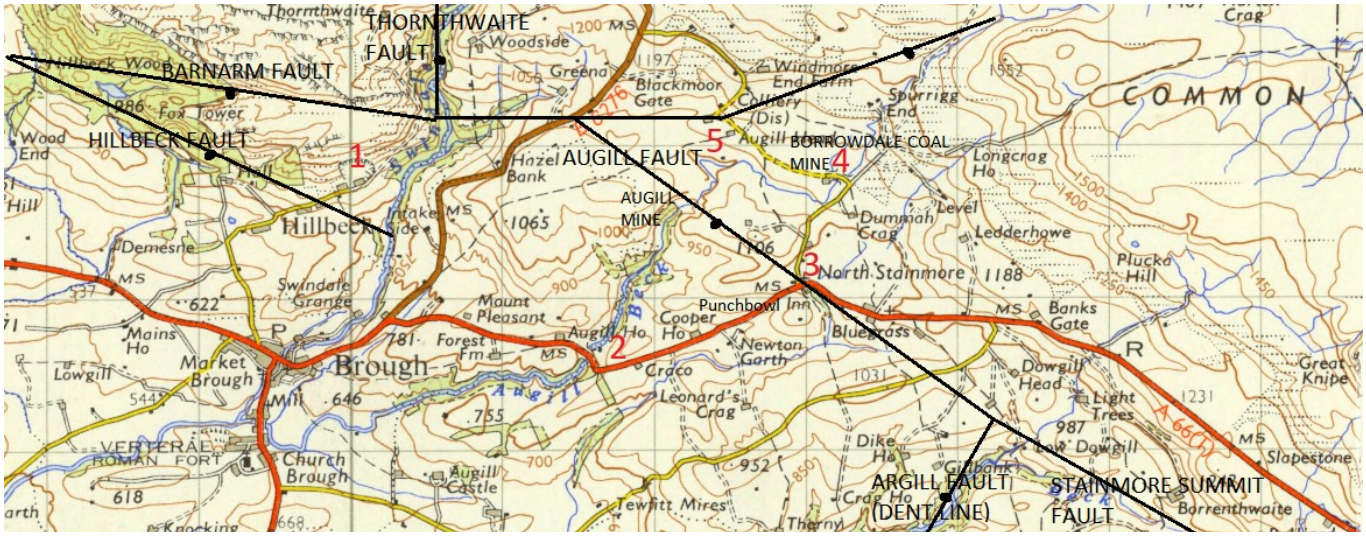


Figure 1 Main faults with downthrow. The main A66 is shown c. 1950. East of Brough the current dual carriageway runs south of the old road to Augill House, cuts the corner at the Punchbowl Inn and runs north of Bluegrass to rejoin at Bank Gate.

Location 1. Barnarm Fault above Helbeck Quarry.

Starting from the parking area (NY 800 158), below the entrance to Helbeck Quarry (sometimes known as Hillbeck), the route follows the track NE, for 600m, up to the Carry Band area to enter Open Access ground. Turning SW, a track carries on to the vantage point of Spoonymire Hill (NY 801 162). Figure 2 shows the panorama with centre left, the Melmerby Scar Limestone (MsL) at the core of an anticline and the overlying Robinson Limestone (RsL) to the right, dipping into the Barnarm Fault. The reservoir at the left is situated on an impermeable clastic bed in between the two limestones. Right, or north of the fault, the Carry Band dips gently to the north, but in E-W cross-section exhibits, as yet unmapped, faults and folds. The steeper NE downfolding at the eastern end of the escarpment has clearly been affected by the Thornthwaite Fault.

The route continues below Horseshoe Scar and to the left of Barnarm Scar. Figure 3 gives a better view of the dextral slip between the two. Eventually a viewpoint is reached (NY 791 163). To the north, the previously observed structures in the escarpment continue with,



Figure 2 View from above the Helbeck Quarry. The Barnham Fault west to east runs below the escarpment and into North Stainmore



Figure 3 View SW from Carry Band of the Barnham Fault, with dextral movement of Barnham Scar with respect to Horse Shoe Scar, both Melmerby Scar Limestone.

lower down, some tight folding (again unmapped). The view to the south looks over the Outer Pennine (Hillbeck) Fault and the downthrown Alston Formation in Yosgill Sike which underlies the Permian sandstones in the middle distance. Here the A66 essentially follows the Eden Valley Syncline to the north west.

The route now returns to the north of the steeply dipping Barnarm Scar, where the colour contrast between the pale MsL and darker RsL can be seen in hand specimens and there is also a closer view of the folding. Then go back to the turn on to the main path, where the continuation of the Barnarm Fault can be inferred to the east. On return to the parking area around 3.5k will have been covered.

Location 2. Augill Smelting Mill.

Taking the Middleton-in-Teesdale road from Brough, then right towards the A66 and left to Augill Bridge (NY 815 146), there is a convenient stopping point to car-share for the next location. Not without interest, this is a Cumbria Wildlife site with information about a smelt mill that served the Augill lead mine, further upstream, in the 19th Century. It was later converted to an iron roasting plant in 1859/60 which was presumably more profitable. (More detail can be found on the Historic England web-site).

Location 3. Punchbowl Inn.

About 2km east of Augill Bridge there is a turn to the north off the A66 to Borrowdale. This is the old road which passes the former Punchbowl Inn. Continuing up the road for 100m there is parking by the Parish Hall opposite a field (NY 829 151) at Location 3. The site is off the footpath which crosses the field so access was checked with the farmer first.

Location 3 is a Local Geological Site, noteworthy for the NW-SE limestone scarp face, shown in Figure 4 and the succession of sandstones and limestones all dipping SW at around 60°. Because the sequence, essentially the Alston Formation, becomes younger to the NE, the interpretation is that these beds have been overturned during compressional movements, with even younger

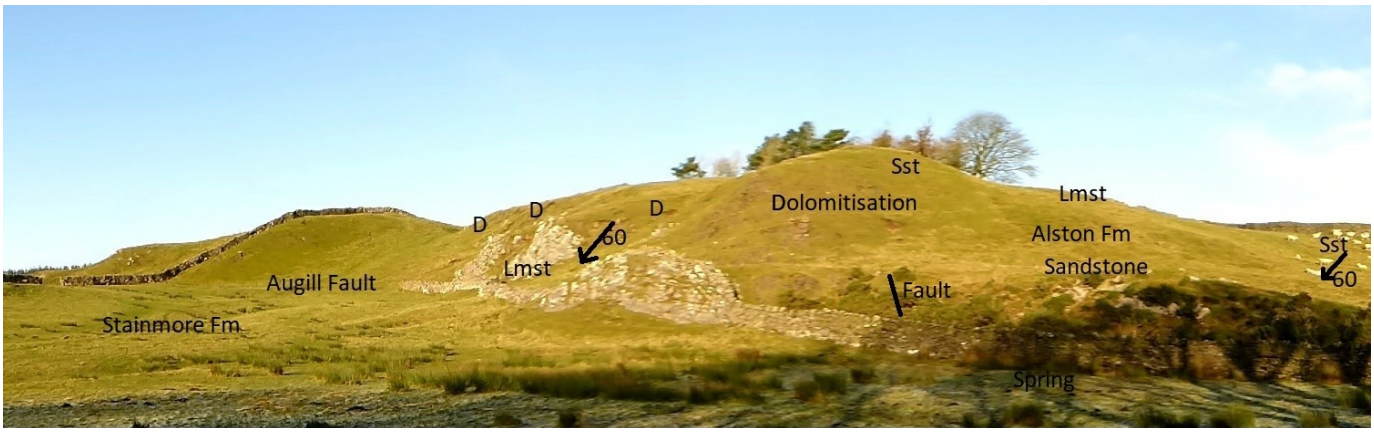


Figure 4 View NW of the Augill Fault Zone with overturned limestones younging NE into Alston Formation.

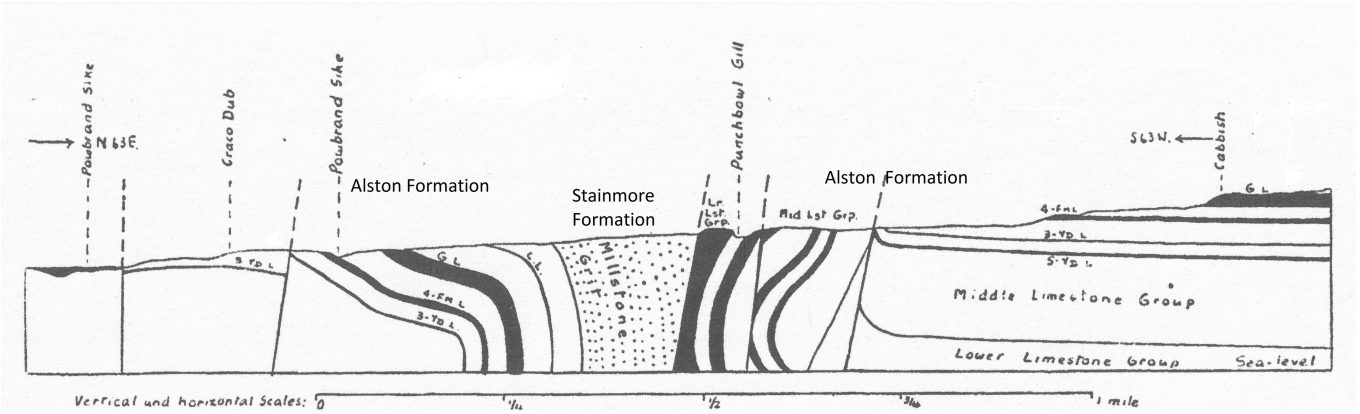


Figure 5 Turner's 1935 cross-section of the Augill Fault Zone just east of the Punchbowl Inn.

beds later down-faulted to the SW as Turner (1935) makes clear in his cross-section, shown in Figure 5. This is the Augill Fault Zone. It continues under the A66 to the SE where a similar SW facing scarp can be seen east of Punchbowl Sike. (The whole of the fault zone can best be appreciated from a vantage point south of the A66 on the Roman Road at NY 834 144).

Closer examination of the pale limestone scar shows several zones of dark brown, iron-stained, dolomitised rock interspersed seamlessly with the limestone. Presumably this is evidence for fluid movement along minor faults and fractures. The presence of a spring and a displaced sandstone bed, on the right of Figure 4, are also features of this fault zone. Without being specific, it is generally thought that these limestones and sandstones belong to the upper part of the Great Scar Limestone Group and the base of the Alston Formation. Colour differences from pale to dark differentiate bedding. Fossils are not conspicuous probably due to brecciation and alteration along the fault zone.

Location 4. Borrowdale Mining Area.

Continuing north on the Borrowdale road and turning left through a gate, a brief stop can be made by Borrowdale House (NY 832 158). Old maps show 'Shafts' nearby which continue north of the road for the next kilometre. These have been excavated through the Four Fathom Limestone to gain access to the Borrowdale Coal Seam which is only 30 to 50cms thick but was worked from the mid 19th century until 1934. The limestone seen by the bridge over



Figure 6 Borrowdale Beck view east upstream, cutting beds below the Borrowdale Coal above 3 Yard Limestone