Crinkle Crags Excursion:
formation of the Scafell caldera

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Photos: Clive Boulter unless otherwise acknowledged

Photo: Crinkle Crags

LOGISTICS

- **Please Note: for localities 2 & 7 you may feel more comfortable with a hard hat for close examination of the layer and grain characteristics.**
- Start at Three Shire Stone, Wrynose Pass [NY 278027].
- The climb is a fairly steady gradient towards Crinkle Crags, leave the path to skirt the western side of the first Crinkle, and from a height of 780m drop down to Locality 1 on the side of Adam-a-Cove at 710m.
- Once Locality 2 is reached there is a string of localities at around the 750m contour though the last stop is just below Long Top at 850m. The return walk to Three Shire Stone takes just over an hour.
- A brief pause at Red Tarn [NY 2674 0392] on the long climb up will allow inspection of the remnants of exploratory drilling for iron ore – small fragments of kidney ore can be found on spoil tips. This is just before the path takes a sharp left turn. From here down to the small stream draining Red Tarn the path is a ruddy colour highlighting the presence of haematite vein[s] in the saddle. There is an account dated 1709 that suggests iron was mined at Red Tarn to supply a furnace in Langdale. Exploration variously dated as 1860 or 1872 records test borings and shallow workings as well as a trial in 1922.

The word red turns up in many Lake District place names. The reddening probably formed at the same time as the haematite ore bodies on the west coast of Cumbria in the mid-Triassic. Small deposits in the Lower Palaeozoic rocks have been economic but mostly the introduction of ferric iron has added variety to the generally green colour of the Borrowdale volcanics.

TOPICS

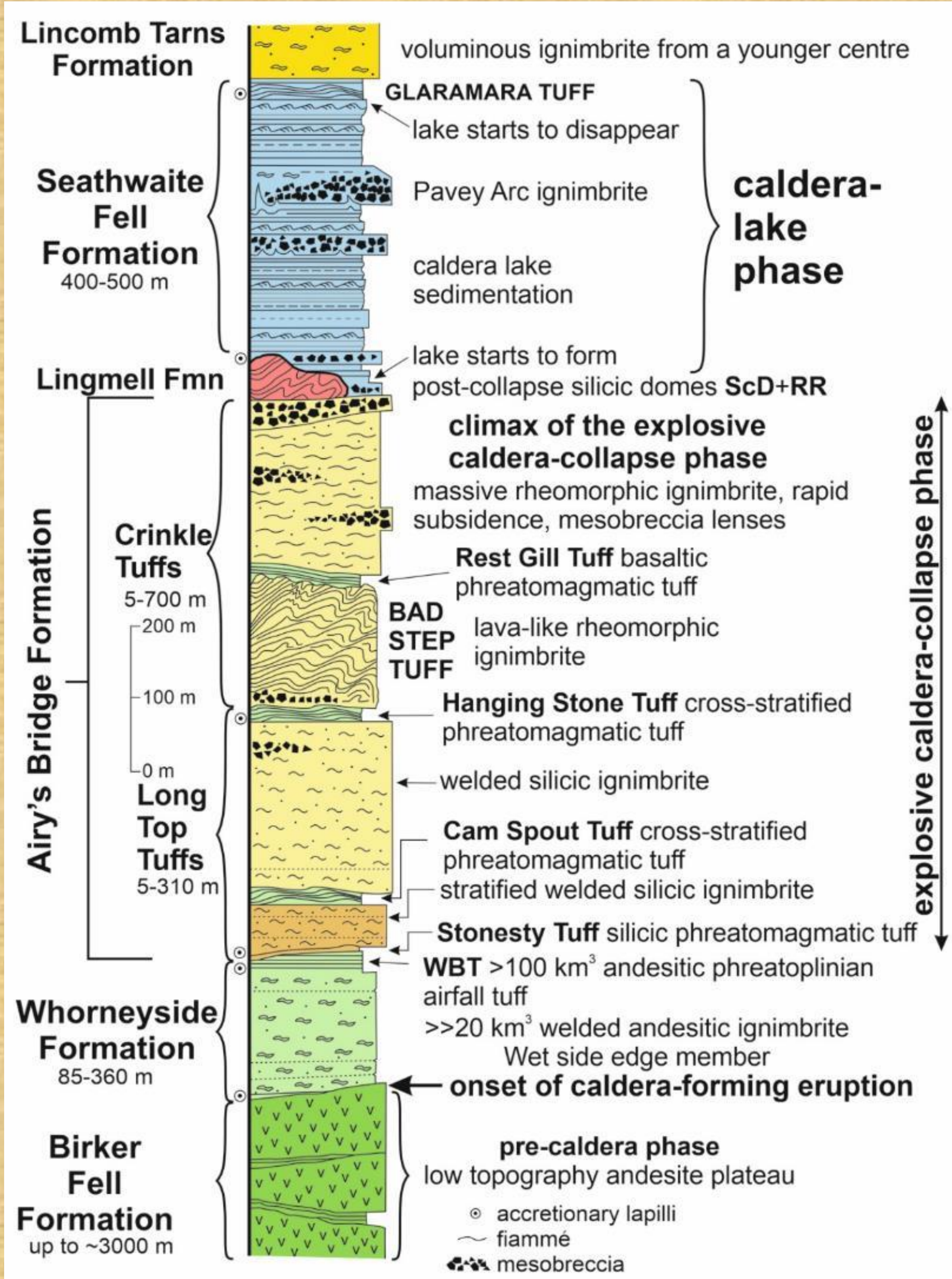
- through its infill of pyroclastic deposits, to trace the explosive history of the Scafell caldera [>>400 km^3]. Super-eruptions?
- to use deposit characteristics to determine how the magma fragmented, and how the fragments were transported and deposited.
- to consider the evidence for foundering of the magma chamber roof in a highly faulted manner [piecemeal].

Pyroclastic density currents and Phoenix clouds at Mayon Volcano. C.G. Newhall, United States Geological Survey

Brief Outline

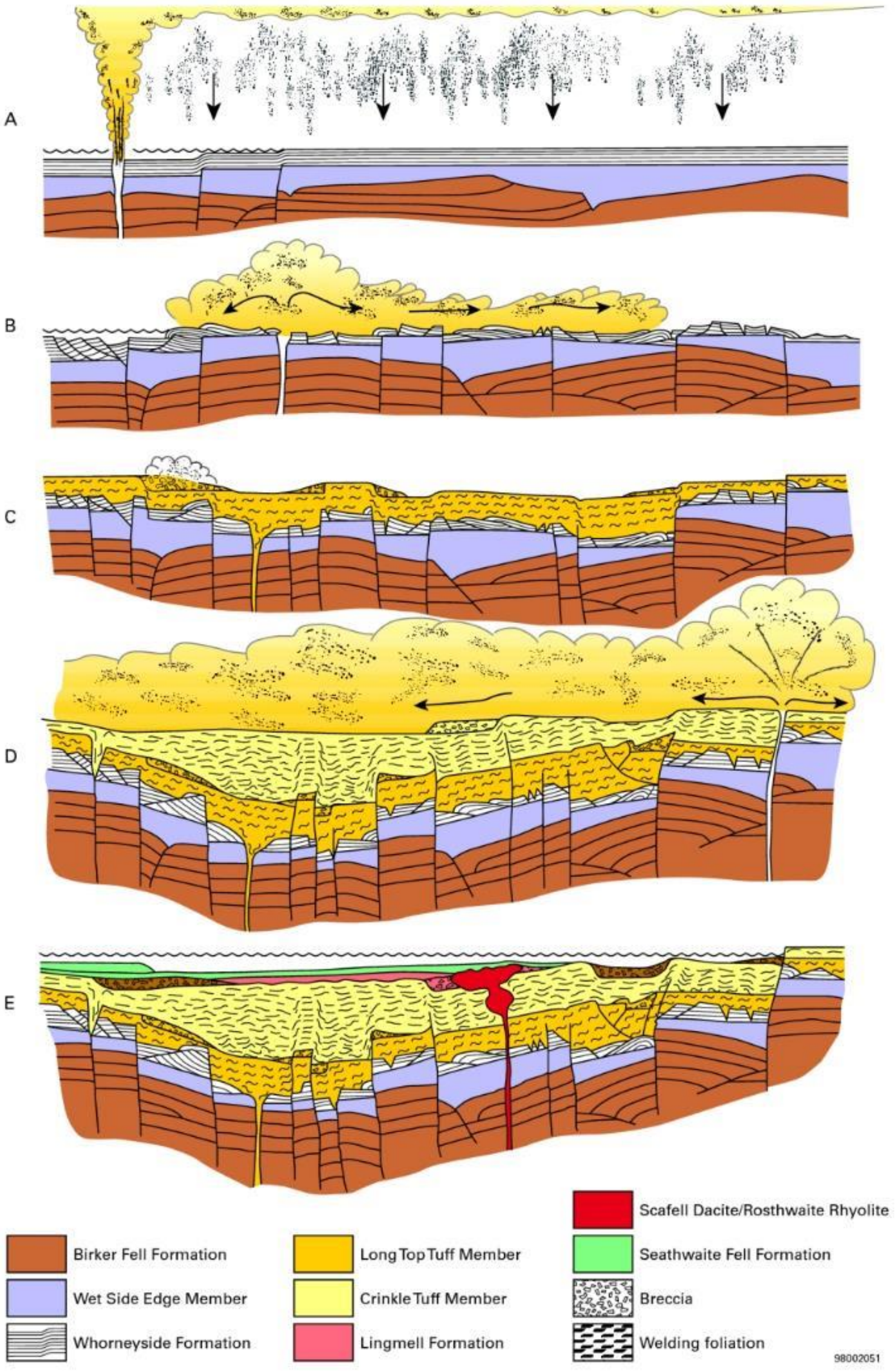
- We will start in the Birker Fell Formation at the point where the volcanic behaviour of the Borrowdale volcanics changed dramatically from mainly lava eruptions to massive-scale violent explosive eruptions.
- It is claimed that the Scafell caldera is one of the best places in the world to study the effects of removing large volumes of magma from a magma chamber particularly the collapse and breakup of the roof.
- This piecemeal caldera collapse episodically tipped large volumes of lake water into the magma chamber. The Scafell caldera had several events of this nature including the largest of this kind in Earth history.
- As the magma chamber roof broke up, bedded air-fall tuffs were tilted, before significant lithification, to produce an array of outstanding soft-sedimentary deformation structures.
- We will see cross-bedded ignimbrites, and welded ignimbrites, and will use the deposits to infer how the magma fragmented, the eruption style, how the pyroclasts were transported, and how they were deposited.
- We will assemble the evidence for the air-fall nature of the Whorneyside bedded tuff which is very different from air-fall deposits of purely magmatic explosivity.

A loose block of welded ignimbrite seen on the path from Red Tarn to the First Crinkle. The pumice fragments [brown] have been considerably flattened and the ragged ends are broken vesicles. An ignimbrite is any deposit from a pyroclastic density current [PDC]; welding is not a requirement but fortunately many of the Lake District's ignimbrite are welded. Unwelded ignimbrites are deposited by dilute low-temperature PDCs and they are commonly stratified as at **Locality 1**.



Simplified vertical succession for the Scafell caldera in the Borrowdale Volcanic Group [from Brown et al. 2007 based on Branney & Kokelaar 1994].

WBT = Whorneyside Bedded Tuff



Schematic cross-sections showing development of the Scafell Caldera during piecemeal collapse. The sequence of events is greatly simplified (after Branney and Kokelaar, 1994).

A Emplacement of the Whorneyside Formation ignimbrite [Wet Side Edge Member] and succeeding phreatoplinian ash [Whorneyside Bedded Tuff].

B Onset of piecemeal subsidence causing deformation of the Whorneyside deposits; burial beneath hot silicic ash of the Long Top Tuffs erupted from new vents.

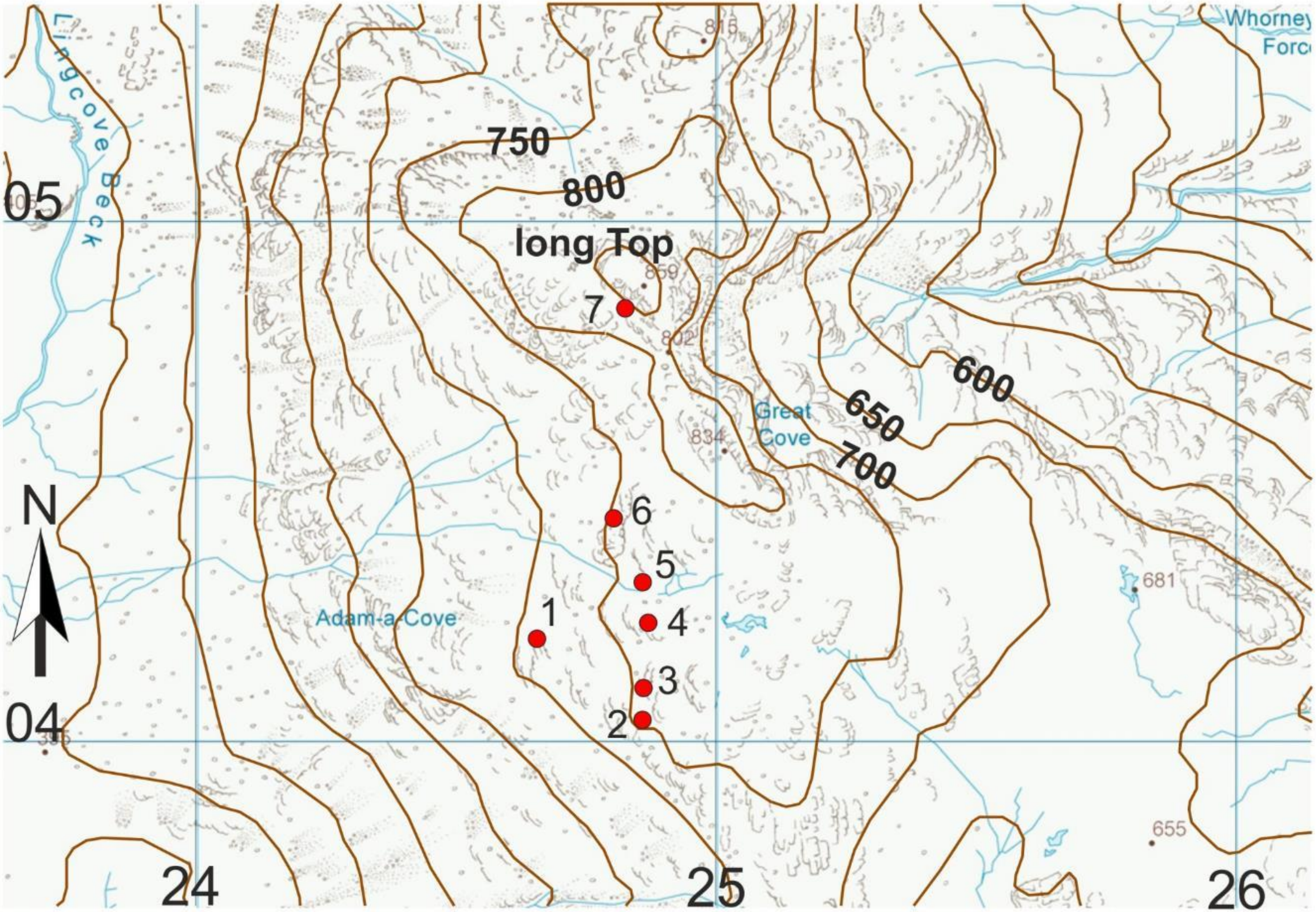
C Further collapse causing ductile deformation of the hot ignimbrite.

D Paroxysmal eruptions producing very densely welded ignimbrites of the Crinkle Tuffs and causing renewed subsidence and fault-scarp collapse.

E Waning eruptions and silicic dome emplacement; sedimentation in a caldera lake.

Figure 20 in Stone, P, Millward, D, Young, B, Merritt, J W, Clarke, S M, McCormac, M and Lawrence, D J D. 2010. British regional geology: Northern England. Fifth edition. Keyworth, Nottingham: British Geological Survey.

P916050 Earthwise, British Geological Survey.



Base map from Ordnance Survey OpenData. Kilometre grid.

Excursion Locality Map

LOCALITY 1 NY 24649 04227 In the bottom few metres of the Whorneyside Formation there are interbeds of welded and unwelded ignimbrite. Both were deposited by pyroclastic currents, the unwelded examples as shown here are from the lower end of the density spectrum and they develop sedimentary structures such as the cross-bedding seen in this photo. Typically low-density pyroclastic currents are generated by magmatic explosivity enhanced by interaction with external water [phreatomagmatic]; these are cooler, damp flows, and hence do not weld. Unwelded ignimbrites can be very difficult to distinguish from deposits created by aqueous sedimentation. In this case it is the association with the intercalated welded ignimbrite that supports the pyroclastic origin. Coin 22.5 mm. Locality 1 marks the start of major explosive activity in the Borrowdales.

Above Locality 1 there is over 100m of andesitic welded ignimbrite – the Wet Side Edge Member of the Whorneyside Formation. In contrast to the pale weathering rhyolitic ignimbrite higher in the sequence, the andesitic variety is a bit gloomy in its weathering aspect. What were blocks of pumice/scoria have been flattened [because the deposit was hot] to form fiamme; here recessively weathered probably because they were hydrothermally altered. Welding requires that the PDC retained heat during transport and deposition, so must have been fairly dense. 15 cm ruler scale.

The Whorneyside Eruption Phreatoplinian Phase

Mike Branney has documented this eruption in detail and is shown in outline on the earlier diagram of the evolution of the Scafell Caldera [P916050 Earthwise, British Geological Survey]. The Birker Fell Formation andesite lava plateau was completely buried by the Whorneyside ignimbrite [Wet Side Edge]. Volcanotectonic faults formed early in the caldera collapse process and allowed large-volumes of surface water to access the magma leading to intense fragmentation and very moist conditions. As a result, ash clumped together in the umbrella cloud hence the erupted products fell out of the cloud as dense showers of ash and accretionary lapilli. In brief interludes the sub-aerial ash-fall deposit was subjected to minor rill erosion by surface water run-off following eruption-triggered precipitation. Not seen on this excursion are the complications associated with near-vent processes.

Recent research at the University of Leicester has indicated that the Scafell Caldera was generated by at least three co-existing magma storage zones, one andesitic and two silicic.

Branney, MJ, 1991, Eruption and depositional facies of the Whorneyside Tuff Formation, English Lake District: An exceptionally large-magnitude phreatoplinian eruption. Bull. Geol. Soc. Amer., vol. 103, pp. 886-897.

Locality 2 [NY 2487 0403] At least two significant thrusts and many minor ones in the Whorneyside bedded tuff on Stonesty Pike; the deformation took place as fault blocks, defined by caldera-forming volcano-tectonic faults, tilted. The pale bed just below the centre is formed of accretionary lapilli. Perfectly-parallel bedding is the key indicator of an air-fall origin for these deposits despite the poor sorting generated by clumping of ash in a very moist eruption.

Locality 2 Detail of a bed of accretionary lapilli. Several overall features in the Whorneyside bedded tuff, particularly the parallel bedding, clearly demonstrate its airfall origin from an eruption umbrella cloud. However the sorting characteristics are at odds with this interpretation. Airfall deposits are typically well-sorted but here there is a large range of grain sizes from the finest ash to several mm sized grains. These apparently conflicting observations can be reconciled with a phreatomagmatic model for the eruption. It is inferred that large volumes of water, probably from a lake, poured into the magma chamber to intensely fragment the magma. This process produced a very damp eruption cloud and led to ash clumping together to prematurely fall out of the cloud hence explaining the poor sorting. This possibly the deposit of the world's largest ever phreatoplinian eruption. Ruler cm-scale.

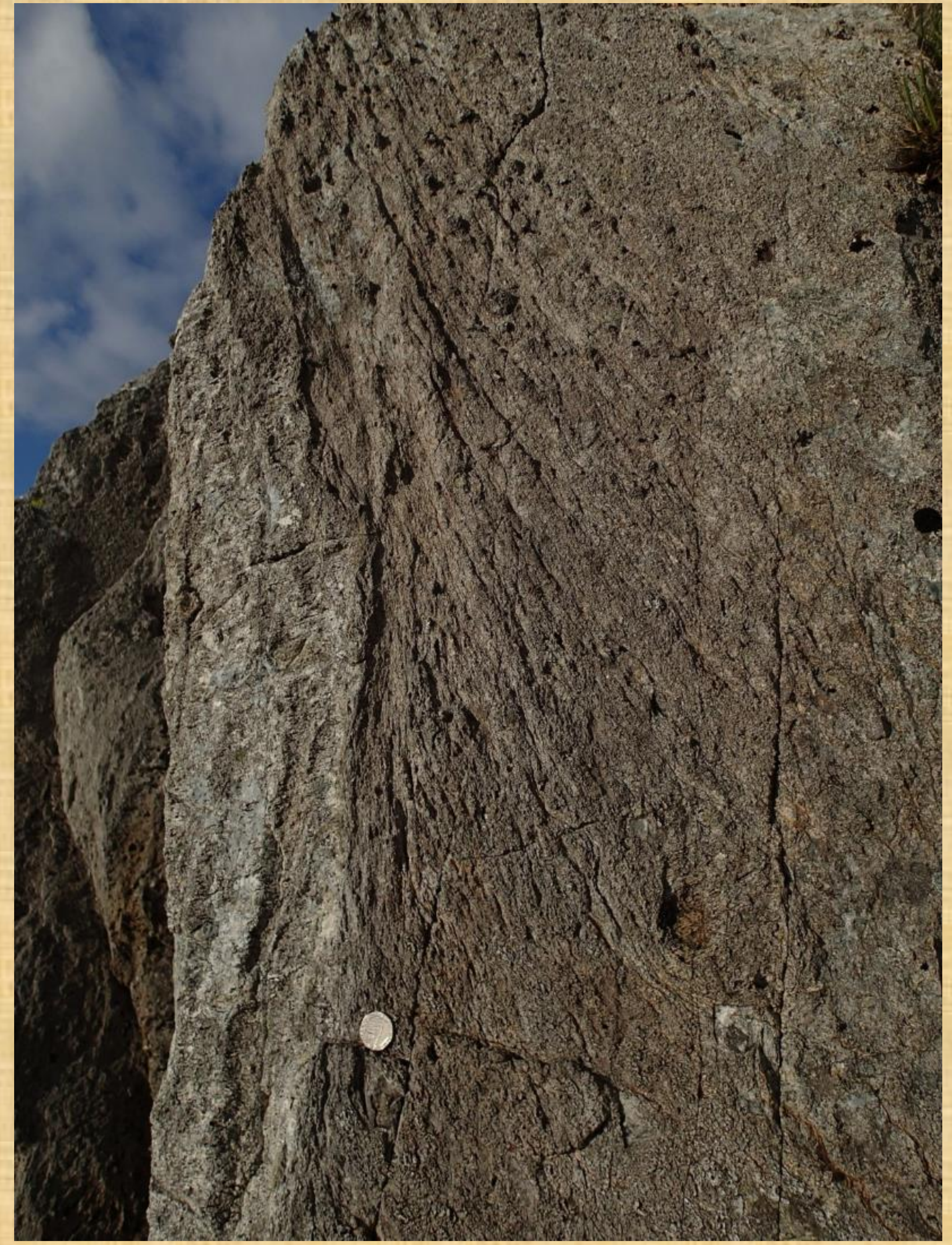
Above the crag with the thrust faults there is a zone of erosional rills within the Whorneyside bedded tuff formed in a brief lull in the fall-out event. The dampness of the eruption cloud means that it created its own rain leading to the minor erosional rills. Layer thickness variations in the rill-filling material is key to distinguishing between deposits from pyroclastic currents and air fall processes. If the sides of the erosional troughs are not too steep then air fall deposits maintain a near-constant vertical thickness. If the troughs were infilled with ignimbrite from a PDC, the layer thicknesses will vary considerably.

In the zone of erosional rills a gully's sides were so steep that they collapsed into the channel.

Locality 3 [NY 24867 04085] impact sags caused by lapilli-sized fragments [not quite bomb-sags]. Whorneyside bedded tuff, scale centimetres.

Locality 4 [NY 24855 04111] Angular unconformity between the andesitic Whorneyside bedded tuff  and the overlying pale-weathering rhyolitic Stonesty Tuff  , the basal component of the Airy's Bridge Formation. Siccar Point this is not as the events represented here happened on a timescale of years to decades and were created by block rotation during piecemeal caldera collapse.

Locality 5 [NY 24849 04316] Isaac Gill Fault – a volcano-tectonic fault that downthrows Airy's Bridge Formation rhyolitic ignimbrite to the north against Whorneyside bedded tuff clearly rotating the bedding in the latter. Looking back to Locality 4 shows the general dip of the bedded tuffs and at locality 5 the bedding → abruptly turns to near vertical.



Locality 6 [NY 24815 04417] Rhyolitic ignimbrite, Airy's Bridge Formation.

From Locality 5 to here all the exposures are of rhyolitic welded ignimbrite of the Airy's Bridge Formation. These deposits are the product of magmatic eruptions where the driving force is mainly expansion of volatiles in the magma.

At Locality 6 the background gently-dipping welding fabric is deflected to near-vertical adjacent to a volcano-tectonic fault that formed during caldera collapse. The ignimbrite was still hot during the deformation of the fabric as demonstrated by the ductile nature of the deflection. This is a very dynamic environment as 100s of cubic kilometres of pyroclastics are evacuated from the magma chamber leading to collapse and break-up of the roof.

Locality 7 [NY 2487 0481] Cross-bedded accretionary lapilli tuff. This is the Hanging Stone Tuff and, despite being only a few metres thick, can be traced to Seathwaite Slabs, near Seatoller. The abundant welded rhyolitic ignimbrites hereabouts are punctuated by several similar horizons; they are the result of water briefly accessing the magma resulting in a phreatomagmatic eruption which generates moist low-density pyroclastic currents characteristically creating sedimentary structures and ash aggregates. The overlying unit, the Bad Step Tuff, is now classed as a “lava-like rheomorphic tuff” which has variously been interpreted as a lava flow or an intrusion but has now been shown to be an ignimbrite.

Detail of the accretionary lapilli from **Locality 7**; the largest is 10 mm in diameter. Note the rim fragments which show that the laminated coatings were brittle during transport. Accretionary lapilli in settings like this were generated during the interaction between the eruption column and Phoenix clouds above PDCs moving away from the source of the eruption.

If you venture further than Locality 7 this will take you into the Bad Step Tuff, central Crinkle Crags. This ignimbrite is so intensely welded that the pumice fragments are hard to recognise, so much so that this was initially recognised as a lava flow rather than a deposit from a pyroclastic current. The grey lichen is 3cm in diameter.

Source Material

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2. Branney, M.J. 1990. Explosive volcanism and volcanotectonic subsidence at Crinkle Crags. Geologists' Association Guide, The Lake District.
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