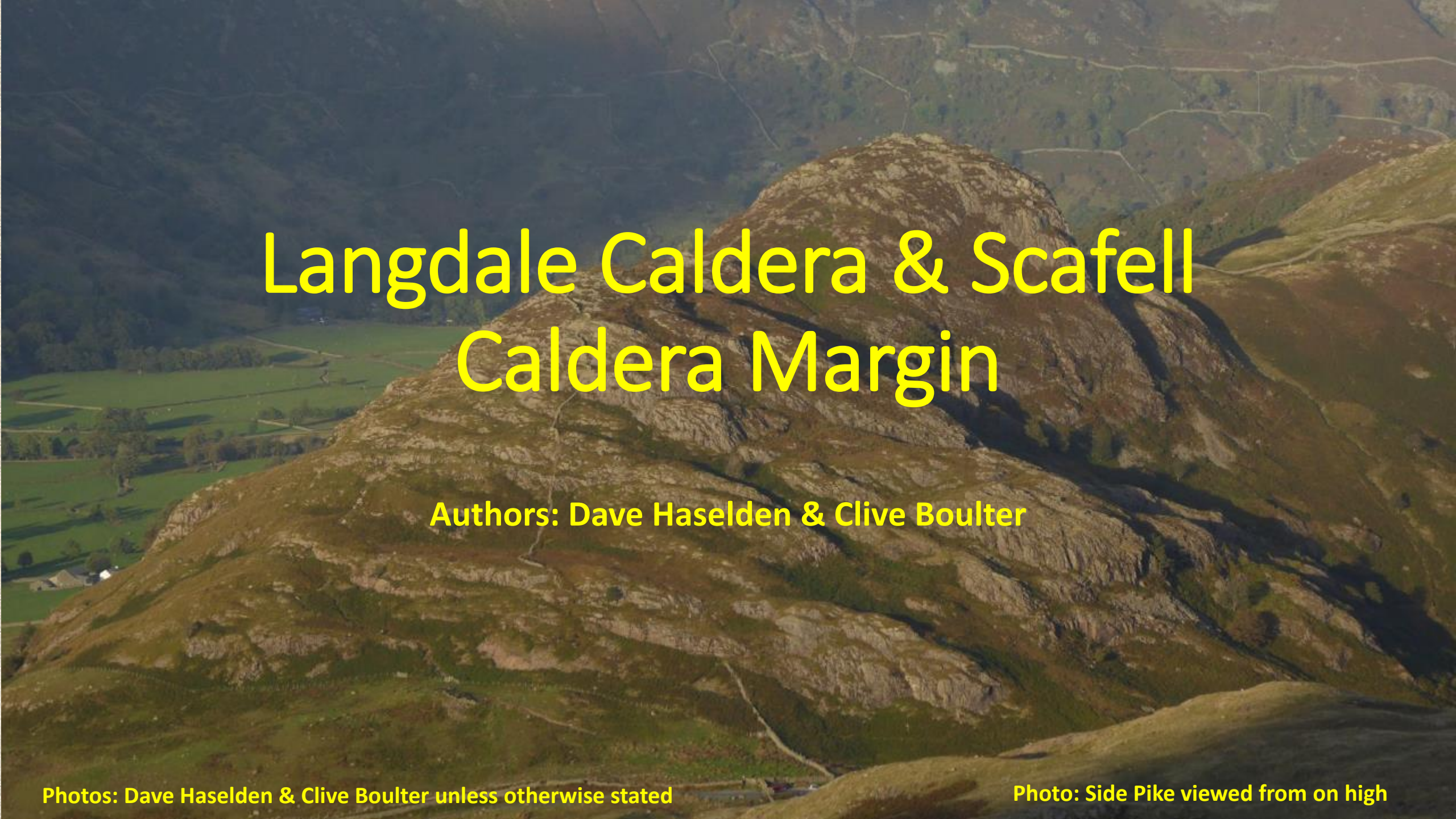
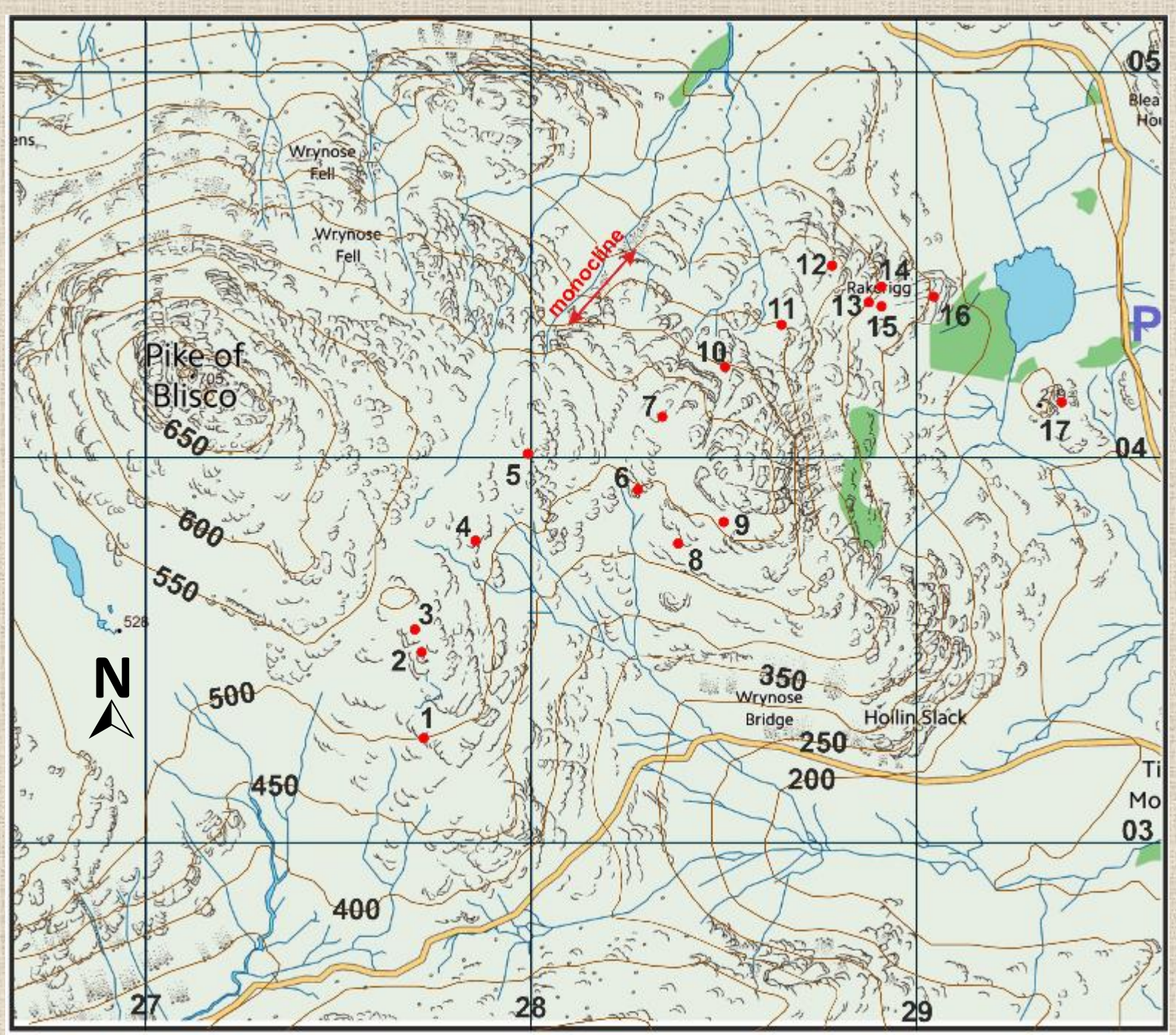


Langdale Caldera & Scafell Caldera Margin

Authors: Dave Haselden & Clive Boulter

Photos: Dave Haselden & Clive Boulter unless otherwise stated

Photo: Side Pike viewed from on high



LOGISTICS

This excursion can be approached in two ways. One is an out and return trip from Blea Tarn and the other starts at Three Shire Stone and ends at Blea Tarn which requires at least a vehicle at either end or a long return walk in the valley between Little and Great Langdale finishing with a slog up Wrynose Pass. Starting at Three Shire Stone provides a bit more context as it is unlikely the first three localities would be visited if Blea Tarn is the start point though the majority of the climb is done early on this route. A Three Shire Stone start means gravity is much more on your side.

None of the walking is on well-defined paths and much is over open fellside. The descent from Blake Rigg to Blea Tarn is steep and only partly on a weakly defined path.

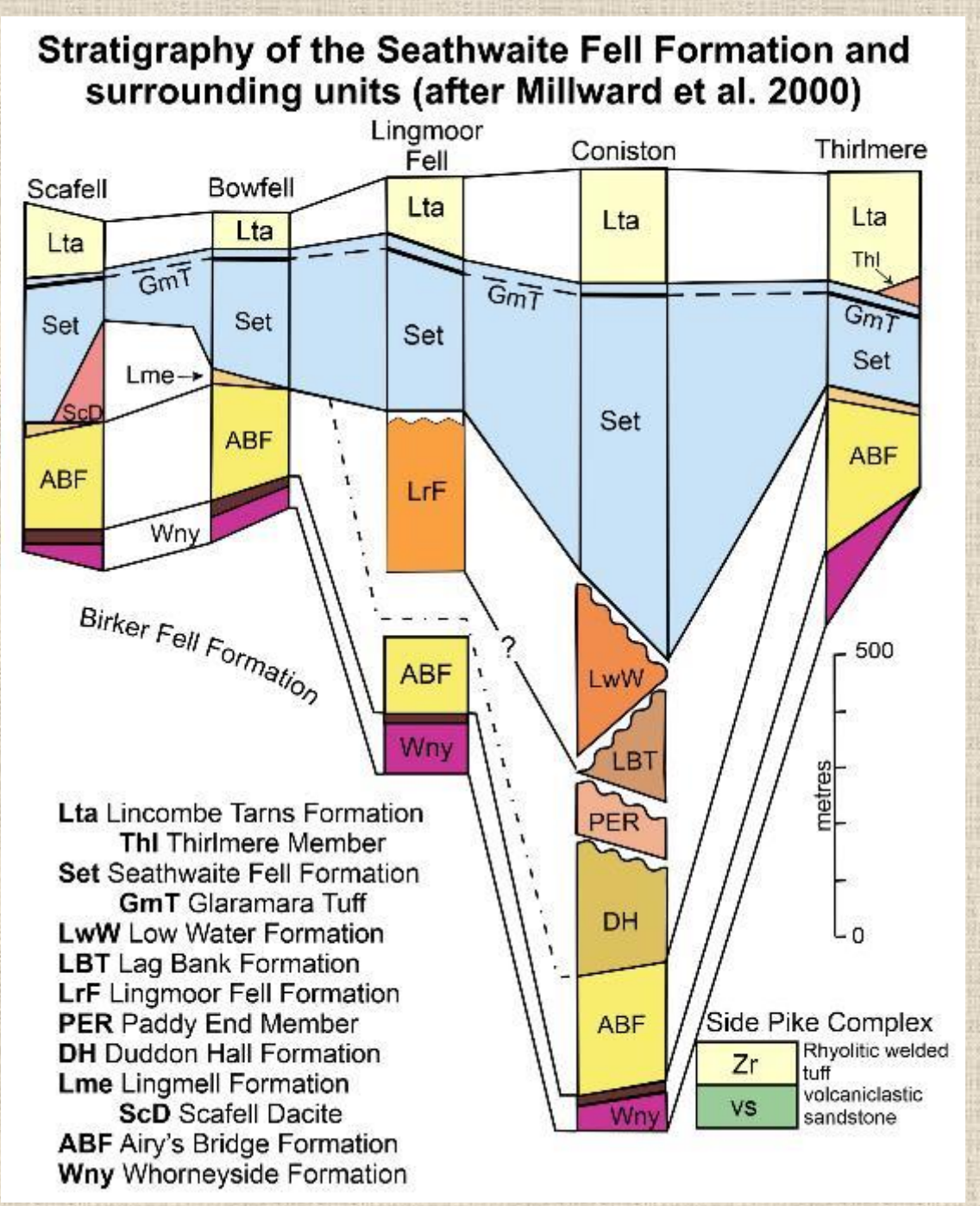
INTRODUCTION

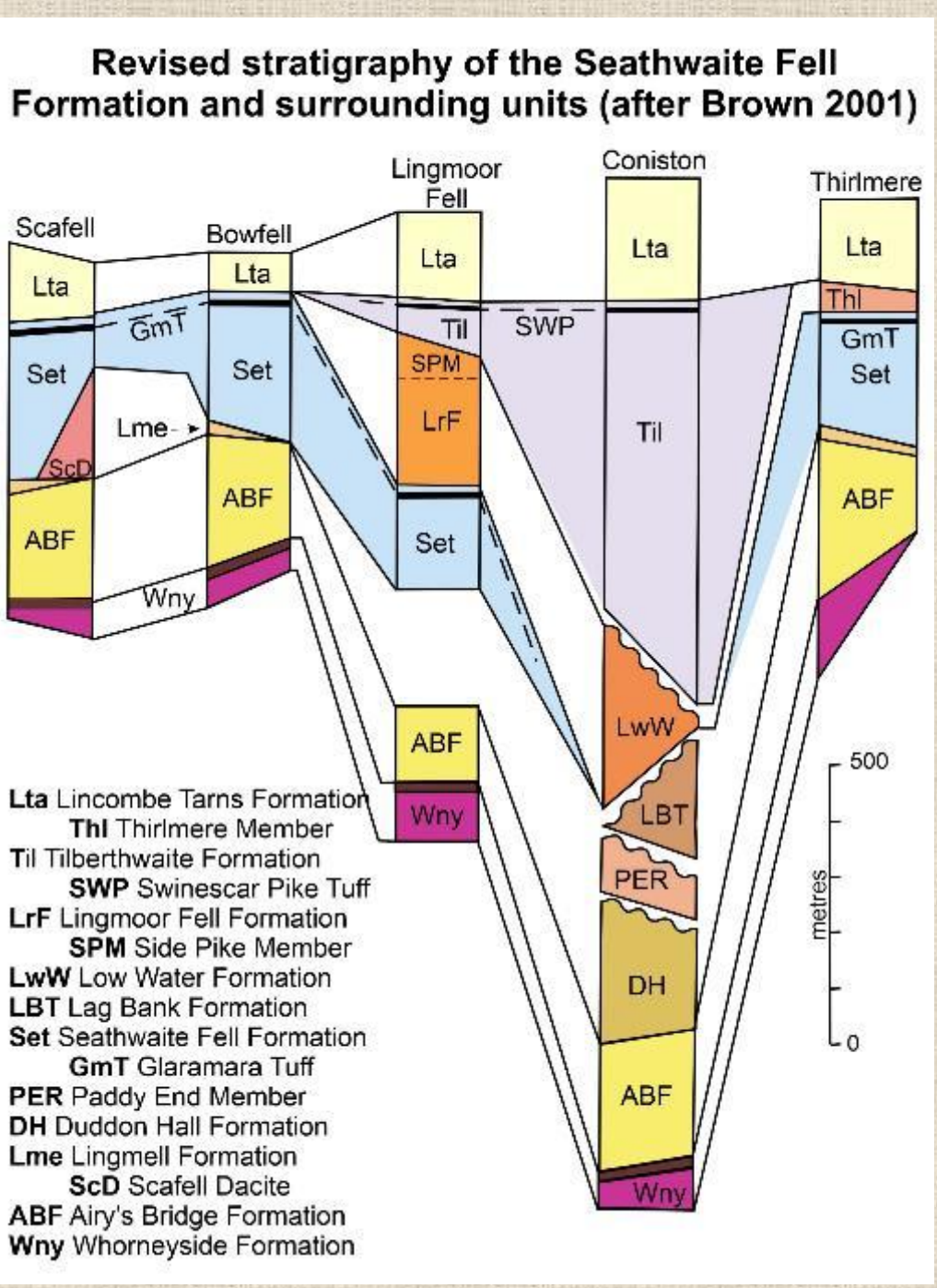
The main focus of the excursion is the Langdale Caldera but the area also provides an opportunity to examine part of the margin of the earlier Scafell Caldera. Both calderas involved piecemeal collapse which means volcanotectonic faults [VTFs] are abundant though those belonging to the younger caldera are much more prominent and will be a major topic of the day. To help put visitors into context the route takes advantage of some magnificent exposures of the Birker Fell Formation andesite lava flows which are the greater part of the plateau lava field pre-dating the abrupt change to paroxysmal eruptions. Explosivity started with andesitic magmas but was predominantly silicic. The initial andesitic explosivity is represented by 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]. Most of the excursion is in the former Side Pike Complex, a 5 km^2 area that could not be tied into the regional stratigraphy in the BGS resurvey.

However, very detailed work on part of the established stratigraphy of the Scafell Caldera was extended to the former Side Pike Complex with dramatic consequences for the stratigraphy of the Borrowdale volcanics and its volcanological model [Brown 2001]. At Long Crag five metres of stratigraphy 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. Having got this reference point it was apparent that the underlying twenty or so metres of water-lain volcaniclastics are the equivalent of the Seathwaite Fell Formation which is typically 100s of metres thick and at its maximum is 540 metres; this is a massively reduced section compared to the Scafell Caldera section just a short distance away on Crinkle Crags. This work implies a marginal Scafell Caldera setting and part of the steep-sided margin will be examined on the trip.

Another result, from the reassessment of the stratigraphy by Brown [2001], was the identification of the Langdale Caldera. Mapping by Dave Haselden and Clive Boulter has now documented some of this caldera and in particular the large number of VTFs, many of which are substantial structures. The new stratigraphic elements identified by Brown [2001] provided the basis for the mapping and additional units have been recognised during our mapping including a very thick ponded ignimbrite within the caldera.

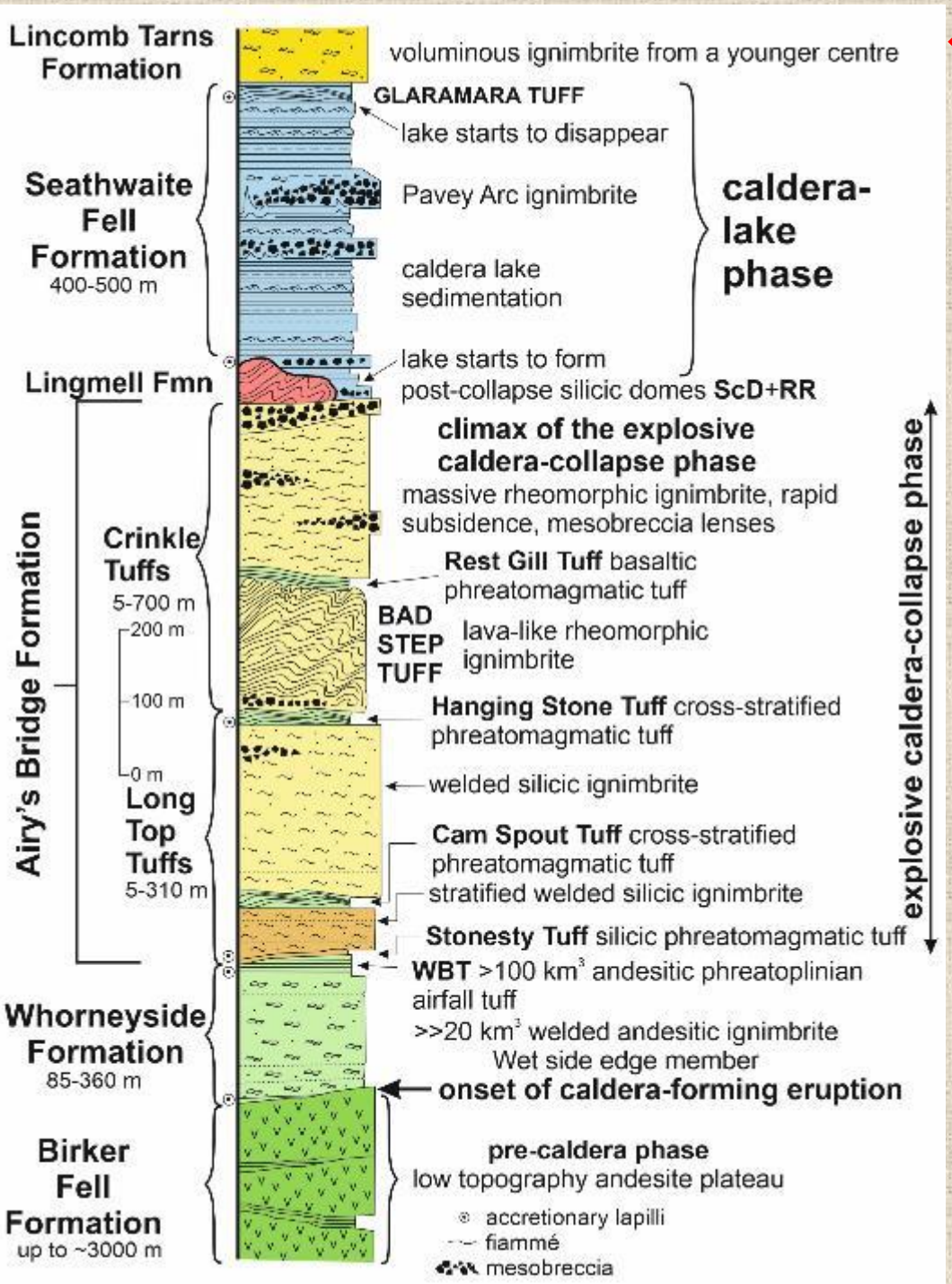
It is remarkable that the Langdale Caldera sequence repeats many of the Scafell Caldera's main elements. In particular the caldera sedimentary fill has a tuff ring event right at the end of the infilling process causing correlation problems in highly faulted and/or not well exposed areas.





Comparison of the correlations made in the Ambleside Memoir (Millward *et al*. 2000) and those made after recognition of Airy's Bridge and Seathwaite Fell Formation elements in the former Side Pike Complex (Brown 2001). The latter has been modified to remove some stratigraphic correlations that have not been generally accepted (Millward 2004). The projections shown here of the Seathwaite Fell Formation into the Coniston area may be conservative – it may pre-date the Duddon Hall Formation

Section locations are as follows: Scafell NY 215072; Bowfell NY 245065; Lingmoor Fell NY 305045; Coniston NY 290990; Thirlmere NY 320130; Side Pike Complex NY 285045.



Scafell Caldera stratigraphy as seen in the Central Fells [adapted from Brown et al. 2007].

Simplified stratigraphy for the flank region of the Langdale Caldera.

Several informal stratigraphic names have been introduced here within the Lingmoor Fell Formation. Brown [2001] subdivided the Side Pike Member [**SPM**] into Units 1 to 4. As used here the Side Pike Member includes Units 1 to 3. Unit 4 of Brown is mapped as the Miller Stands Member [**MSM**] and includes the Blake Rigg Rhyolite lava dome. The Tarnclose Crag Member is a few metres thick on the flanks and much thicker within the caldera.

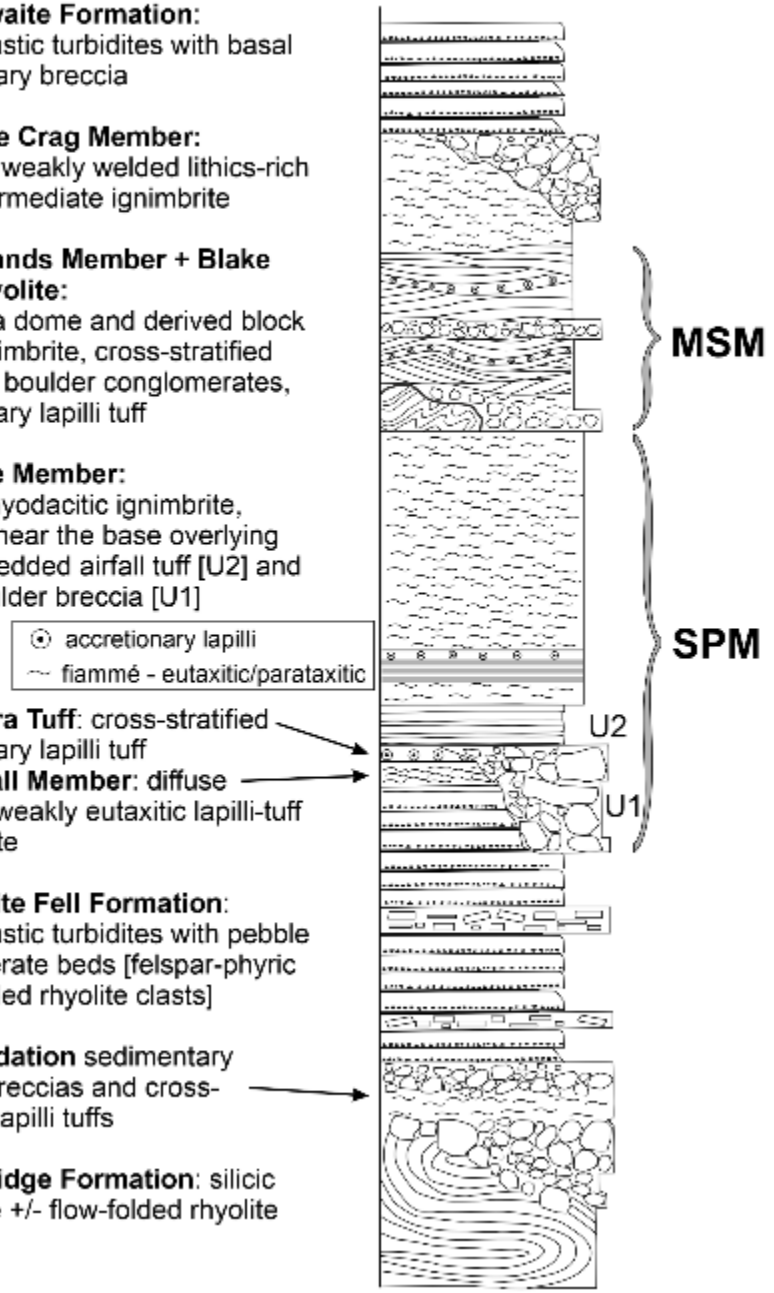
Simplified Stratigraphic Succession Langdale Caldera Flanks

Tilberthwaite Formation: volcaniclastic turbidites with basal sedimentary breccia

Tarnclose Crag Member: generally weakly welded lithics-rich felsic/intermediate ignimbrite

Miller Stands Member + Blake Rigg Rhyolite: silicic lava dome and derived block & ash ignimbrite, cross-stratified lapilli tuff, boulder conglomerates, accretionary lapilli tuff

Side Pike Member: welded rhyodacitic ignimbrite, stratified near the base overlying parallel-bedded airfall tuff [U2] and basal boulder breccia [U1]



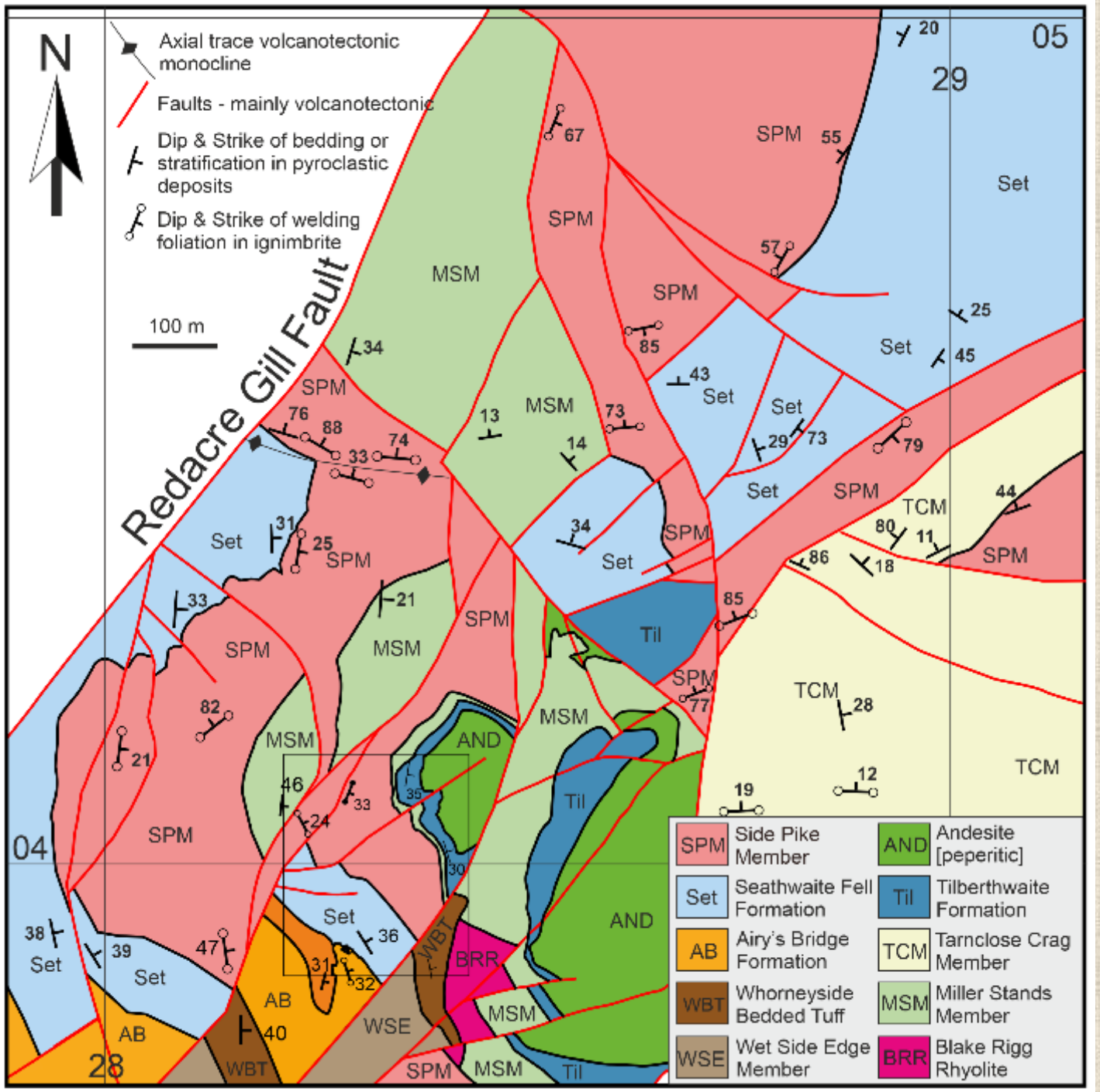
Glaramara Tuff: cross-stratified accretionary lapilli tuff

Black Wall Member: diffuse stratified weakly eutaxitic lapilli-tuff - ignimbrite

Seathwaite Fell Formation: volcaniclastic turbidites with pebble conglomerate beds [felspar-phyric flow-banded rhyolite clasts]

Pre-inundation sedimentary boulder breccias and cross-stratified lapilli tuffs

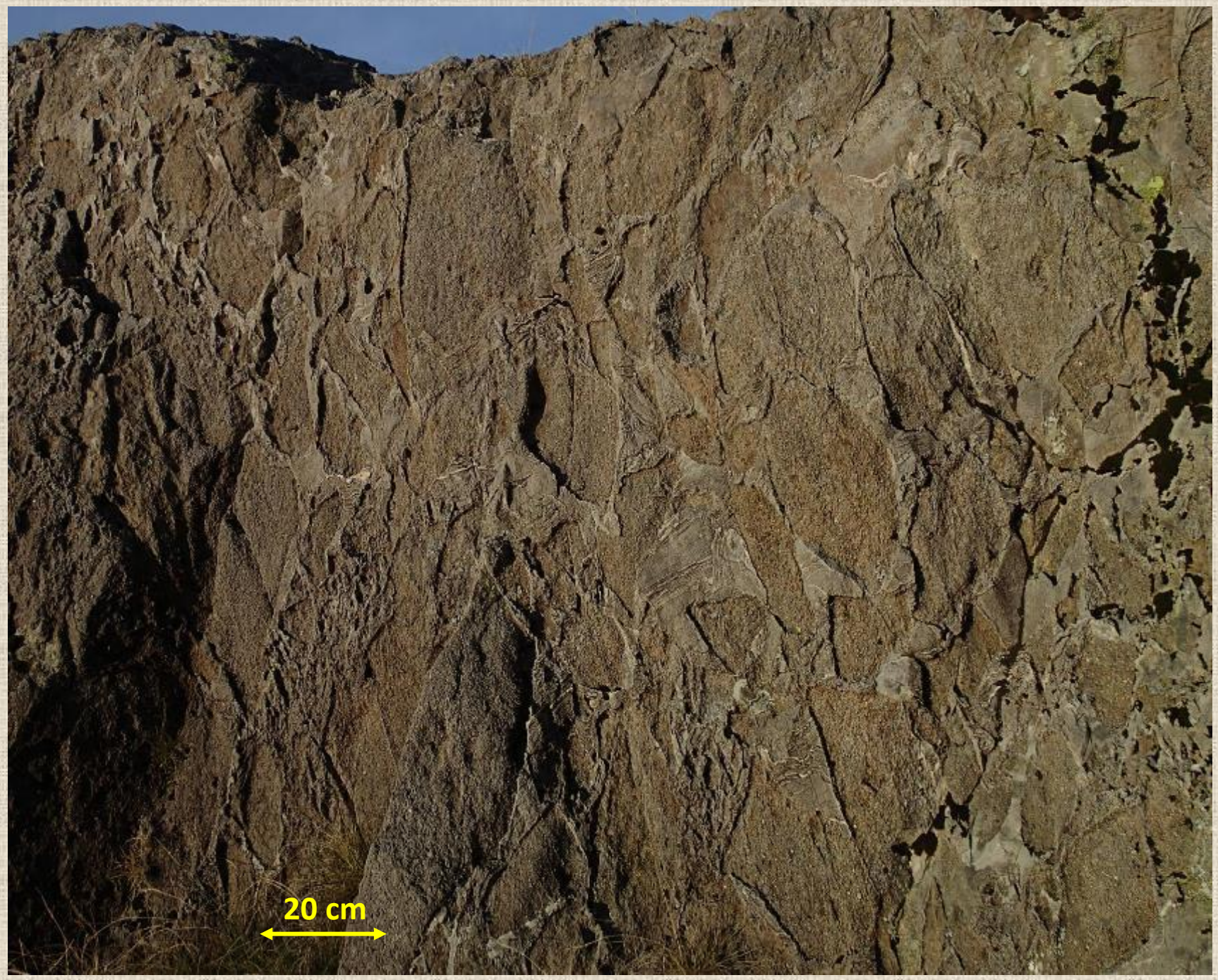
Airy's Bridge Formation: silicic ignimbrite +/- flow-folded rhyolite



Preliminary map of the Langdale Caldera in the excursion area.

Mapping, at scales between 1:1,000 and 1:2,000 on air photographs, started after the Coronavirus lockdown and, by that stage, bracken growth caused problems hence preliminary in the title. The area is characterised by an abundance of volcanotectonic faults including a couple of 70 to 100 m wide zones of sub-vertical welding fabrics in the Side Pike Ignimbrite [SPI]. One of these zones on the western flanks has folded the contact between the pre-Langdale Caldera Seathwaite Fell Formation and the SPI in a large monocline. In the centre of this fold there is a sharply and deeply incised gully which follows an Acadian brittle structure with no discernible displacement despite its physiographic expression. Some of the volcanotectonic faults are heavily iron stained interpreted to be caused by Acadian brittle reworking that allowed access of iron-rich solutions in the Triassic. Acadian reactivation has in some cases propagated VTFs into previously unfaulted ground but with no evident offset at the map scale.

The orange coloured unit is the pre-inundation sequence of the Scafell Caldera between the Airy's Bridge and Seathwaite Fell formations. It is a mixture of sub-aerial pyroclastics [ignimbrite] and boulder conglomerates.



Locality 1 NY 27736 03273

Birker Fell Formation

Top of an andesite sheet where a sedimentary network infills the gaps between feldspar-phyric andesite blocks. 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.

On the first part of the traverse to Long Crag there are many excellent exposures of andesite lava flows and intercalated stratified rocks both pyroclastics and reworked materials. This part of the Birker Fell Formation has a higher percentage of andesite than the average 60%. Overall the unit has the form of a plateau andesite field.

Locality 1 NY 27736 03273

A closer look at the relationships between the sedimentary and andesite components. At this scale the phenocrysts in the andesite give an almost granular texture which might be mistaken for a sedimentary texture.

At this locality 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. Weak hydrothermal alteration is responsible for this reversal of fortunes.

Coin is 21.4 mm in diameter.

Lava Flow vs High Level Sill Discrimination

Diagrams in text books make this task look simple but in reality it is a significant challenge. You have to concentrate on the top contact because the base of a lava flow can produce a peperitic interaction with the underlying soil or sediment. 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 effects, if present, are typically restricted to millimetre thick zones because most of the energy of the intrusion goes in heating the sediment pore fluid.

Peperite in the River Sprint, Longsleddale.

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

Andesitic welded ignimbrite with a weak welding fabric. The WSE marks the start of large-scale explosivity in the Scafell Caldera.

Coin is 21.4 mm in diameter.

Locality 3 NY 27697 03564 Whorneyside bedded tuff & evidence for early piecemeal caldera collapse

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. Large volumes of water accessed the magma chamber and created a very damp eruption. Ash aggregates are common and sorting is much poorer than typical airfall tuffs. Damp ash and lapilli clumped together and showered out of the umbrella cloud.

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 create horst & graben patterns as can be seen in the background of this photo.

Locality 4 NY 27861 03797 Airy's Bridge Formation overlain by sedimentary breccias and thin ignimbrites

At this locality a bedded sequence of boulder to pebble sedimentary breccias is intercalated with thin welded ignimbrites. These deposits rest on the youngest Airy's Bridge unit in the region which is probably a high-grade lava-like ignimbrite. It is either the Bad Step Tuff or some other part of the Crinkle Member.

Not an essential locality but it is a well-exposed example of the pre-inundation deposits before the Scafell Caldera began to fill with water. The equivalent unit at **Locality 7** is less clearly displayed. Seathwaite Fell Formation turbidites occupy the poorly exposed ground between here and Long Crag, but there is a VTF immediately south of Locality 4 which is not seen on Long Crag hence there must also be a N/S fault west of the crag.

FROM THIS REFERENCE POINT TRAVERSES WILL BE MADE TO THE SOUTH AND EAST

Locality 5 NY 27992 04002 Long Crag Black Wall “Member” and Glaramara Tuff, Seathwaite Fell Formation

Perhaps the most important locality in the region because two distinctive units were recognised by Brown [2001]. These two units 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 crag is about 4.5 metres 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 [fiammé] 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 [Brown et al. 2007].

Locality 5 NY 27992 04002
Glaramara Tuff at Long Crag

The whole of the field of view 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.

If you go south from here, over the grassy gully, the Glaramara has been removed by erosion at the base of the Lingmoor Fell Formation. The Glaramara exists in only small pockets in the area mapped for this excursion guide because of this erosive event.

Coin: 21.4 mm in diameter.

Locality 5
Glaramara Tuff at Long Crag

Closeup view of the multiply rimmed accretionary lapilli up to 1 cm long.

Traversing south along the west side of Long Crag takes you through continuous exposure of the massively reduced Seathwaite Fell Formation section most of which is seen in this photograph **[NY 28010 03892]**. The well-developed bedding is mainly turbiditic in origin but none of the distinctive members [Three Tarns, Harrison Stickle, Cam Crags, Bell Crags, Dungeon Ghyll, Pavey Ark, Bowfell Links, Cockley Pike] 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 up to 50 cm pumice clasts from a subaqueous eruption.

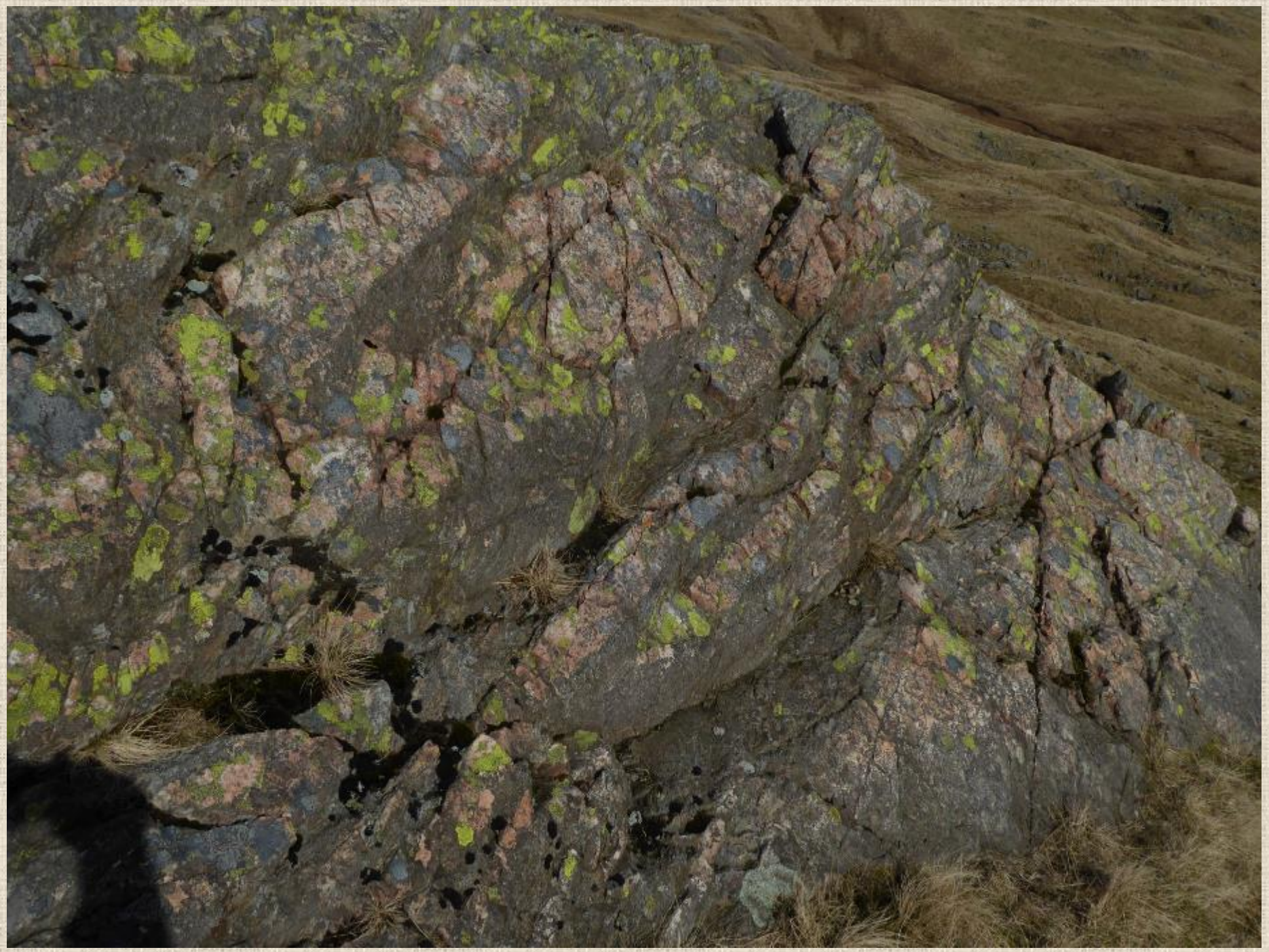
Just below this point is the Airy's Bridge Formation which here is either a flow-folded rhyolite or a lava-like ignimbrite.

NY 28010 03894

Pumice breccia bed, roughly half way up the Seathwaite Fell Formation sequence. This is the result of a subaqueous explosive eruption within the Scafell Caldera. The coin is resting on a pumice clast. Follow the bed down dip to see the pumice bed on a vertical joint face.

At **Locality 6** [Scafell Caldera margin] correlates of this bed occur about halfway through a 70 m thick Seathwaite Fell sequence.

Coin is 21.4 mm in diameter.



The southerly traverse from **Locality 5** ends in an Airy's Bridge correlate. The contact is at NY 28020 03845. It is either a rhyolite with flow banded and flow folded [NY 28037 03776] on a metric-scale or it is a rheomorphic high-grade, lava-like ignimbrite. On the BGS Ambleside 1:50,000 Sheet this unit was correlated with the Oxendale Tuff but it could be part of the Crinkle Member.

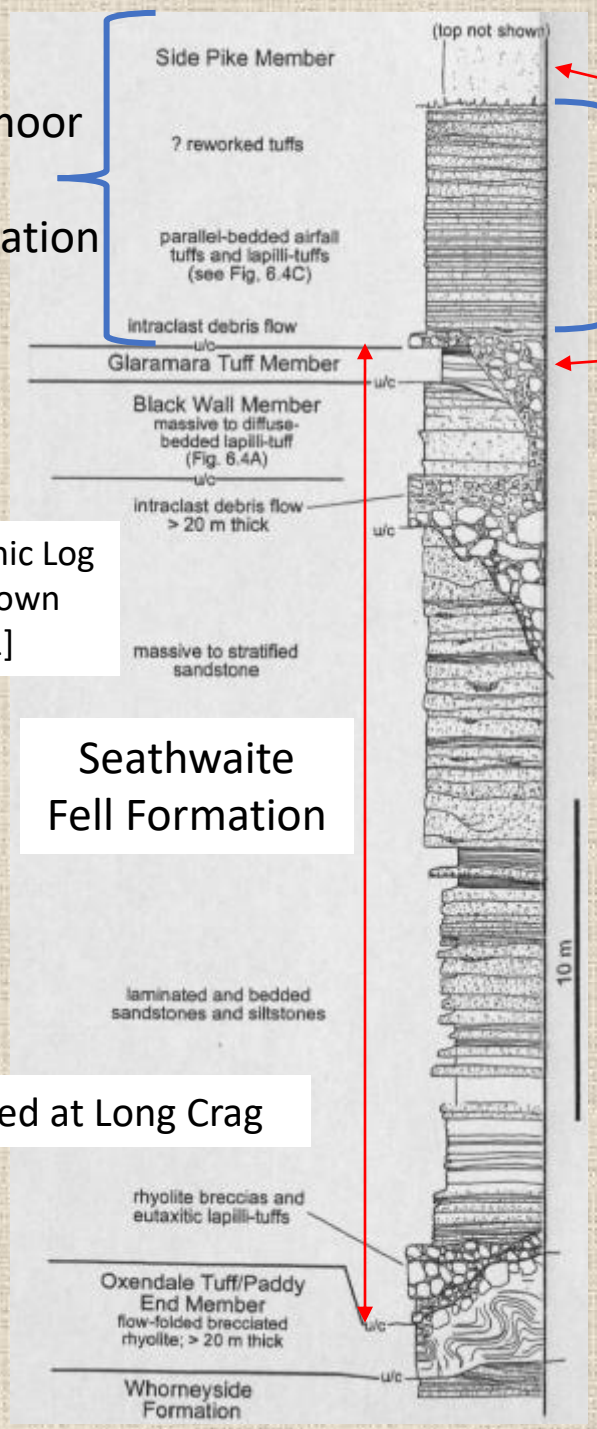
The lower southern contact of the Airy's Bridge here is a minor fault.

Return to the Glaramara/Black Wall exposure.

Above the Glaramara there is an erosive contact with an overlying pebble/boulder breccia – Unit 1 of Brown's Side Pike Member [part of the Lingmoor Fell Formation]. The contact is in the form of deeply-incised gullies and can be traced to the south near the top of the crags of Long Crag. Unit 1, which is up to 20 metres thick, cuts out the Glaramara immediately to the south of Locality 5 and the Glaramara is only intermittently present in the Langdale Caldera because of this erosion. Also Unit 1 is only locally present being highly lenticular.

Immediately above **Locality 5** the pebble/boulder sedimentary breccia is only a metre or so thick. Above that is eight metres of mainly parallel-bedded airfall tuffs [Unit 2], some of which has been aqueously reworked, overlain by a distinctive rhyolitic welded- ignimbrite which is about 30 metres thick. This silicic ignimbrite is the Side Pike Ignimbrite and is very distinctive in most exposures and, without such a recognisable unit, the mapping of the Langdale Caldera would have been even more difficult than it was.

In most of the Langdale Caldera the Lingmoor Fell Formation is represented by the Side Pike Member [Brown, 2001]. This has been subdivided into four units, two of which are laterally impersistent. **Unit 1** is the basal breccia, **Unit 2** is the predominantly airfall component, and **Unit 3** is the rhyolitic ignimbrite seen east of **locality 5**. **Unit 4** is another predominantly pyroclastic unit seen at **localities 7 & 9**. We have informally named Unit 4 the Miller Stands Member.



Lingmoor Fell Formation

Graphic Log By Brown [2001]

Seathwaite Fell Formation

Logged at Long Crag

Unit 3

Unit 2

Unit 1

SIDE PIKE IGNIMBRITE [Unit 3]

50 cm accretionary lapilli tuff

20 m massive parataxitic lapilli tuff with small rheomorphic folds and wrapped lithics. Top 9 m has white weathering felsic lithics <20 cm

1 m massive tuff grading upwards

5 m massive eutaxitic welded lapilli tuff with a diffuse crystal-rich zone at the base in which fiammé increase in size and abundance upwards

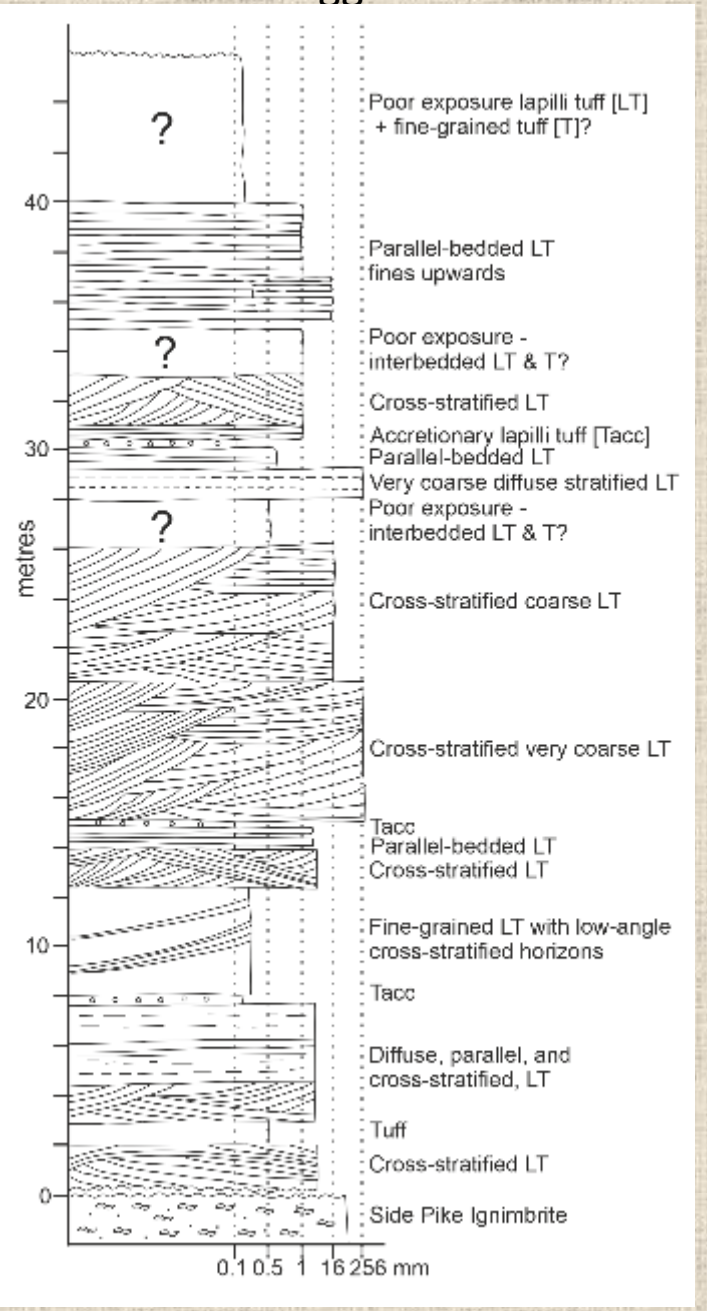
1.5 m thin-bedded partly silicified tuffs and lapilli tuffs with accretionary lapilli horizons

3.5 m thin to thick bedded lapilli tuff with low angle truncations

8 m massive partly silicified tuff

Miller Stands Member[Unit 4] Log

south of Blake Rigg NY 28710 03575



A traverse from **Locality 5** going east will give a good idea of the internal features of the Side Pike Ignimbrite which are useful for mapping the area and determining where exposures are within the unit.

This is a very distinctive exposure **[NY 28040 04022]** a few tens of metres east of **Locality 5**. It allows close examination of the stratified five metres zone between eight and thirteen metres above the base of the Side Pike Ignimbrite. For the exposures of the ignimbrite overlooking Redacre Gill, this stratified zone is in contact with Seathwaite Fell Formation turbidites in an area where the Black Wall ignimbrite has thickened considerably.

Continuation of the Side Pike Ignimbrite traverse.

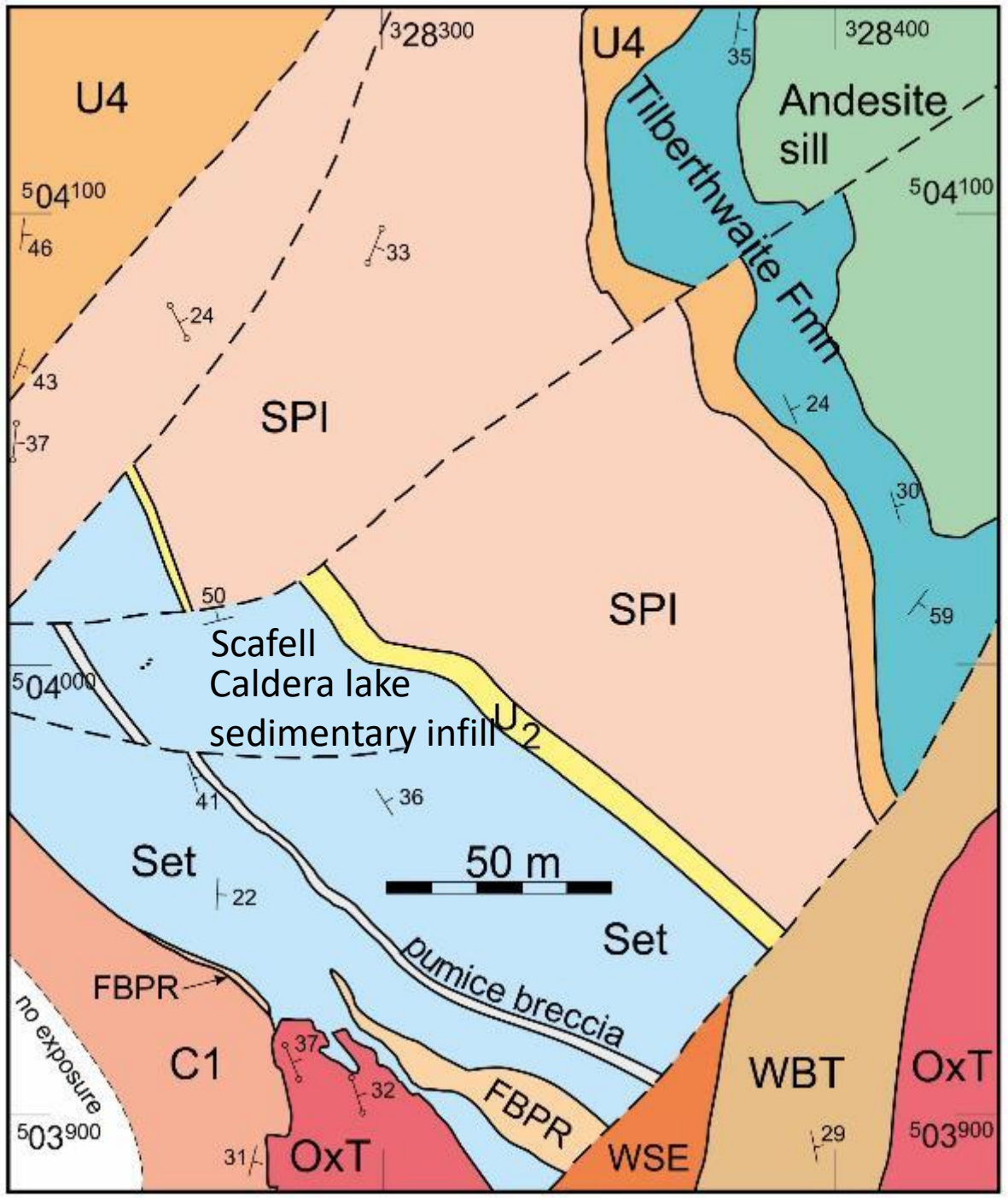
NY 28067 04044
Left: a high concentration of small fiammé around 2-3 cm in length. This is a characteristic feature of much of the Side Pike.

Right: microfolding of the parataxitic welding fabric creating a crenulated effect.

NY 28067 04039 & 28076 04058 have large fiammé and wrapped lithics.

Left: a wrapped lithic that has not been compacted.

Right: a very large fiammé showing extreme flattening.



LOCALITY 6 NY 28282 03919 Scafell Caldera Margin

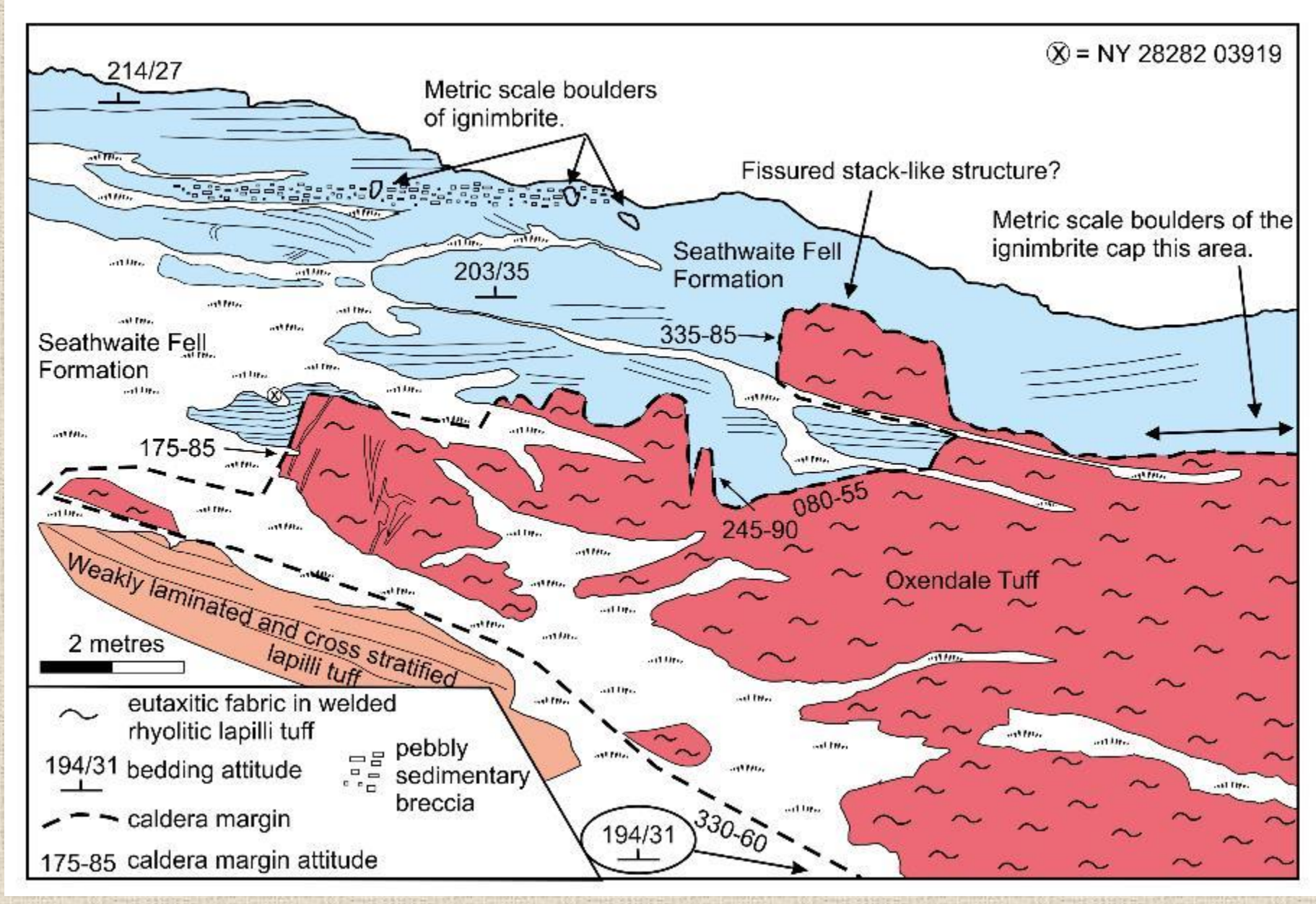
This locality was documented in Branney & Kokelaar [1994] and the relationships here were used to support the chaos/megabreccia interpretation of the former Side Pike Complex. Boulter *et al*. [2020] have interpreted the locality as being the steep-sided margin of the Scafell Caldera.

U4	Unit 4 Cross stratified lapilli tuff & boulder conglomerate
SPI	Side Pike Ignimbrite - welded rhyolitic lapilli tuff
U2	Unit 2 Side Pike Member - parallel bedded tuffs
Set	Seathwaite Fell Formation - turbiditic volcaniclastic sandstones
C1	Subaerial succession of stratified lapilli tuff, boulder conglomerates
OxT	Welded rhyolitic lapilli tuff **Oxendale Tuff?**
WBT	Whorneyside Bedded Tuff andesitic air fall tuff
WSE	Wet Side Edge Member

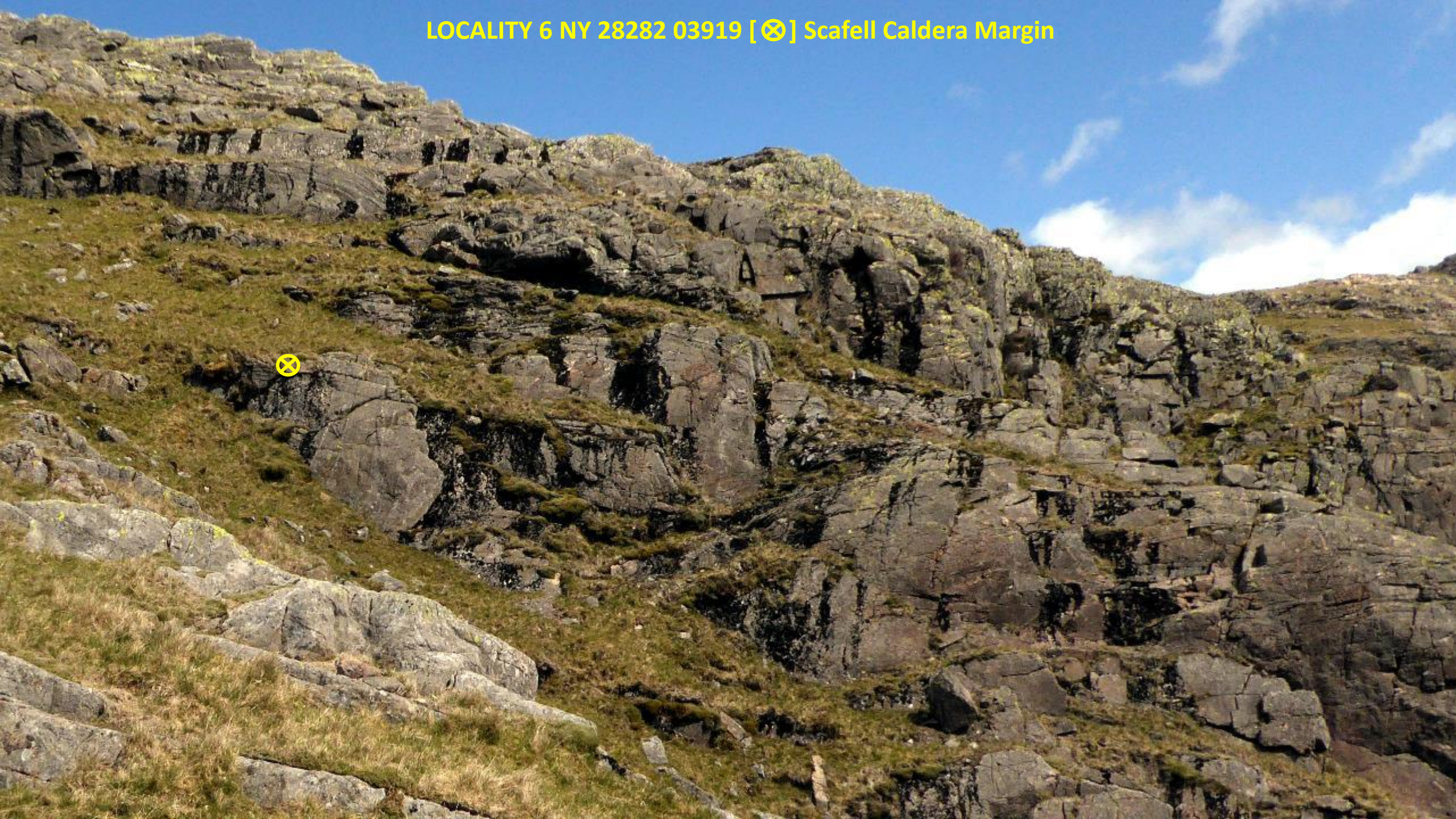
≈ a homocline

dip & strike – welding foliation

LOCALITY 6 NY 28282 03919 [⊗] Scafell Caldera Margin



This line drawing from Boulter et al. [2020] covers the main features of **Locality 6** and the next slide is a photograph of approximately the same area. In red is part of the Airy's Bridge Formation – a moderately welded silicic lapilli tuff, possibly the Oxendale Tuff or part of the Crinkle Member. In places a locally derived boulder conglomerate overlies the welded ignimbrite and this in turn is overlain by weakly-laminated and cross-stratified lapilli tuff deposited by dilute PDCs. These two units are interpreted as pre-inundation deposits formed before the caldera lake was established. In blue is the Seathwaite Fell Formation which is a mainly turbiditic unit. At ⊗ bedding in the turbidites but-up against a steeply-dipping contact with the Airy's Bridge unit. This contact has a variable attitude but is mainly steep. It is interpreted as the post-caldera collapse margin of the Scafell Caldera. The alternative interpretation is that it represents the edge of a mega-block that ploughed into the sediments.


LOCALITY 6 NY 28282 03919 [⊗] Scafell Caldera Margin

A typical example of the in-situ welded lapilli tuff [ignimbrite] at **Locality 6** which is from the Airy's Bridge Formation, possibly the Oxendale Tuff or part of the Crinkle Member. Flattened pumice fragments [fiammé] are recess-weathered.

Below: the small crag south of the reference point NY 28282 03919 with sediment-filled fractures in the in-situ welded ignimbrite.
Right: a sediment-filled fissure in the welded ignimbrite that is continuous with the overlying Seathwaite Fell Formation.

A boulder conglomerate from the pre-inundation deposits that immediately overly the in-situ welded ignimbrite. The boulders are mainly of welded ignimbrite and the welding fabrics are variably orientated from boulder to boulder. Careful examination is necessary to identify the boulder/matrix contacts. Immediately above the boulder conglomerate, in some areas, is a weakly-stratified ignimbrite with a weak welding fabric which is also part of the pre-inundation sequence.

An example of the pebbly turbidites at Locality 6.

The Seathwaite Fell Formation at **Locality 6** has a lower part of thin to medium bedded sand-grade turbidites whereas the upper part is thickly bedded pebbly coarse-sand turbidites deposited from high-concentration turbidity currents. Approximately halfway through the seventy metre thick sequence is a zone of white weathering beds including a bed of large pumice clasts correlated with the similar bed on Long Crag. The soft-sedimentary deformation at this locality is comparable in intensity to that seen in much of the Scafell Caldera.

Two horizons of pebbly breccias are distinctive. The pebbles are flow-banded rhyolite which has pink feldspar phenocrysts around a millimetre in length. The uppermost example thickens to the south.

Locality 7 NY 28346 04111

A weakly stratified accretionary lapilli tuff caps the Side Pike Ignimbrite [closeup photo bottom left next slide]. It has been interpreted as a co-ignimbrite air fall deposit. Below it is a good section showing the characteristics of the uppermost Side Pike Ignimbrite [top two photos next slide]. Above the accretionary lapilli there is a grassy ledge before the first exposures of a very thin section of the Miller Stands Member [MSM] – approx. twenty metres north along this horizon there is a bed with large accretionary lapilli up to 2 cm in diameter in the MSM. The small scarp above the grassy ledge exposes the erosional contact of Miller Stands Member with basal breccias of the Tilberthwaite Formation [bottom right photo next slide]. Above this breccia, Tilberthwaite turbidites mark the establishment of the lake in the Langdale Caldera.

Fans of **peperite** might want to check out the lower contact of the andesite sill close by at NY 28375 0413. This contact is generally well exposed for several tens of metres.

Locality 7 Uppermost Side Pike Ignimbrite just below and a little to the north of the bed of accretionary lapilli. In the upper nine metres the axial ratio of fiammé decreases and large [<20 cm] silicic lithics become common. These features are useful to monitor where exposures are in the stratigraphy.

Left: Detail of the cap to the Side Pike Ignimbrite. The accretionary lapilli are typically around 5 mm.

The pale lower part of the photo to the right is the Miller Stands Member. Above the erosional contact is the basal sedimentary breccia of the Tilberthwaite Formation marking a return to caldera lake depositional conditions.

Locality 8 NY 28397 03779
VTF in Side Pike Member

Left: Side Pike Ignimbrite with a steeply dipping welding fabric outcrops faulted against Whorneyside Formation to the north. The steep fabric is indicative of a volcanotectonic fault (VTF) trending approximately NE-SW dipping at about 80 degrees south. To the NW and SE the welding fabric is less inclined so that overall the outcrop forms a monoclinal structure.

The Side Pike Ignimbrite is overlain by flow banded rhyolite (informally named the Blake Rigg Rhyolite) which can be traced uphill to the lava dome at **Locality 9**. Along most of its length the rhyolite rests on Whorneyside Bedded Tuff from the Scafell Caldera succession and was assumed by the BGS survey to be Oxendale Tuff. However at this locality the rhyolite can be seen to overstep the WBT onto the Side Pike Ignimbrite indicating it is much younger and part of the Langdale caldera succession.

The Side Pike Ignimbrite is faulted against Whorneyside Formation at what must be a significant VTF whereas the overlying Blake Rigg Rhyolite and Miller Stand Members are only displaced by a few meters indicating the major fault movement was linked with the emplacement of the Side Pike Member. The fault can be traced up into the overlying Tilberthwaite Formation suggesting it was reactivated much later, possibly during the Acadian orogeny.

The Side Pike Ignimbrite continues to the south but there is limited outcrop with a gently sloping grassy boulder strewn hillside instead of the almost continuous exposure of earlier localities. This suggests much of the SPI here has been weakened by hydrothermal alteration associated with faulting and has been readily eroded.

Locality 8a NY 28461 03801

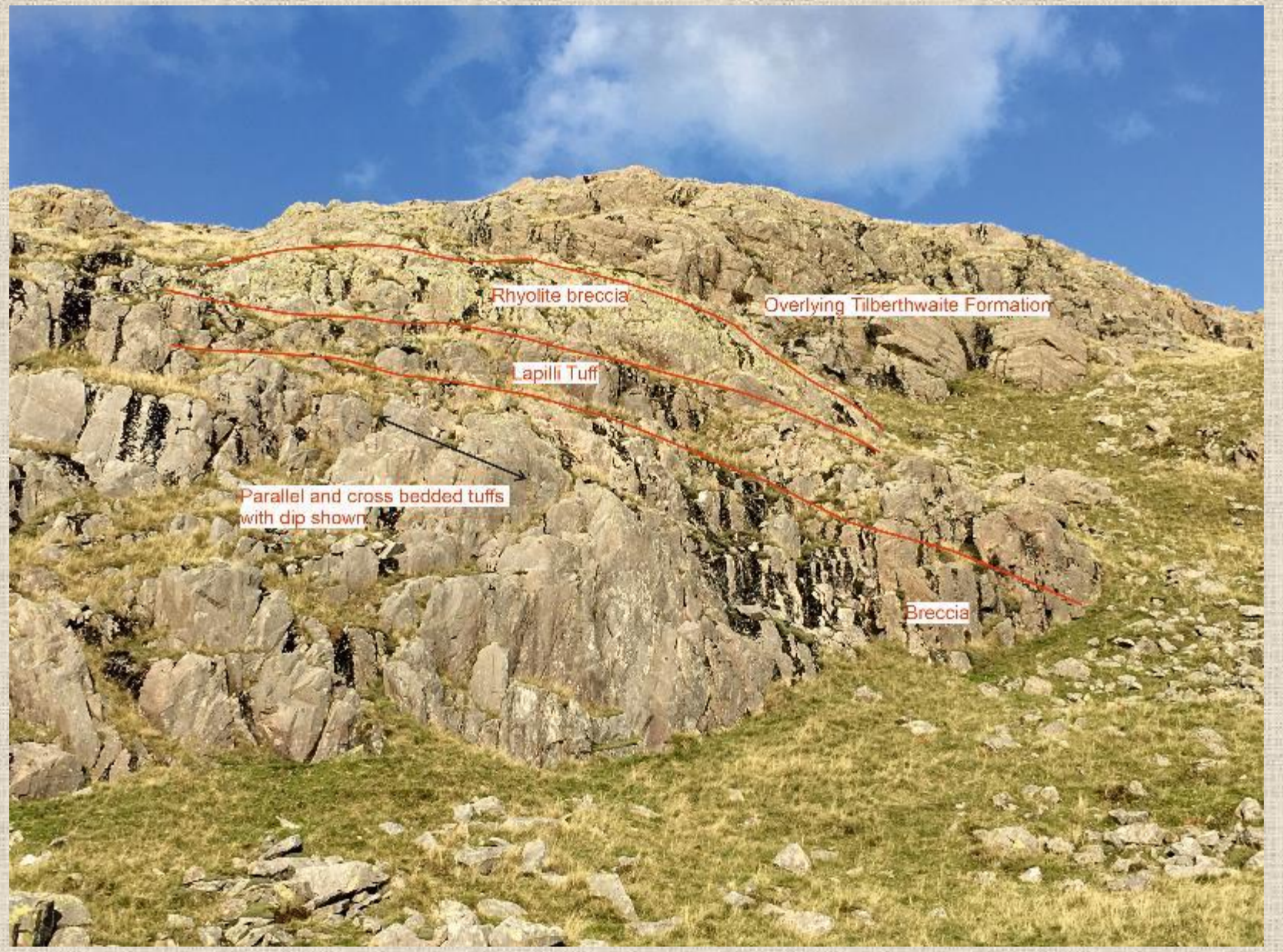
The Miller Stands Member is very varied and below Blake Rigg going towards Miller Stands it is mainly cross-stratified lapilli tuff typical of deposits from dilute PDCs. Locality 8a is close to the VTF of Locality 8 and is a reasonable example of the MSM style.

Other localities to show some of the variations on the Miller Stands theme.

Locality 9 NY 28435 03925
Blake Rigg Rhyolite

As an expression of the variability of the Miller Stands Member, at this locality it takes the form of a flow banded silicic lava dome which is informally named the Blake Rigg Rhyolite. It is faulted against the Miller Stands Member to the south by a VTF and the highest exposure is capped by Tilberthwaite Formation turbidites. A breccia comprising flow banded rhyolite overlies the Miller Stands Member suggesting the dome was active in late Miller Stands times – see **Locality 9a** To the north, the rhyolite is capped by a thin welded ignimbrite of a similar composition has shed an apron of boulder breccias. Folding of flow banding is common. The dome probably represents ascent of degassed magma towards the end of the main eruptive phase of the Langdale Caldera. Parallels with the Scafell Caldera again become obvious as this dome, in its position in the caldera-forming sequence, is equivalent to the Scafell Dacite and the Rosthwaite Rhyolite.

Locality 9a Miller Stands Member NY 28459 03843



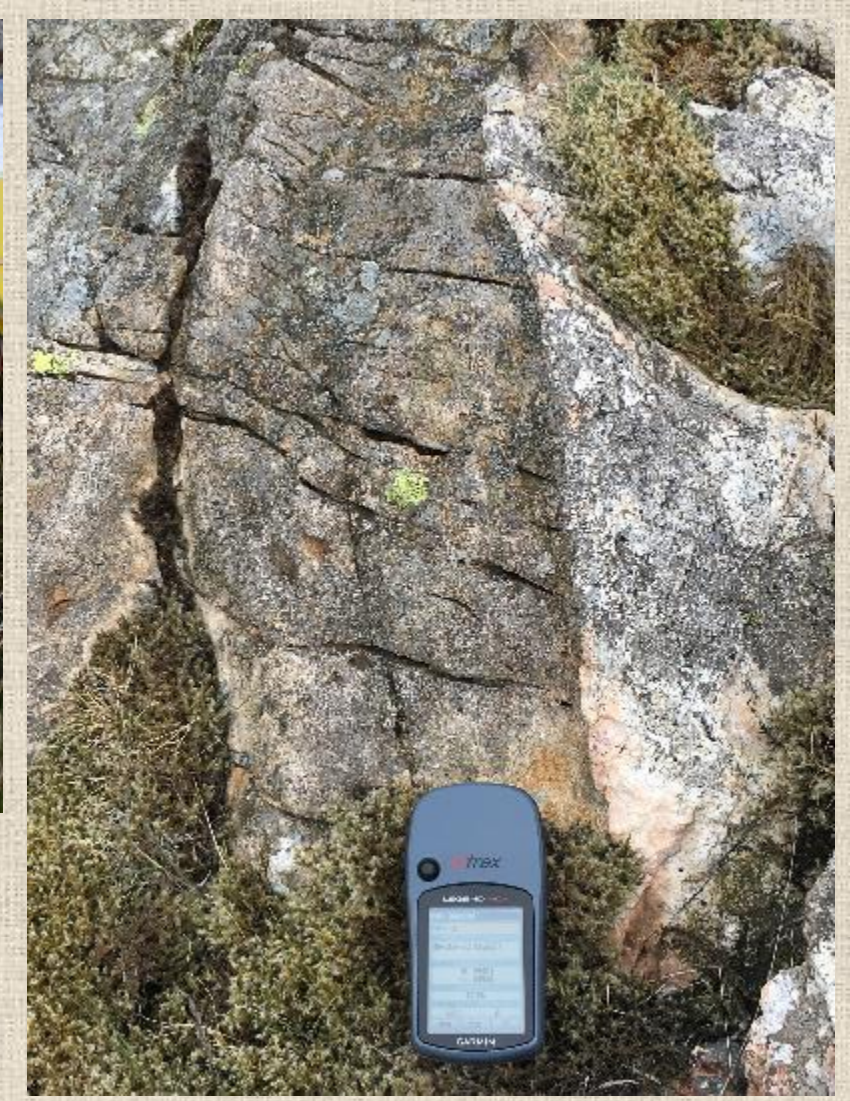
This locality demonstrates that the Blake Rigg Rhyolite dome was active in late- or post-Miller Stands times. The Miller Stands Member bedded tuffs and lapilli tuff are overlain by breccia with clasts of predominately flow banded rhyolite (below).

Locality 9b NY 28420 03942

Boulder breccia possibly a block-ash PDC deposit shed from the rhyolite dome in the Miller Stands Member. The clasts are a mixture of flow-banded rhyolite, welded ignimbrite, and clasts from the pre-Miller Stands stratigraphy.

At this locality the Miller Stands Member rests on Whorneyside Bedded Tuff because a volcanotectonic fault to the south has had a major effect on the stratigraphy. When you cross the fault in the large slack [with tarns] below **Locality 9**, the stratigraphy is more complete as we see at **Locality 7**.

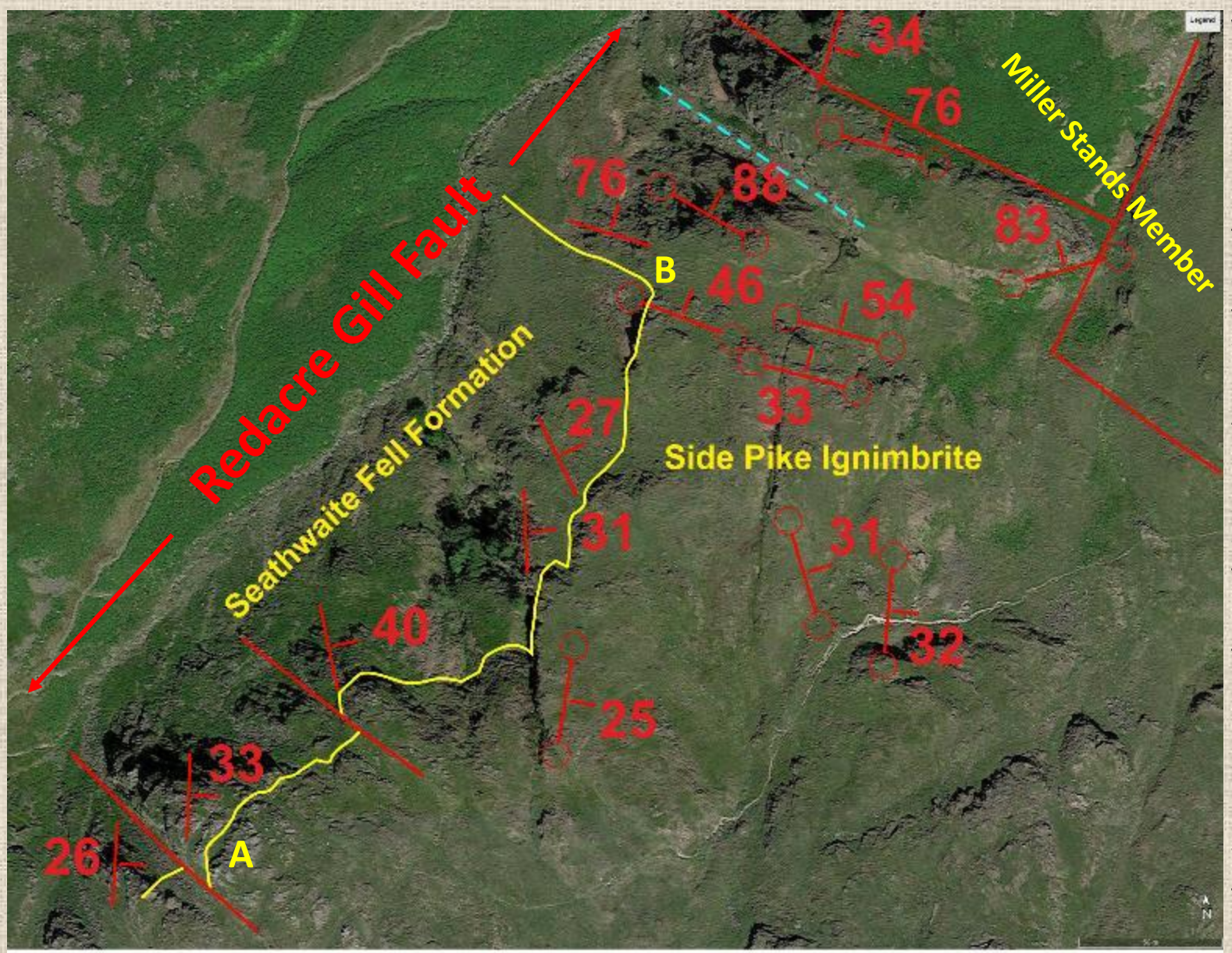
Above: Eutaxitic lapilli tuff resting on the Blake Rigg Rhyolite



Above: Vertical contact between the lapilli tuff on the left and flow banded rhyolite on the right

Locality 9c NY 28439 03933
Thin welded ignimbrite on top of the Blake Rigg Rhyolite lava dome

Immediately on top of the lava dome a very thin ignimbrite has a moderately-well defined welding fabric. The contact becomes vertical a few meters to the south west indicating a steepening margin to the dome.



Volcanotectonic-Monocline

Bit of a detour but this is the best exposed example of a volcanotectonic structure in the area.

At A [NY 28106 04280] there is a well exposed section through the basal Side Pike Ignimbrite into the Seathwaite Fell Formation. The top seven metres of the latter are turbidites and below that 25 m of Black Wall ignimbrite.

At NY 28251 04515 just south of B the crags are of stratified basal Side Pike Ignimbrite and poorly exposed below the crags there are small exposures of Seathwaite Fell Formation turbidites. The bedding in the turbidites and stratification in the ignimbrite have similar moderate dips to those seen in the traverse A to B. Close by to the north [NY 28252 04507] the stratification in the Side Pike Ignimbrite dips 76° to the north striking 107/287. This abrupt change marks the closure of a highly angular fold and to the north there is an eighty metre wide belt of sub-vertically dipping welding fabric in the Side Pike Ignimbrite truncated to the north by a VTF. In the centre of this belt there is a sharply incised gully that has no discernible offset which appears to be an Acadian fracture perhaps generated when caldera blocks responded to the orogenic stresses.
Google Earth used as the base map.

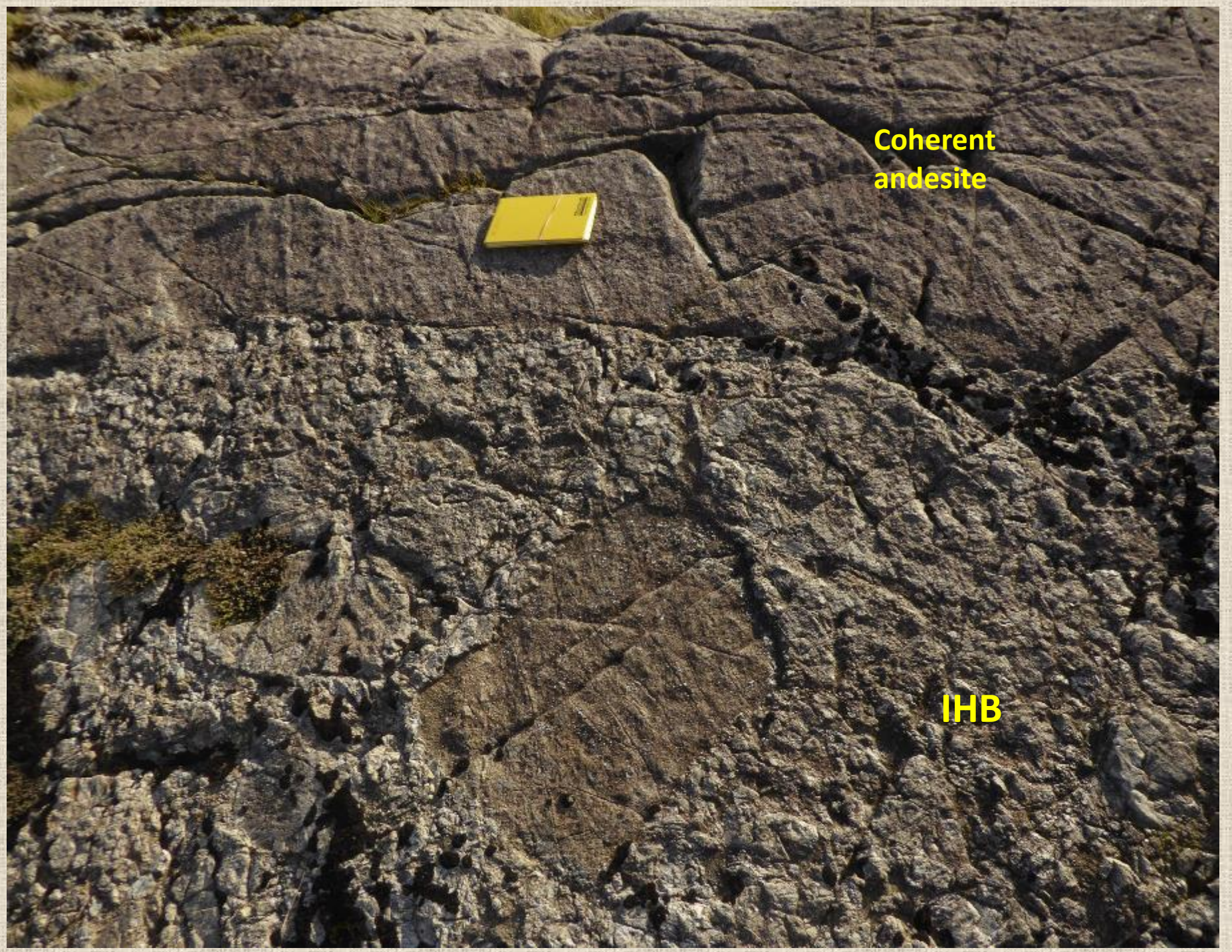
Locality 10 NY 28557 04243 peperitic contact andesite/Miller Stands Member

Not an essential part of the story but it is a fine example of peperite at a transgressive margin of a generally concordant andesite intrusion. It is also an unusually well exposed example of in-situ hydroclastic brecciation. In many places along this margin small fragments of the Miller Stands Member have been rafted off and incorporated into the marginal zone whilst undergoing a peperitic interaction with the andesite but at this locality a larger raft, about a metre thick and more than five metres long, has been isolated in the sill. Surrounding the large raft is a zone of in-situ hydroclastic breccia [IHB] where the host andesite has been fragmented by cooling contraction granulation and hydrothermal solutions have altered the andesite close to the fracture network but fluidised sediment did not penetrate along the fractures. The andesite was altered by infiltration of fluids mostly over distances of a few millimetres to a centimetre or so. Weathering renders these zones recessive in contrast to the background andesite that better resists the weathering process.

Locality 10a

The marginal zone of the andesite sill just above the large raft. Here the contact zone has larger than usual fragments of the Miller Stands Member. Away from its margin the andesite is pervasively hydrothermally altered at a low intensity. Epidotisation is widespread.

Breccia dykes extend from the marginal zone into theMiller Stands Member probably generated by the high pore fluid pressures at the andesite/sediment contact.



Locality 10b NY 28537 04251

Towards the slack that leads down from Blake Rigg, coherent andesite passes into jigsaw fit textures but without a sedimentary matrix which is the in-situ hydroclastic breccia. Originally all of the field of view was coherent andesite and of a uniform composition. The matrix to the IHB now has a different composition because of alteration. The IHB shows that a source of hydrothermal fluid was available in the form of pore-fluid in the Miller Stands deposits.

An example of an in-situ hydroclastic breccia in a quartz feldspar porphyry from the Iberian Pyrite Belt.

This was a completely uniform material until hydrothermal fluids penetrated along fractures and infiltrated a few centimetres into the porphyry. The altered parts were subsequently cleaved. Weathering has left the unaltered parts standing proud. These have been mistakenly identified as agglomerates in many places.

Locality 11 NY 28661 04356 A small patch of Glaramara defining the Seathwaite Fell Formation/Side Pike Ignimbrite contact.

An example of how the stratigraphy can be established even in an area that has been highly disrupted by VTFs. Glaramara Tuff is found in several localities in this immediate area but is not continuously present because of erosion before the Side Pike Ignimbrite was deposited. Just below the accretionary lapilli tuff there may be a metre or so of Black Wall Member.

Glaramara accretionary lapilli are better developed at NY 28665 04403 where it is possibly overlain by a few metres on Unit 2 before the Side Pike Ignimbrite.

Note on the map the number of VTFs in the local area. Between localities 10 and 11 there is a substantial VTF which can be mapped to Redacre Gill. Locality 11 is just to the NW of two VTFs, one of which faults Tilberthwaite Formation against Seathwaite Fell Formation.

Locality 12 NY 28808 04511
volcanotectonic faulting

The prominent dry stone wall has locally been replaced by a fence which can be crossed using the stile at NY 28713 04415.

A VTF of Seathwaite Fell Formation against Seathwaite Fell with limited offset. At this locality the general attitude of the turbidites is a strike of 194/014 dipping 39° towards the east. Just before the slack [the VTF] the bedding abruptly steepens to 73° striking 216/036. Abrupt changes in bedding or welding foliation attitudes define many VTFs in the Langdale Caldera. On a regional scale hydrothermal alteration, away from VTFs, is weak but adjacent to the caldera-related faults it can be intense. The irregular shapes seen in the photo were produced by alteration. Pseudo-ooliths are pervasive through this exposure and are epidote nodules.

Locality 13 NY 28894 04431 a belt of generally steeply-dipping welding fabric in Side Pike Ignimbrite

This locality is at the end of a 70 m wide belt of Side Pike Ignimbrite bounded either side by VTFs. At Locality 13 the welding fabric is crenulated about micro VTFs, making it difficult to determine the overall attitude but it is probably not steep. Following the ridge to the NE, steep dips predominate. The whole belt is interpreted as a VTF similar to the monocline on the western edge of the mapped area next to Redacre Gill. This composite structure can be traced over the top of the major VTF that divides the continuous belt of Tarnclose Crag Member from the belt to the north that contains Side Pike Ignimbrite and the Tarnclose Crag Member.

Locality 14 NY 28920 04425 Tarnclose Crag Member and evidence for block rotation in piecemeal collapse.

If you are working in numerical order then this will be your first encounter with the Tarnclose Crag Member [TCM]. Around Blake Rigg and Bleaberry Knott the Side Pike Ignimbrite is capped by an thin accretionary lapilli tuff and the Miller Stand Member. In the area immediately west of Blea Tarn it is overlain by several hundred metres of ignimbrite that is more intermediate in composition [or more hydrothermally altered] and variably but commonly weakly welded. It also has a much higher lithic concentration. For a few tens of metres above its contact with the Side Pike Ignimbrite the TCM is little disturbed and stratification is homoclinal but around NY 29000 04430 soft-state disruption is common. At NY 28920 04425 stratification is sub-perpendicular to the local attitude as shown by the white-weathering tuff bed in this photo. Contouring upwards at the base of this crag from the photo location will show dips of around 60^{o} reducing to low dips. This deformation was produced as fault blocks rotated during piecemeal caldera collapse.

Locality 15 Starting immediately south of and approximately at the same level as Locality 14, and extending downhill, is a part of the Tarnclose Crag Member characterised by white weathering tuffaceous layers. Close to the woods further downhill there appears to be continuous passage from the more uniform TCM into these well stratified rocks. Layering attitudes are generally low but locally steepening occurs on extensional faults. All of the succession is pyroclastic being uniformly poorly sorted with variably developed welding fabrics ranging from barely perceptible to locally intense. Parallel stratification is the norm with minor convolute disruption.

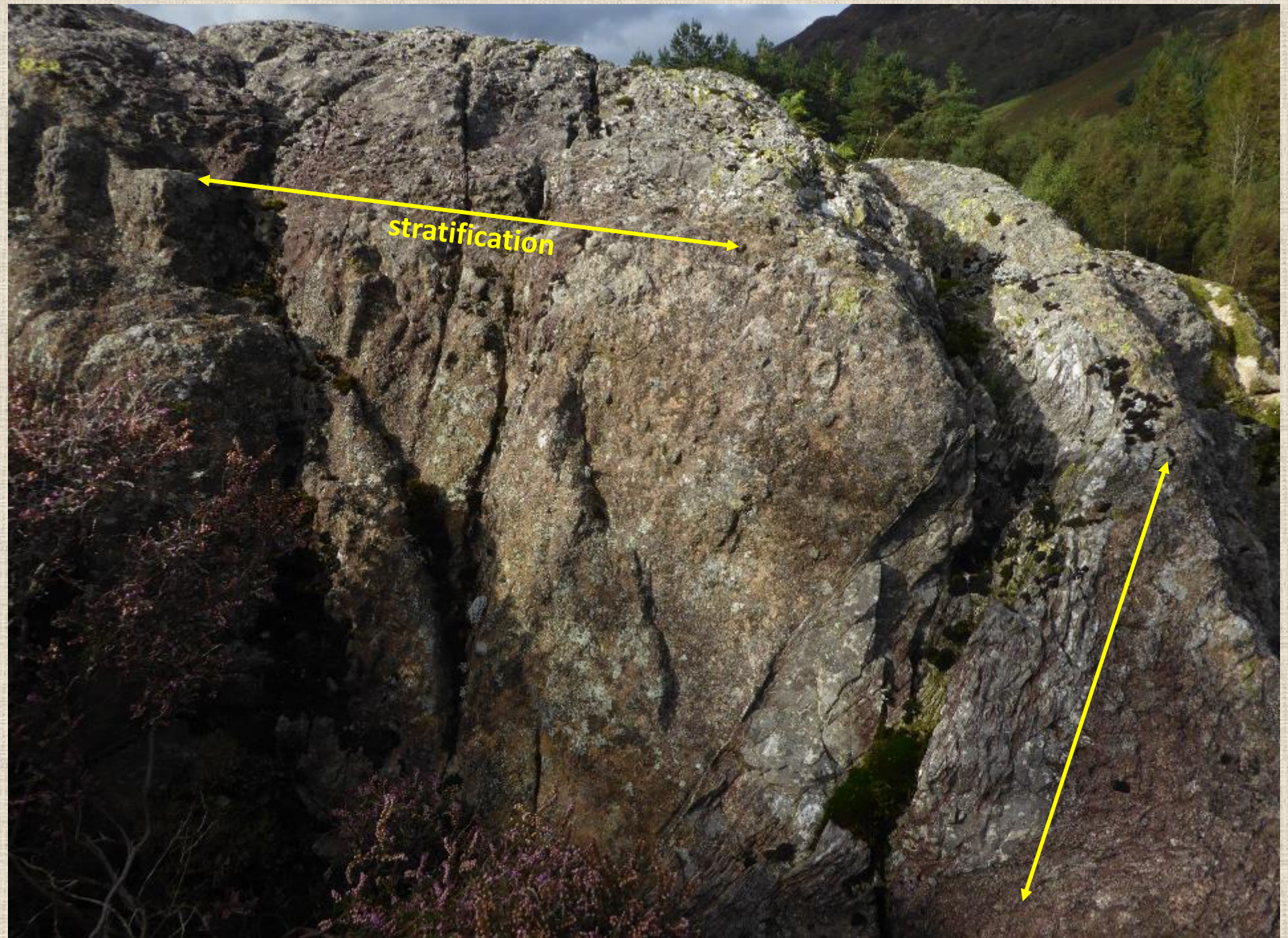
Most of the Tarnclose Crag Member is noticeably darker than the Side Pike Ignimbrite, possibly indicating a composition around the andesite-dacite boundary though alteration may have played a role in the field expression of this unit.

Locality 16 NY 29055 04419 Side Pike Ignimbrite/Tarnclose Crag Member contact.

The grid ref. is the top of the exposure. Pictured is the contact between the Side Pike Ignimbrite and the Tarnclose Crag Member. A few metres below the contact the SPI takes on its characteristic form – intensely welded ignimbrite with a few percent very large fiammé in a background mainly of 2-3 cm fiammé.

Following the contact down about thirty metres takes you to a crag which provides a good thirty metre thick section through a section of the Tarnclose Crag Member. Most of this section is either very weakly stratified or massive but there are several white-weathering tuff layers. At NY 29033 04450 there is a pod or disrupted layer a couple of metres in extent of white-weathering tuff with 4/5 mm accretionary lapilli.

Continuing uphill, deformation is limited in intensity until about NY 29000 04430.



Locality 17 NY 29372 04168 Tarnclose Crag Member at Tarnclose Crag

A small-scale example of the style of deformation seen at **Locality 14**. Generally the layering is gently dipping as can be seen just below where this photograph was taken. Locally deformation has folded layers and welding fabrics. This disruption is inferred to have taken place during piecemeal collapse of the Langdale Caldera when VTF-bounded blocks tilted.

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