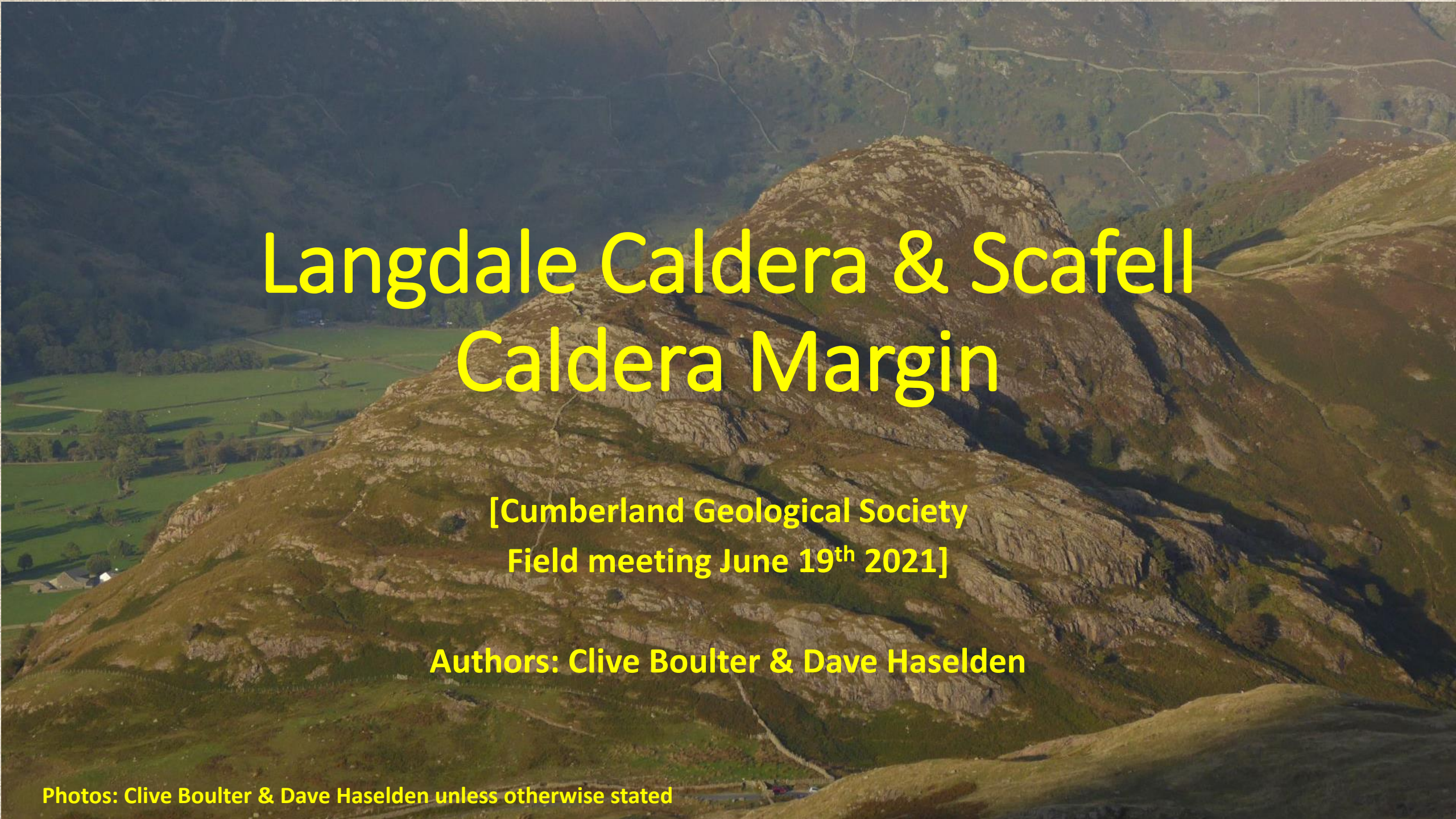
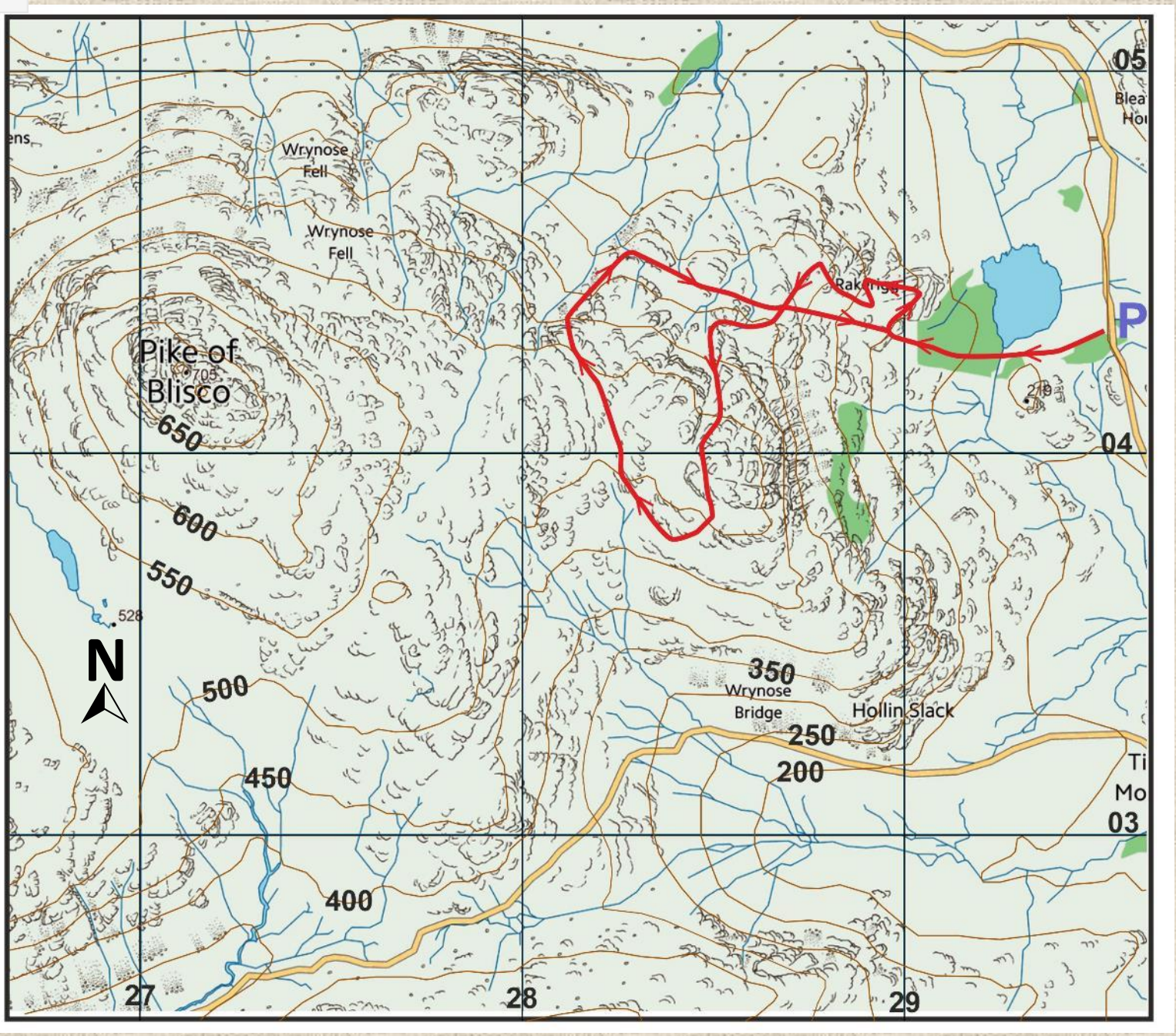


Langdale Caldera & Scafell Caldera Margin

[Cumberland Geological Society
Field meeting June 19th 2021]

Authors: Clive Boulter & Dave Haselden

Photos: Clive Boulter & Dave Haselden unless otherwise stated



LOGISTICS

These notes were provided for a Cumberland Geological Society field meeting in June 2021. This itinerary is an abbreviated version of the Langdale Caldera & Scafell Caldera Margin itinerary already on the English Lake District Geology website. It does not include localities from Three Shire Stone to Long Crag which are useful if you wish to appreciate the context of the much reduced portions of the Scafell Caldera in the excursion area.

The starting point is the National Trust car park at Blea Tarn [NY 29560433]. The trip is 3 km but the ground is rough and steep and very little of it is on marked paths. There is about 450 m of ascent involved.

The route is shown in red is shown on the map taken from Ordnance Survey OpenData.

INTRODUCTION

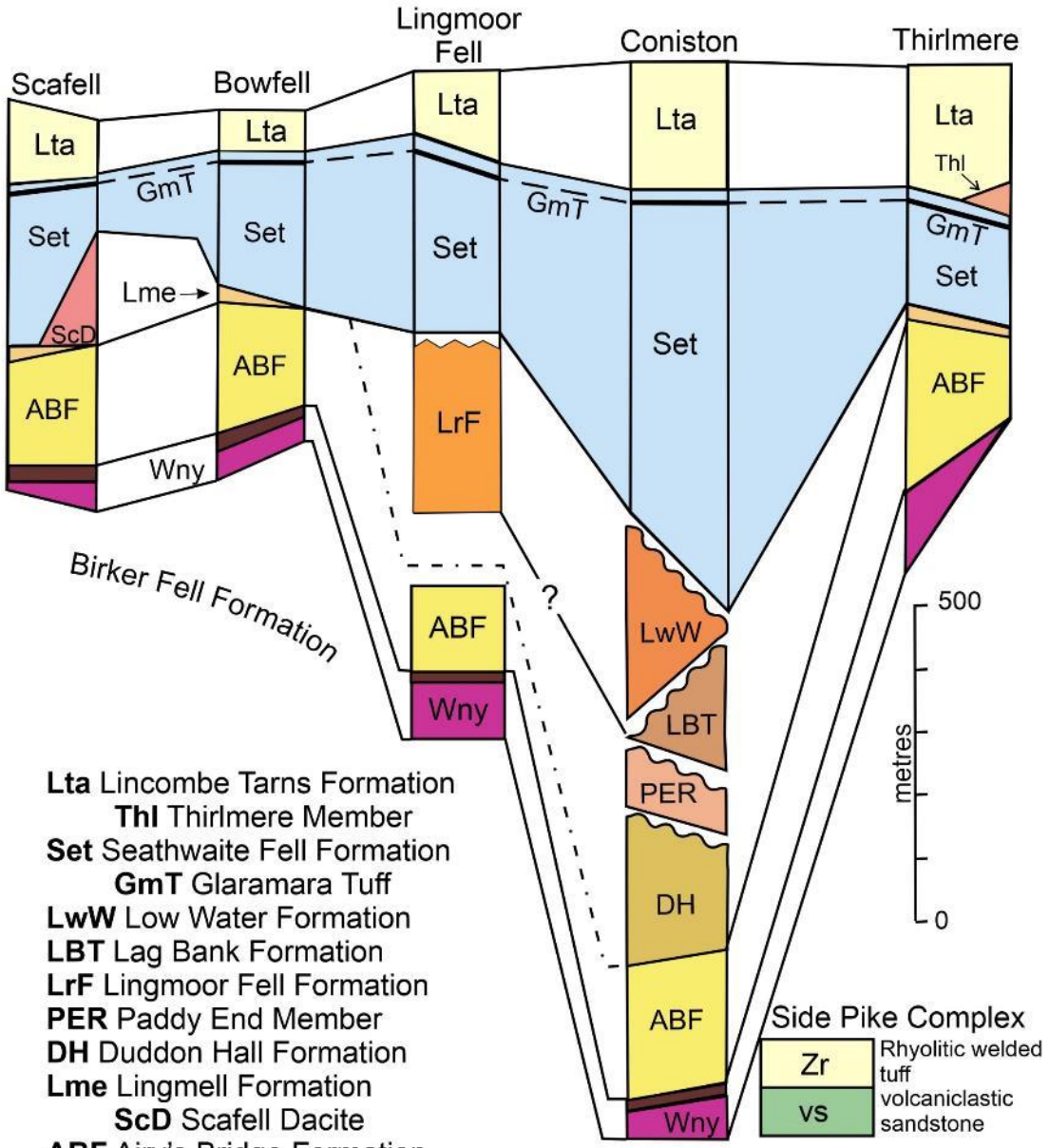
The main focus of the excursion is the Langdale Caldera but the area also provides an opportunity to examine part of the earlier Scafell Caldera. Both calderas involved piecemeal collapse which means volcanotectonic faults [VTFs] are abundant though those belonging to the younger caldera are much more prominent and will be a major topic of the day. Caldera-collapse topography in the Scafell Caldera is preserved in this area of overlap between the two calderas. We pick up the story of caldera-related eruptions early in the evolution of the Scafell Caldera when a gigantic phreatoplinian eruption created the distinctive Whorneyside bedded tuff which was followed by a switch to predominantly silicic explosivity. Because the excursion route is in the overlap between the margins of the Scafell Caldera and the Langdale Caldera, the deposits of the former are condensed, an arrangement that goes a long way to explaining why this 5 km^2 area could not be tied into the regional stratigraphy in the BGS resurvey and why the concept of the former Side Pike Complex came into being.

Very detailed work on part of the established stratigraphy of the Scafell Caldera in the Central Fells 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 caldera collapse topography 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 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 thick ponded ignimbrite within the caldera.

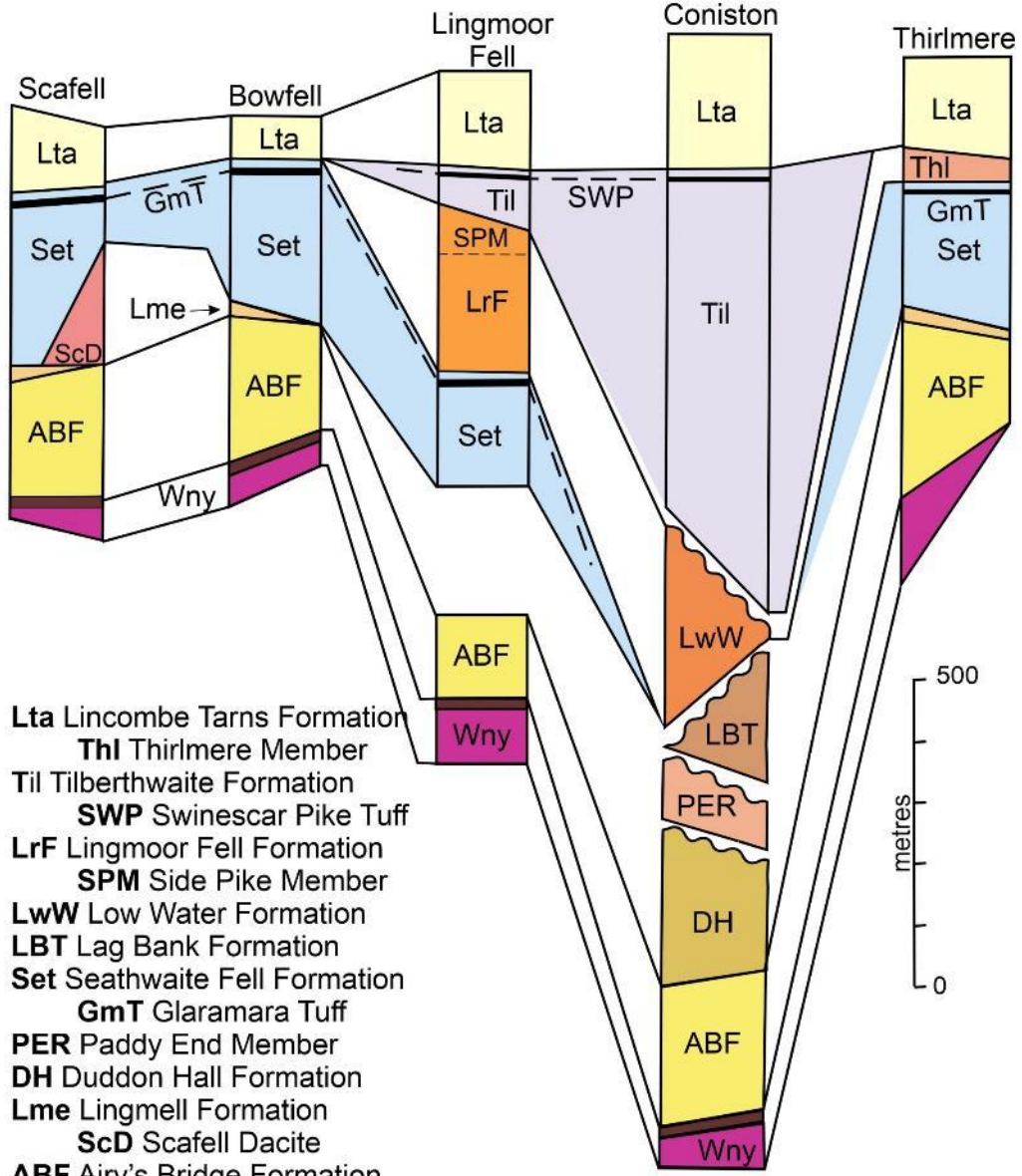
It is remarkable that the Langdale Caldera sequence repeats many of the Scafell Caldera's main elements; in particular the caldera sedimentary fill has a tuff ring event right at the end of the infilling of the caldera making correlations difficult in highly faulted and/or not well exposed areas.

Stratigraphy of the Seathwaite Fell Formation and surrounding units (after Millward et al. 2000)



Lta Lincombe Tarns Formation
Thl Thirlmere Member
Set Seathwaite Fell Formation
GmT Glaramara Tuff
LwW Low Water Formation
LBT Lag Bank Formation
LrF Lingmoor Fell Formation
PER Paddy End Member
DH Duddon Hall Formation
Lme Lingmell Formation
ScD Scafell Dacite
ABF Airy's Bridge Formation
Wny Whorneyside Formation

Revised stratigraphy of the Seathwaite Fell Formation and surrounding units (after Brown 2001)



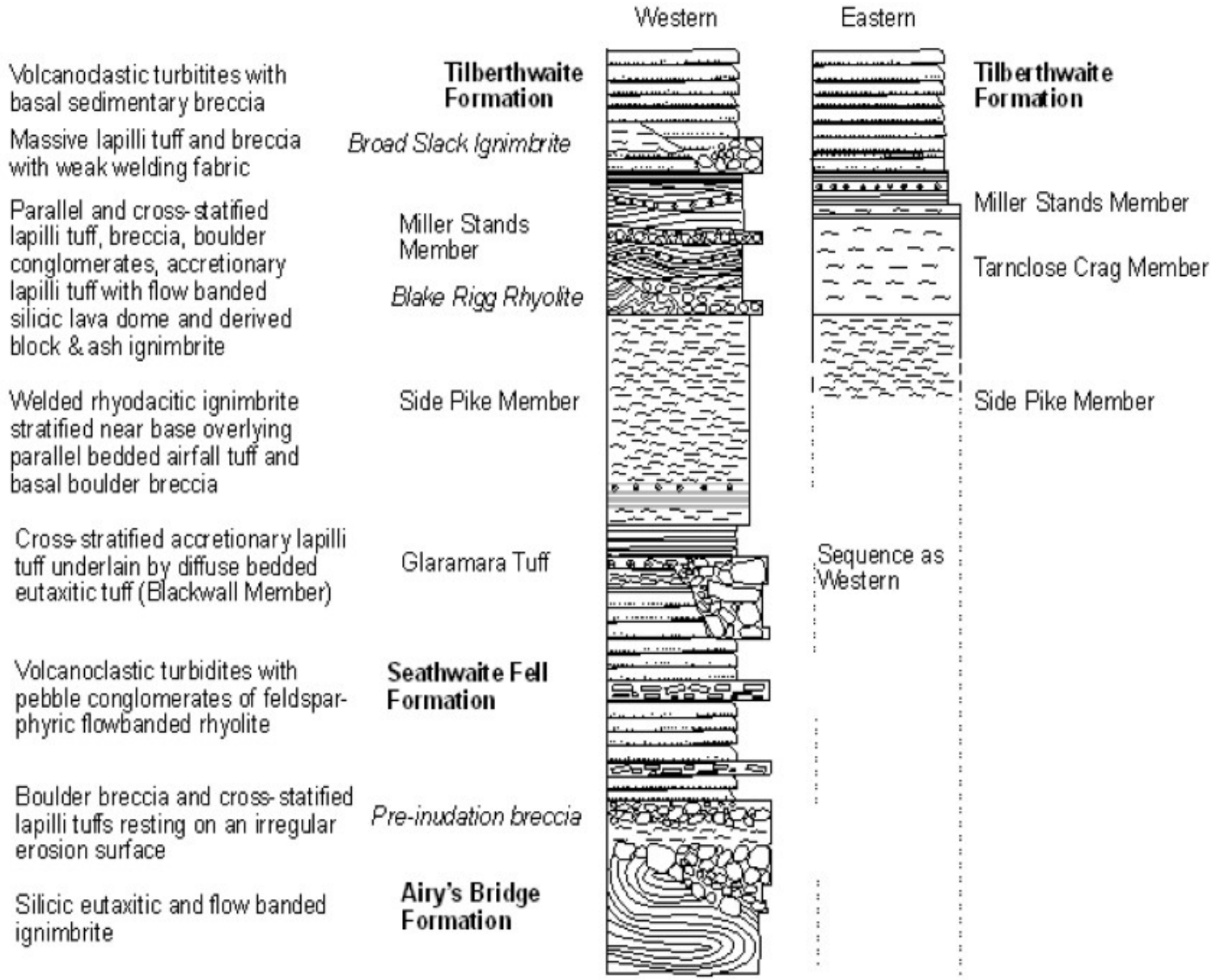
Lta Lincombe Tarns Formation
Thl Thirlmere Member
Til Tilberthwaite Formation
SWP Swinescar Pike Tuff
LrF Lingmoor Fell Formation
SPM Side Pike Member
LwW Low Water Formation
LBT Lag Bank Formation
Set Seathwaite Fell Formation
GmT Glaramara Tuff
PER Paddy End Member
DH Duddon Hall Formation
Lme Lingmell Formation
ScD Scafell Dacite
ABF Airy's Bridge Formation
Wny Whorneyside Formation

Set probably pre-dates DH

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 diagram has been modified to remove some stratigraphic correlations that have not been generally accepted (Millward 2004).

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.

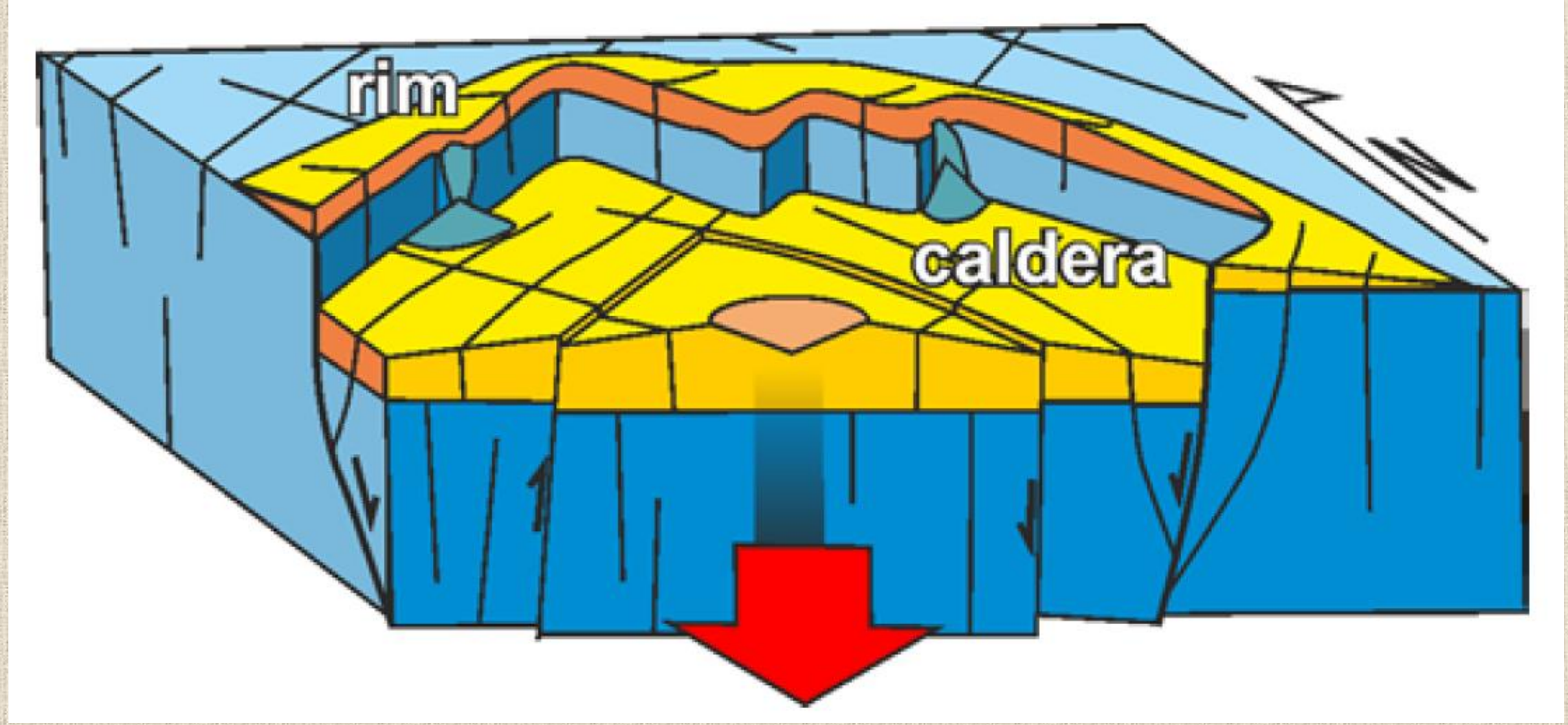
Simplified Stratigraphic Succession
Langdale Caldera Flanks



Langdale Caldera succession

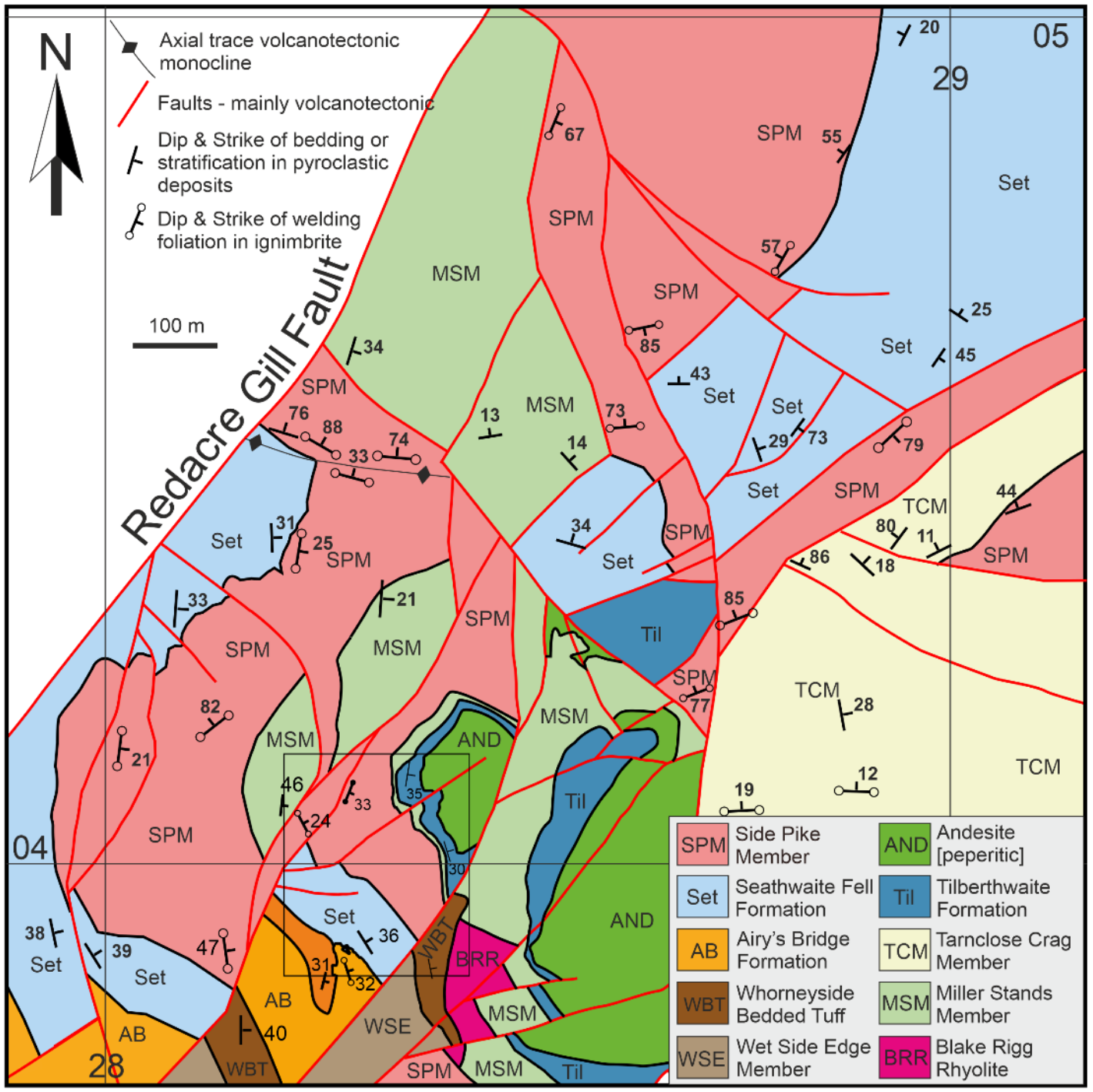
Scafell Caldera succession

Some of our mapped volcanotectonic faults may seem rather odd in terms of features like right angle turns. The diagram below from Vitale & Isaia [2014] may help to appreciate what is possible in a dominantly vertical-collapse setting.

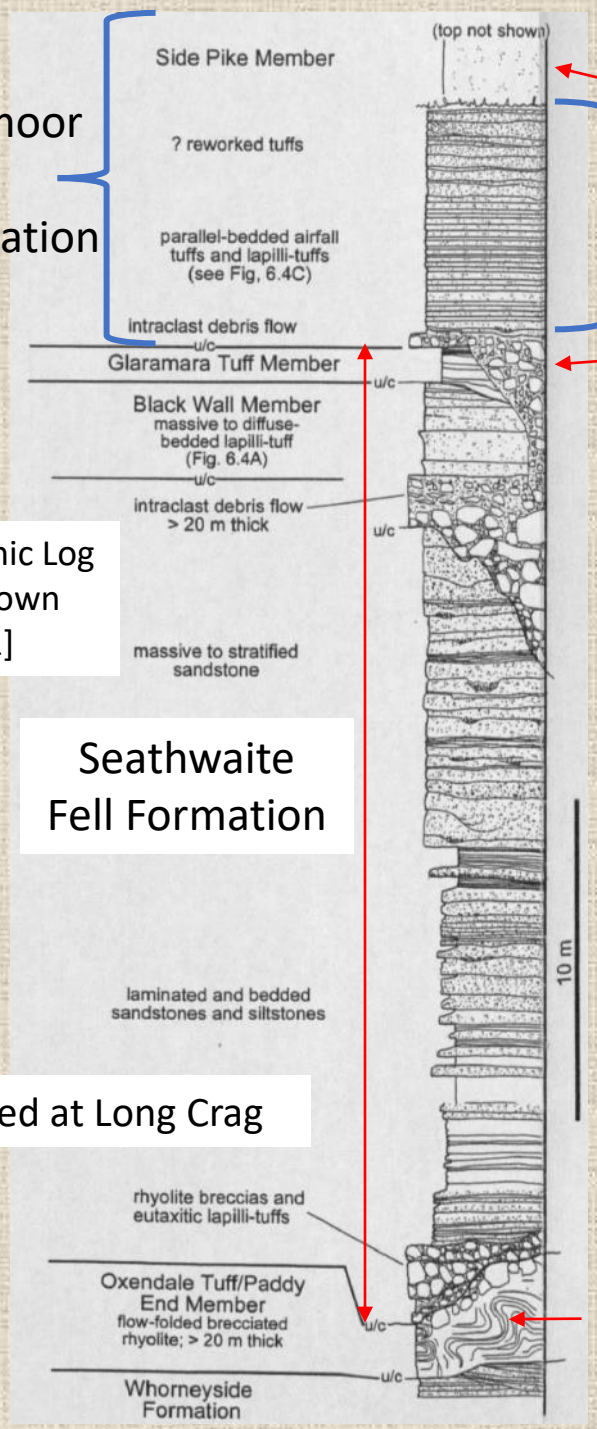


Stefano Vitale & Roberto Isaia, 2014, Fractures and faults in volcanic rocks (Campi Flegrei, southern Italy): insight into volcano-tectonic processes. International Journal Earth Science (Geol Rundsch) vol. 103, pp. 801–819.

Preliminary map of the Langdale Caldera in the excursion area.



Virtually all of the faults shown on the map are volcanotectonic in origin most of which have some limited later displacement. Many are haematised probably at the time the west coast iron ore deposits were forming. Mapping was mainly carried out at scales between 1:1,000 and 1:2,000 on orthorectified air photos.



Lingmoor Fell Formation

Graphic Log By Brown [2001]

Seathwaite Fell Formation

Logged at Long Crag

Unit 3

Unit 2

Unit 1

Massively reduced Airy's Bridge Formation

SIDE PIKE IGNIMBRITE [Unit 3] from Brown 2001

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

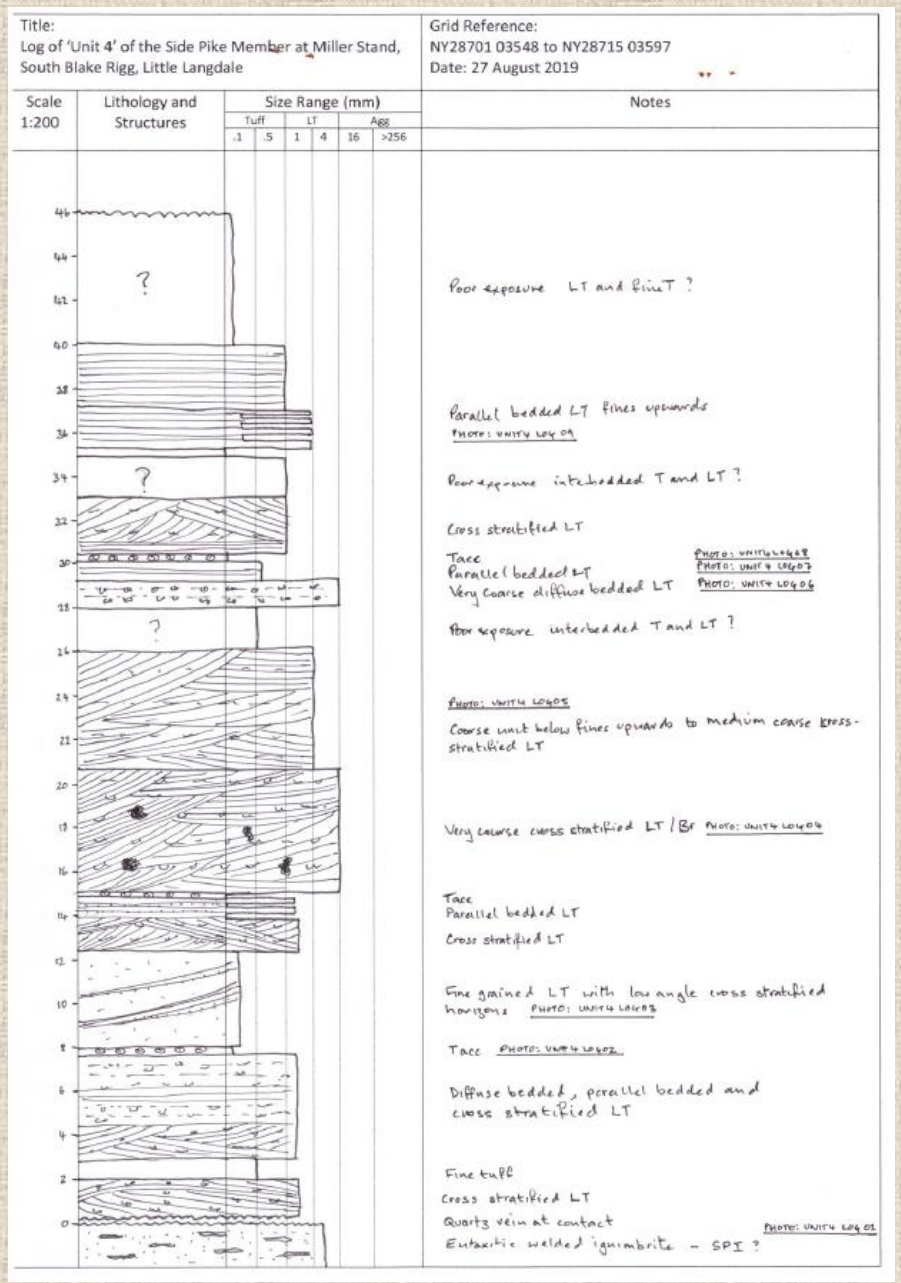
5 m massive eutaxitic welded lapilli tuff with a diffuse crystal-rich zone at the base in which fiammé increase in size and abundance upwards

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



Locality 1 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 [SPI] and the Tarnclose Crag Member [TCM]. 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 thirty metre thick section through the lower part of the Tarnclose Crag Member. This unit is more intermediate in composition [or, less likely, it is more hydrothermally altered] and is variably, but commonly, weakly welded. It also has a much higher lithic concentration. A hiatus is in evidence at the contact between the SPI and TCM as clastic dykes penetrate the top of the SPI.

Most of the Tarnclose Crag section here is either very weakly stratified or massive but there are several thin 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 2 NY 28920 04425 Tarnclose Crag Member and evidence for block rotation and piecemeal collapse.

Around Blake Rigg and Bleaberry Knott the Side Pike Ignimbrite is capped by a thin accretionary lapilli tuff and the Miller Stand Member. The relationships in the area of Localities 1 to 3 are very different with tens of metres of Tarnclose Crag Member lying immediately over the Side Pike Ignimbrite. Making correlations across several significant VTFs has its problems!

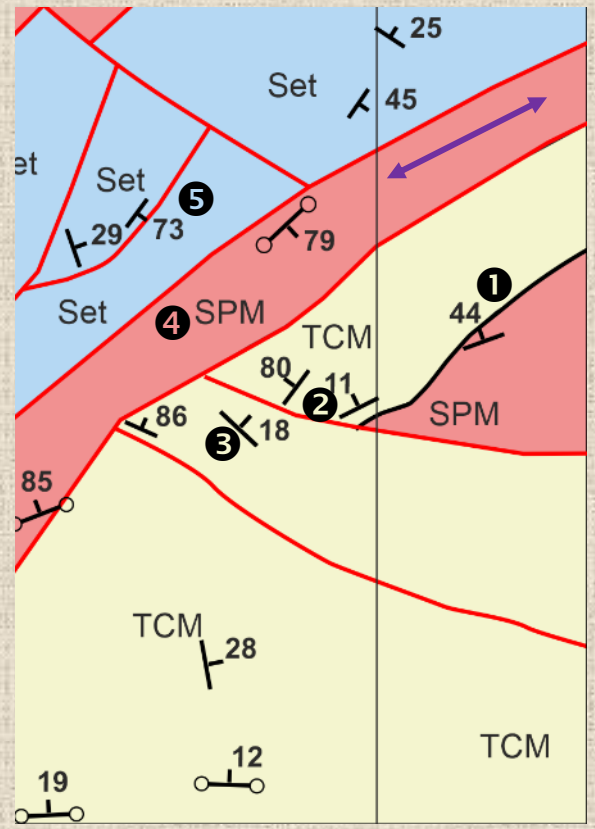
For a few tens of metres above its contact with the Side Pike Ignimbrite the TCM is little disturbed and stratification is homoclinal but around NY 29000 04430 soft-state disruption is common. At NY 28920 04425 stratification is sub-perpendicular to the local overall attitude of layering as shown by 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 and slumping occurred. In the Tarnclose Crag enclosure a welded layer, a few tens of cm thick, similar to the one shown here, has a comparable fold geometry. The ductile deformation of the welded layer implies that the ignimbrites were warm/hot when the slumping took place.

Locality 3 Starting approximately at the same level as Locality 2 but a little to the south, and extending downhill, is a part of the Tarnclose Crag Member characterised by white weathering tuffaceous layers alternating with darker more typical TCM. 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. The white weathering layers are rhyolitic in composition. Two magma storage zones were being tapped to produce these alternations. The rhyolite layers are thought to be equivalent to the Miller Stands Member in the western region.

Locality 4 NY 28896 04470 A belt of generally steeply-dipping welding fabric in Side Pike Ignimbrite – a big VTF!

This locality is in a 70 m wide belt of steeply-dipping welding fabric in the Side Pike Ignimbrite bounded either side by discreet volcanotectonic fractures. Locally in the steep belt the welding fabric is crenulated about micro VTFs but these are limited in extent. The whole belt is interpreted as a VTF similar to the monocline on the edge of Redacre Gill [Locality 11].



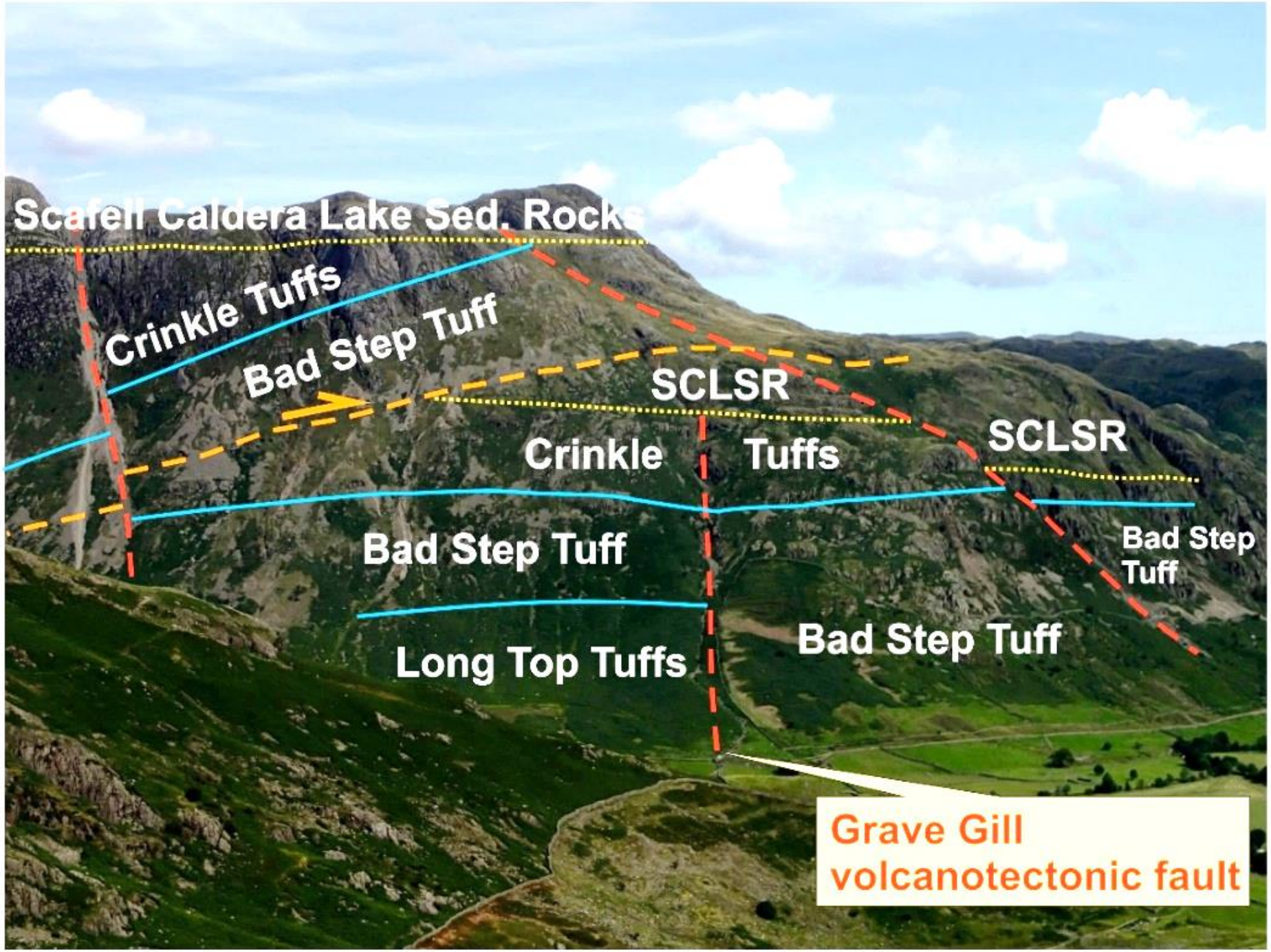
Locality 4 is representative of a belt of sub-vertical welding fabric in SPI [double-headed arrow] which extends until the exposures are lost by the path from Side Pike to Blea Tarn. This belt truncates the two major VTFs to the SE. The northerly of these VTFs divides the continuous belt of Tarnclose Crag Member containing Locality 3 from the belt to the north that contains Localities 1 and 2.

Locality 5 NY 28808 04511 volcanotectonic faulting [Seathwaite Fell Formation against Seathwaite Fell Formation]

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 5 NY 28808 04511

A closeup of the moderately dipping turbidite beds where weathering has emphasised the varying degrees of alteration. Bedding [yellow arrow] has not been totally obscured but it has been heavily overprinted. The highly irregular shapes reflect alteration selectively acting on initial variations in composition and texture some of which may have been diagenetically induced. Thin Acadian quartz veins [v] have formed in the more brittle alteration zones adding to the complexity of the exposure.



Scenic Overview

Heading upwards from Locality 5, the old dry stone wall has been replaced in a short stretch by a fence which we cross at a stile. Looking towards the Langdale Pikes from just past the stile gives an overview of Scafell Caldera features similar to the photo shown here.

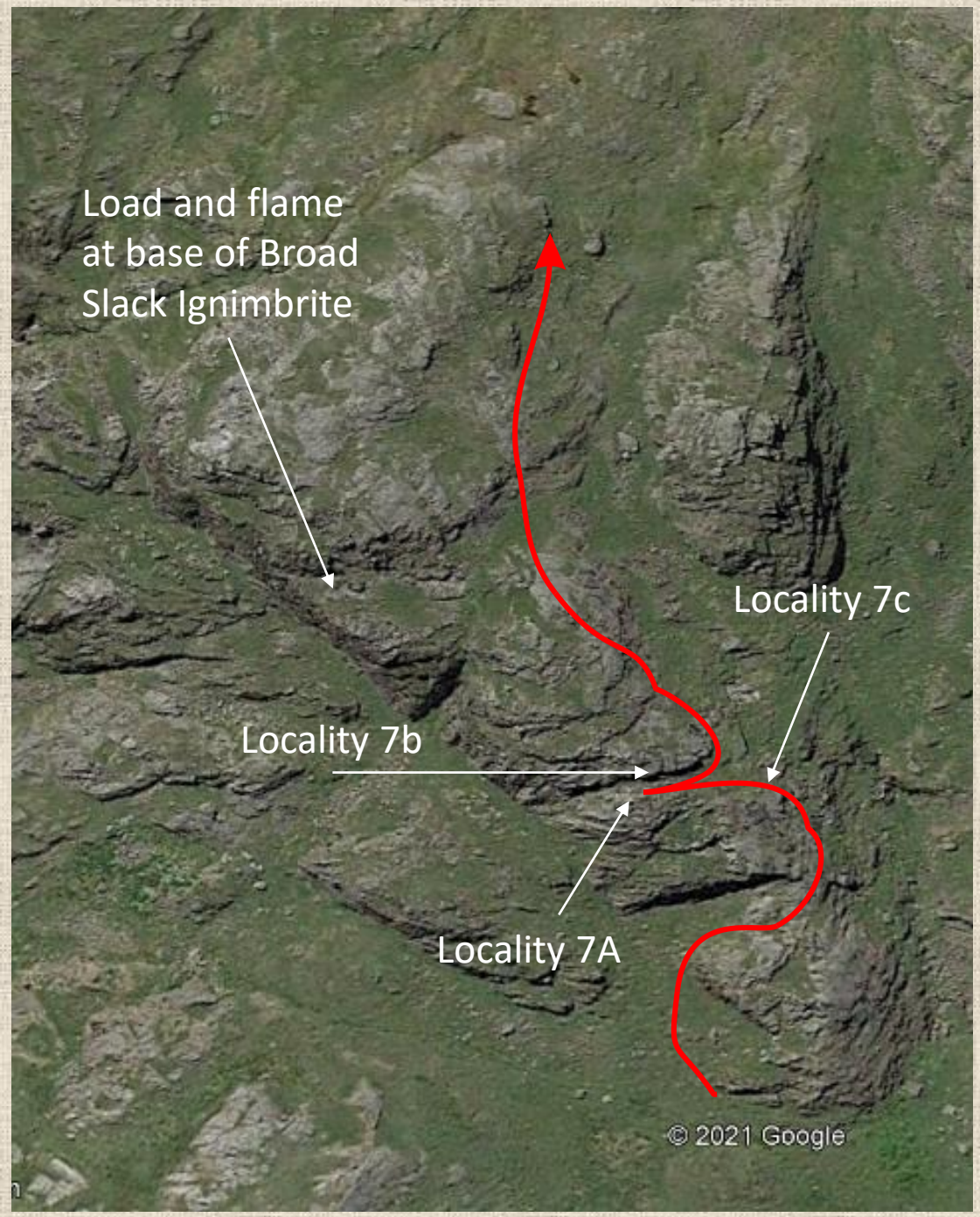
With some guidance contrasts can be made out between ignimbrite units and caldera-lake deposits. The Langdale Thrust repeats much of the stratigraphy and was a major discovery of the 1980s-1990s resurvey in this part of the BGS Ambleside Sheet.

Locality 6 NY 28665 04403 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 as seen at NY 28661 04356. At NY 28665 04403 [Locality 6b]the Glaramara is possibly overlain by a few metres on Unit 2 before the Side Pike Ignimbrite.

Glaramara accretionary lapilli tuff at NY 28661 04356

Note on the map the number of VTFs in the local area. Between localities 6 and 7 there is a substantial VTF which can be mapped to Redacre Gill. Locality 6b is just to the NW of two VTFs, one of which faults Tilberthwaite Formation against Seathwaite Fell Formation.



Locality 7 NE Ridge of Blake Rigg

Subject to having reasonably dry conditions for the Field Meeting it is intended to ascend the rocky ridge towards the summit of Blake Rigg. This will involve some simple scrambling. The diagram on the left shows the line of ascent in red and the localities.

This locality is an example of the uncertainty created by not having access to the backup provided by laboratory techniques. Two interpretations will be provided and participants can join the dabate.

[1] The ridge lies on the of edge a fault zone which repeats units of Miller Stand Member and overlying Tilberthwaite turbidites. The area has been extensively intruded by a transgressional andesite sill which displays spectacular peperitic and hydroclastic brecciation.
A coarse ignimbritic lapilli tuff/breccia has been emplaced within the Tilberthwaite and there is evidence for sub-aqueous emplacement in the form of load and flame structures at the base of the ignimbrite. This is similar to the Pavey Ark Member within the Seathwaite Fell Formation again highlighting the remarkable similarities between the processes operating in the Scafell and Langdale calderas.

[2] The features described above could be a sedimentary breccia created by a sedimentary injectite complex. Crucial to determining the process responsible for the observed relationships is distinguishing between andesite and coarse sand/granule turbidites. Sounds easy but in practice on this ridge it is quite a challenge!

Locality 7a NY 28557 04243 peperitic contact andesite/Miller Stands Member

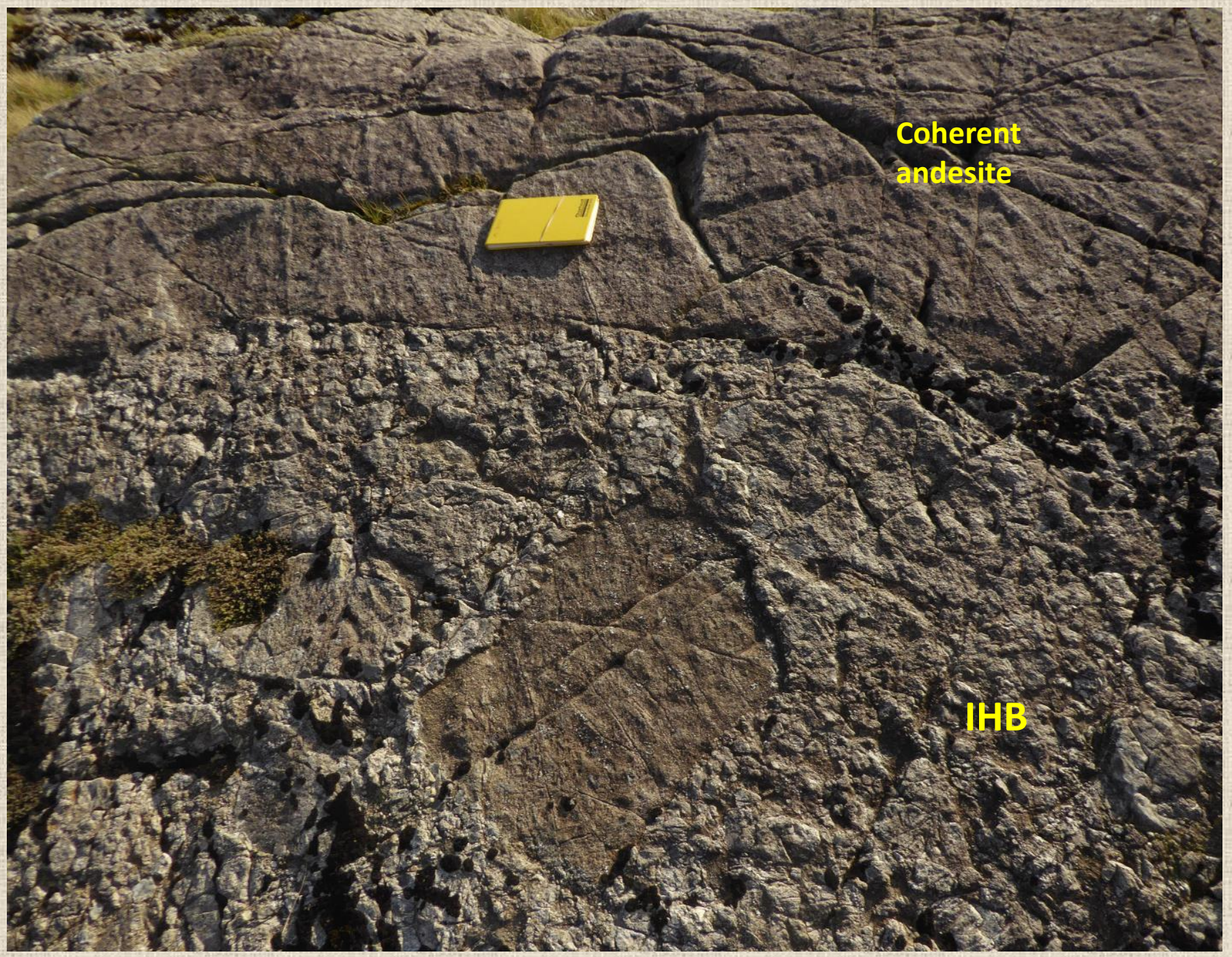
In interpretation **[1]** this is a fine example of peperite at a transgressive margin of a generally concordant andesite intrusion but more significantly it is a rare example in the BVG of an in-situ hydroclastic breccia. In many places along this margin small fragments of Miller Stands Member have been rafted off and incorporated into the marginal zone whilst undergoing a peperitic interaction with the andesite. 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. 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.

In interpretation **[2]** the brecciation is an injectite.

Locality 7b

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 the overlying units, probably generated by the high pore fluid pressures at the andesite/sediment contact.

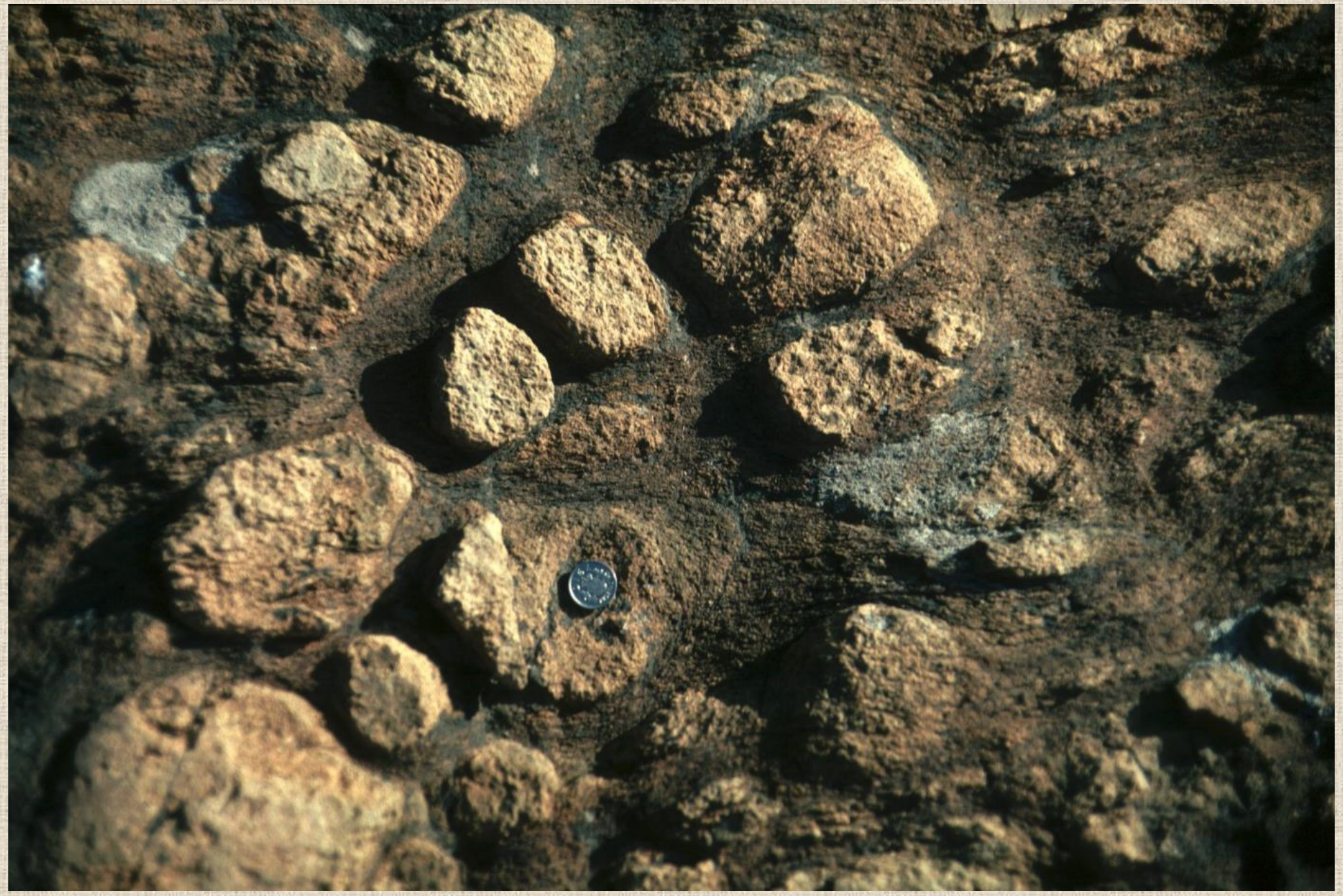


Locality 7c NY 28537 04251
In-situ hydroclastic breccia?

Interpretation **[1]** - Towards the slack that leads down from Blake Rigg, coherent andesite passes into jigsaw fit textures but without a sedimentary matrix; this is the in-situ hydroclastic breccia [IHB]. 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 adjacent sediments. The fluid was sucked into the intrusion when cracks formed and pressure dropped in the resulting voids.

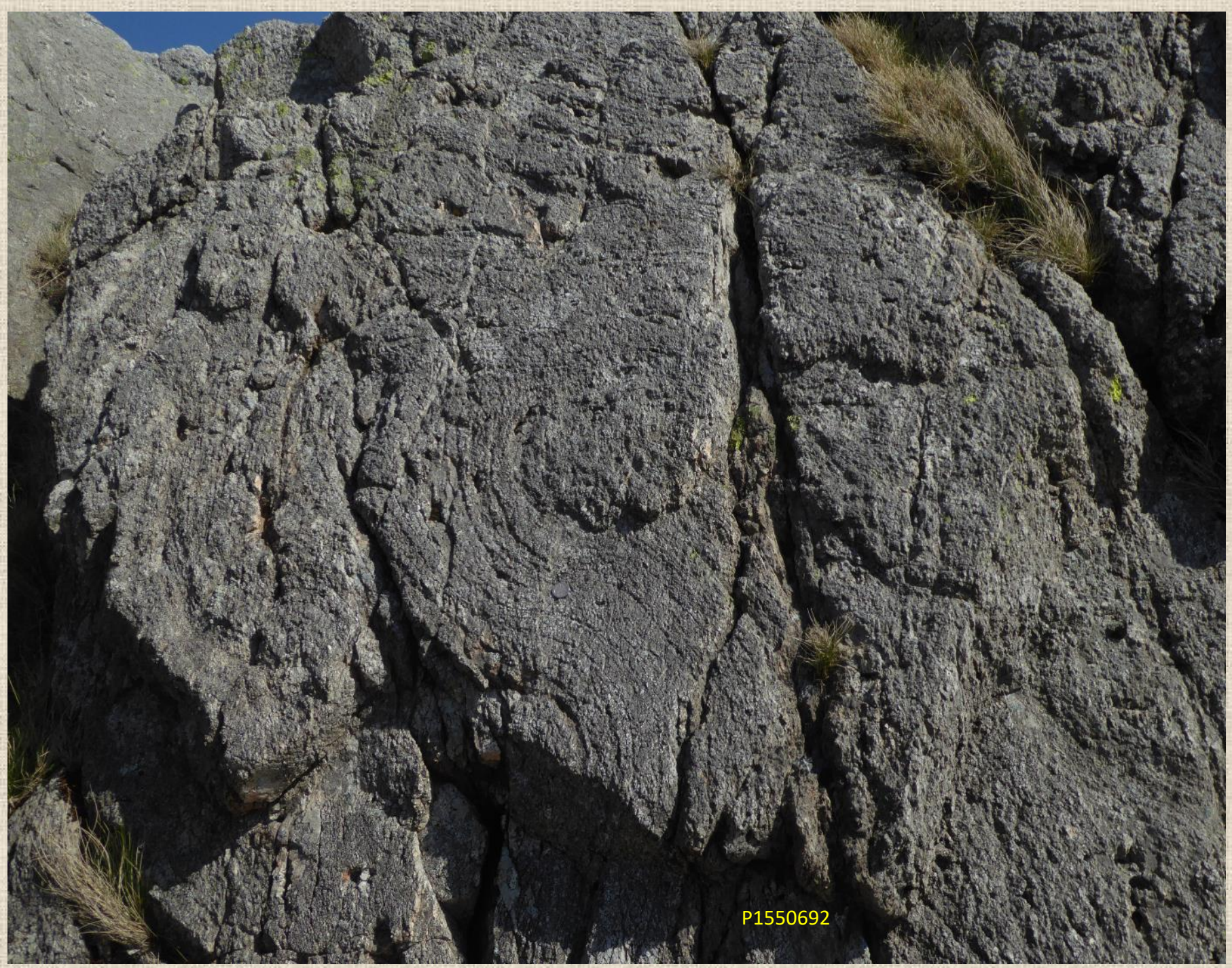
Interpretation **[2]** – all here is sedimentary in varying states of brecciation in an injectite.

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 to alter it. The altered parts were subsequently cleaved. Weathering has left the unaltered [less altered?] parts standing proud. Is the previous locality an example of this process?

Many such materials have erroneously been interpreted as agglomerates and there was a time when such views led to the identification of volcanic vents.



Locality 8 NY 28435 03925

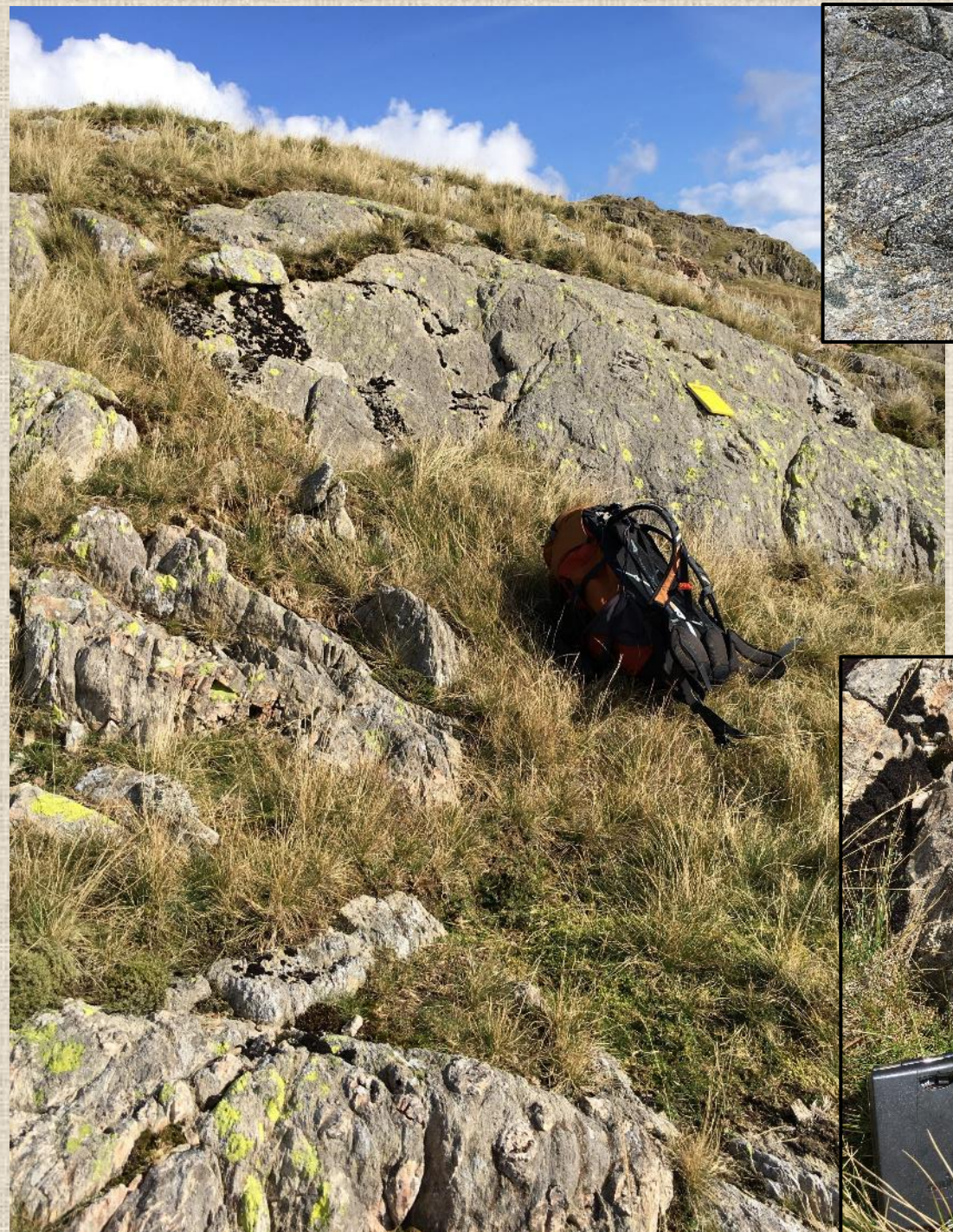
As an expression of the variability of the Miller Stands Member. At this locality it takes the form of a silicic lava dome informally termed the Blake Rigg Rhyolite, which is capped by a thin welded ignimbrite of a similar composition. Folding of flow banding is common. The dome has shed an apron of boulder breccias. The dome may represent ascent of degassed magma towards the end of the main eruptive phase of the Langdale Caldera. Parallels with the Scafell Caldera can be drawn as this dome, in its position in the caldera-forming sequence, is equivalent to the Scafell Dacite and the Rosthwaite Rhyolite.

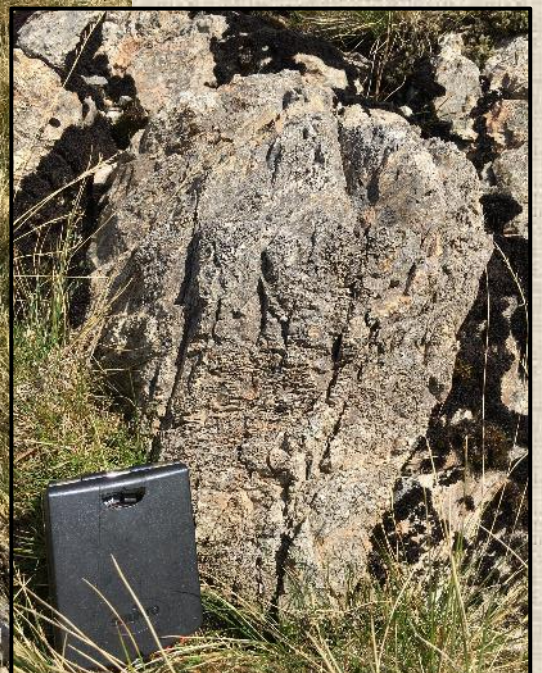
Locality 8a NY 28439 03933 Thin welded ignimbrite on top of the lava dome

Immediately on top of the lava dome a very thin ignimbrite has a moderately well-defined welding fabric. Many of the boulders in the overlying conglomerate have similar welding fabrics and this is probably the source.

Locality 8b NY 28420 03942

Boulder breccia shed from the lava 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 Blake Rigg Rhyolite rests on Whorneyside Bedded Tuff because a volcanotectonic fault to the south has had a major effect on the stratigraphy. This relationship led to the rhyolite being identified as Oxendale Tuff by the BGS but evidence at the next locality shows the Rhyolite rests on Side Pike Ignimbrite and therefore belongs to the Langdale Caldera



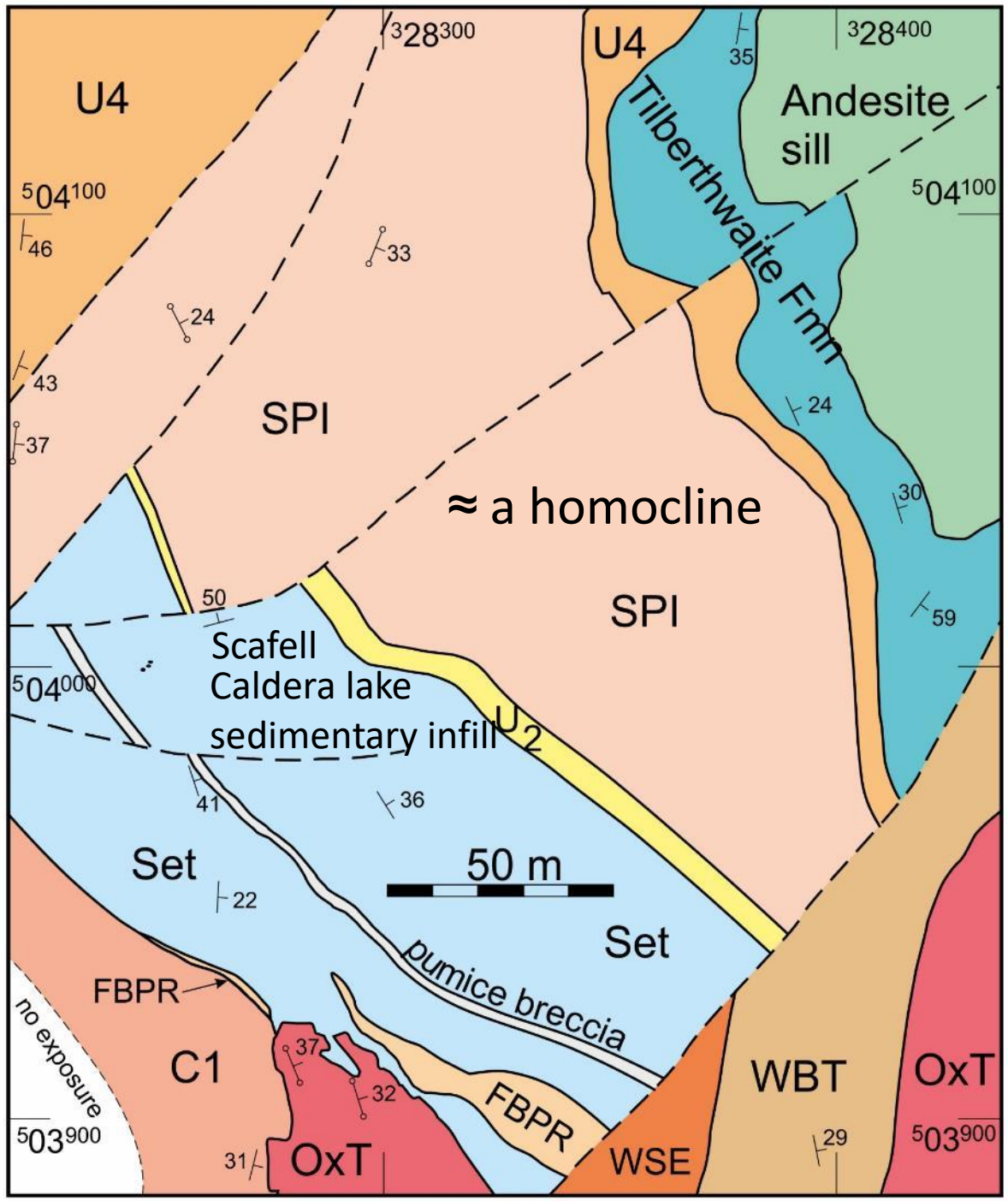


Locality **9 NY 28410 03937**

The Blake Rigg Rhyolite/Whorneyside boundary can be traced from the summit towards locality 9. Just before the locality a VTF brings the Whornside bedded tuff into contact with the Side Pike Ignimbrite. Multiple movement on the fault can be demonstrated since the Blake Rigg Rhyolite has only been displaced a few metres whereas significant movement must have occurred to bring the Side Pike Ignimbrite adjacent to the Whorneyside bedded tuff.

Careful examination of the rocks at locality 9 shows flow folding in the overlying Blake Rigg Rhyolite and eutaxitic textures typical of the Side Pike Ignimbrite below.

Slightly further down the hillside is another good example of a VTF within the Side Pike ignimbrite.



LOCALITY 10 NY 28282 03919 Scafell Caldera-Collapse Topography

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 caldera-collapse topography in the marginal zone 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

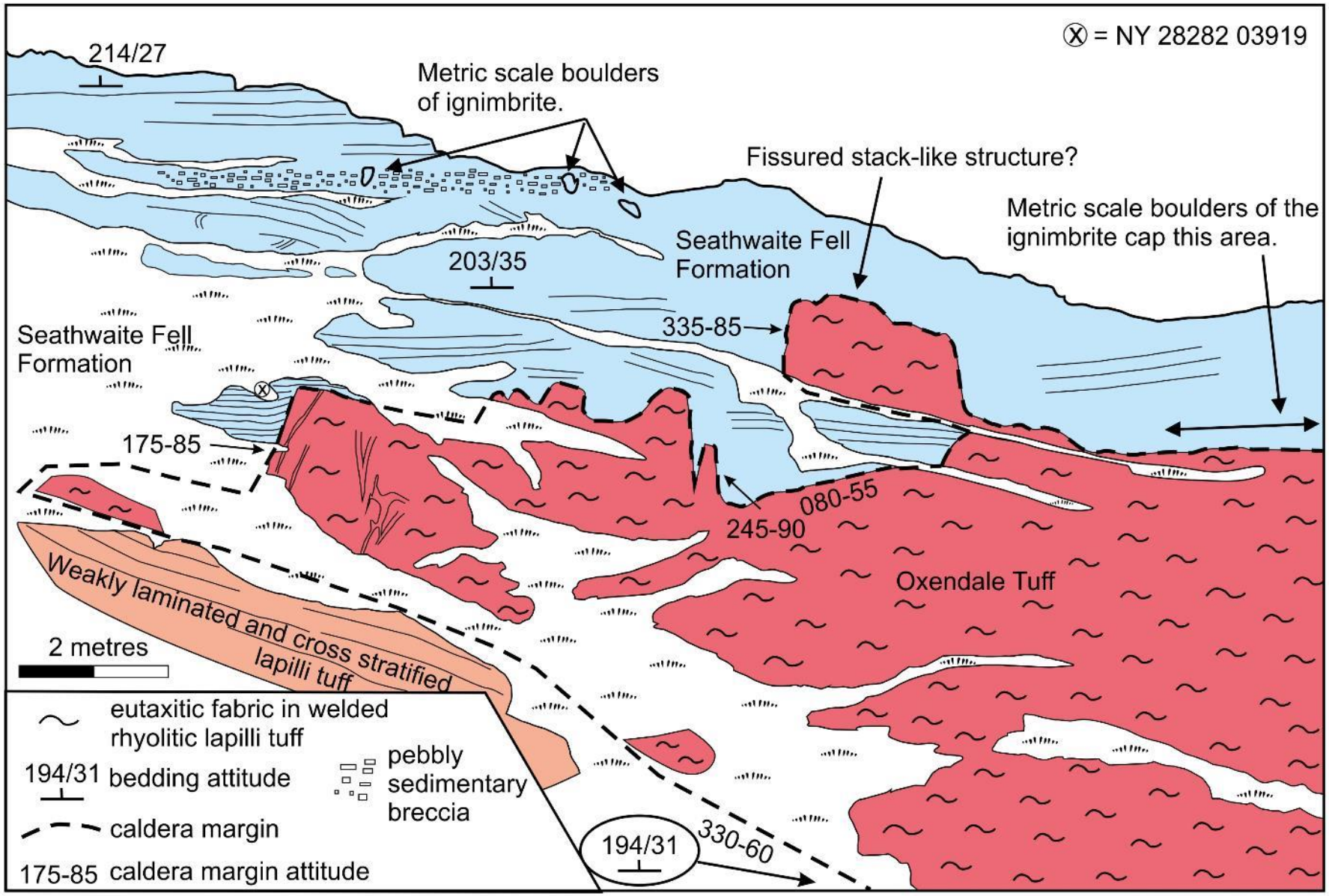
U4 is now informally referred to as the Miller Stands Member.

C1 may be a correlate of the Lingmell Formation.

FBPR = a pebble-grade sedimentary breccia with clasts almost exclusively of white weathering flow-banded feldspar-micro-phyric rhyolite.

dip & strike – welding foliation

LOCALITY 10 NY 28282 03919 [⊗] Scafell Caldera-Collapse Topography



This line drawing from Boulter et al. [2020] covers the main features of **Locality 10** 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 buts-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 caldera-collapse topography of the Scafell Caldera. The previous interpretation was that it represents the edge of a mega-block that ploughed into the sediments.

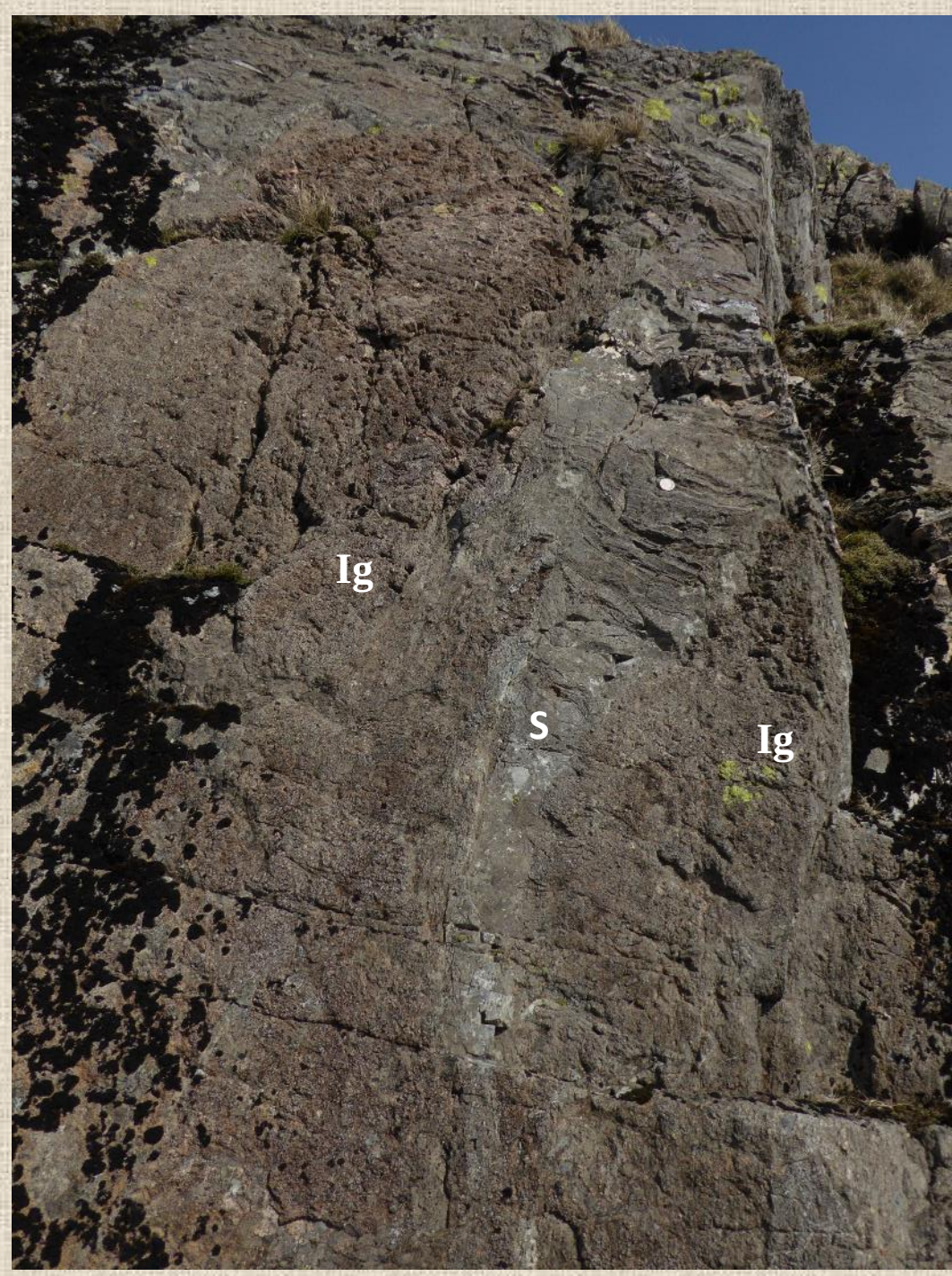

LOCALITY 10 NY 28282 03919 [⊗] Scafell Caldera-Collapse Topography

A typical example of the in-situ welded lapilli tuff [ignimbrite] at **Locality 10** which from the Airy's Bridge Formation, possibly the Oxendale Tuff or part of the Crinkle Member. Flattened pumice fragments [fiammé] are recess-weathered.

LOCALITY 10

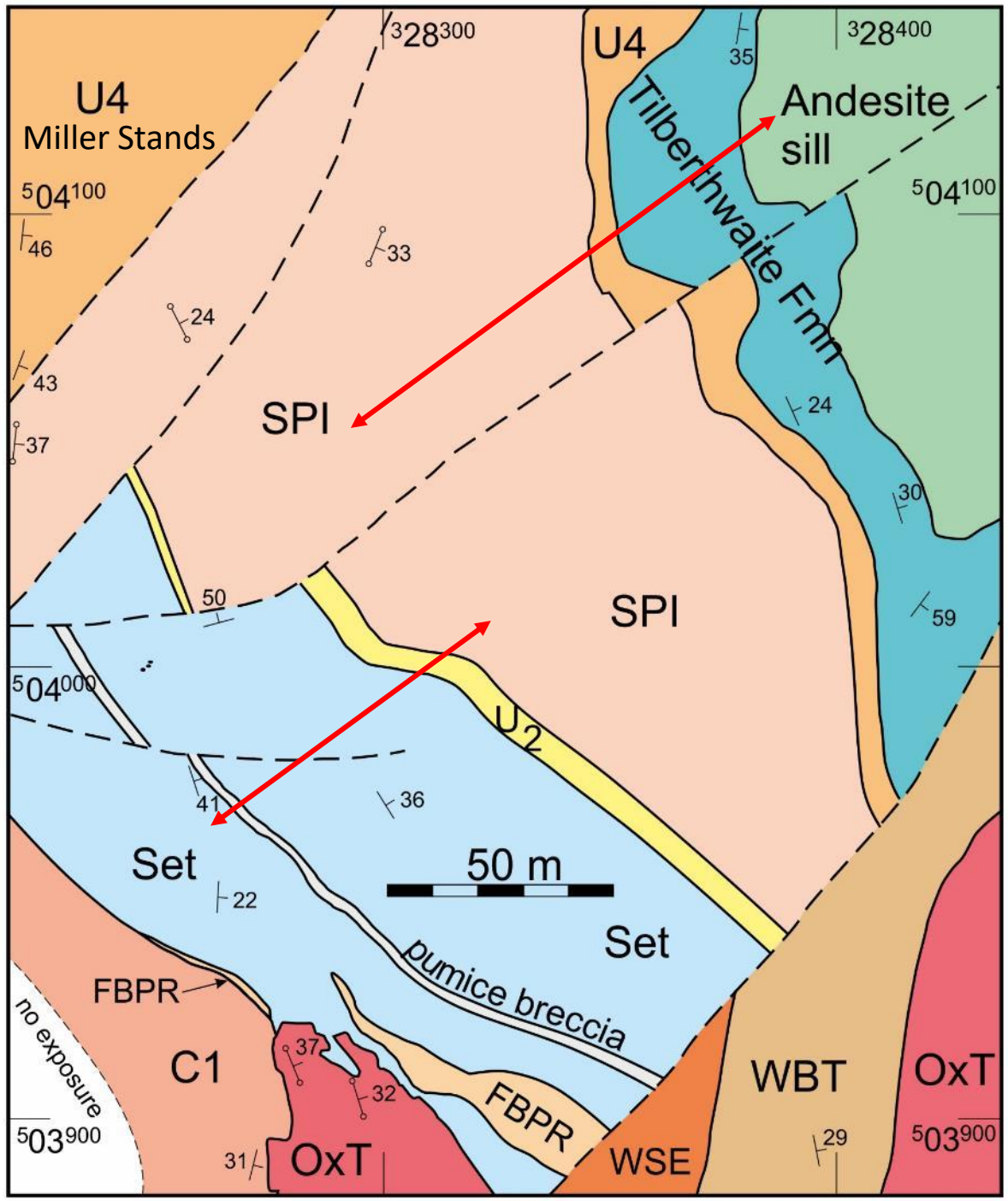
Below: the small crag south of the reference point NY 28282 03919 with sediment-filled fractures in the in-situ welded ignimbrite.

Right: a sediment-filled fissure [S] in the welded ignimbrite [Ig] that is continuous with the overlying Seathwaite Fell Formation.

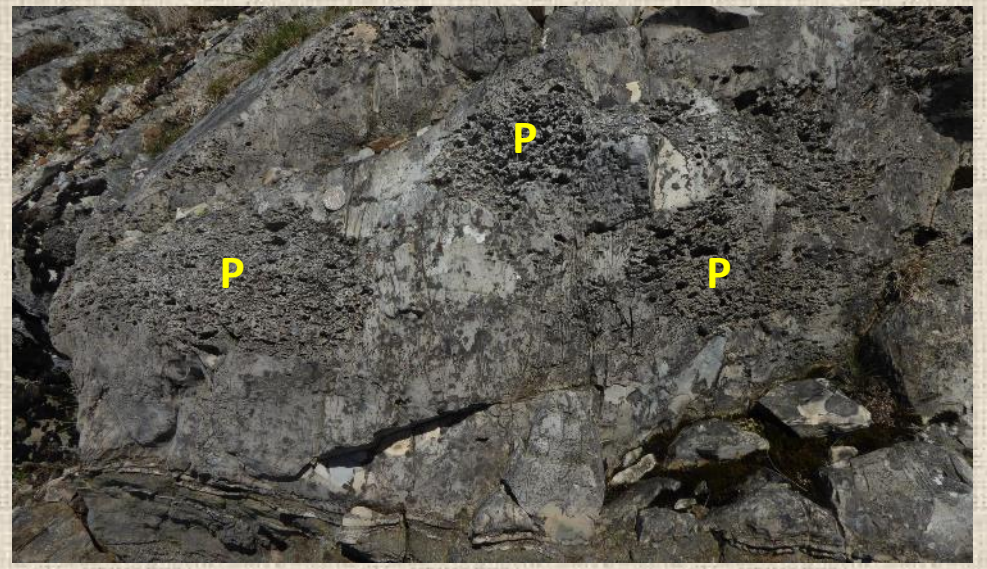


LOCALITY 10

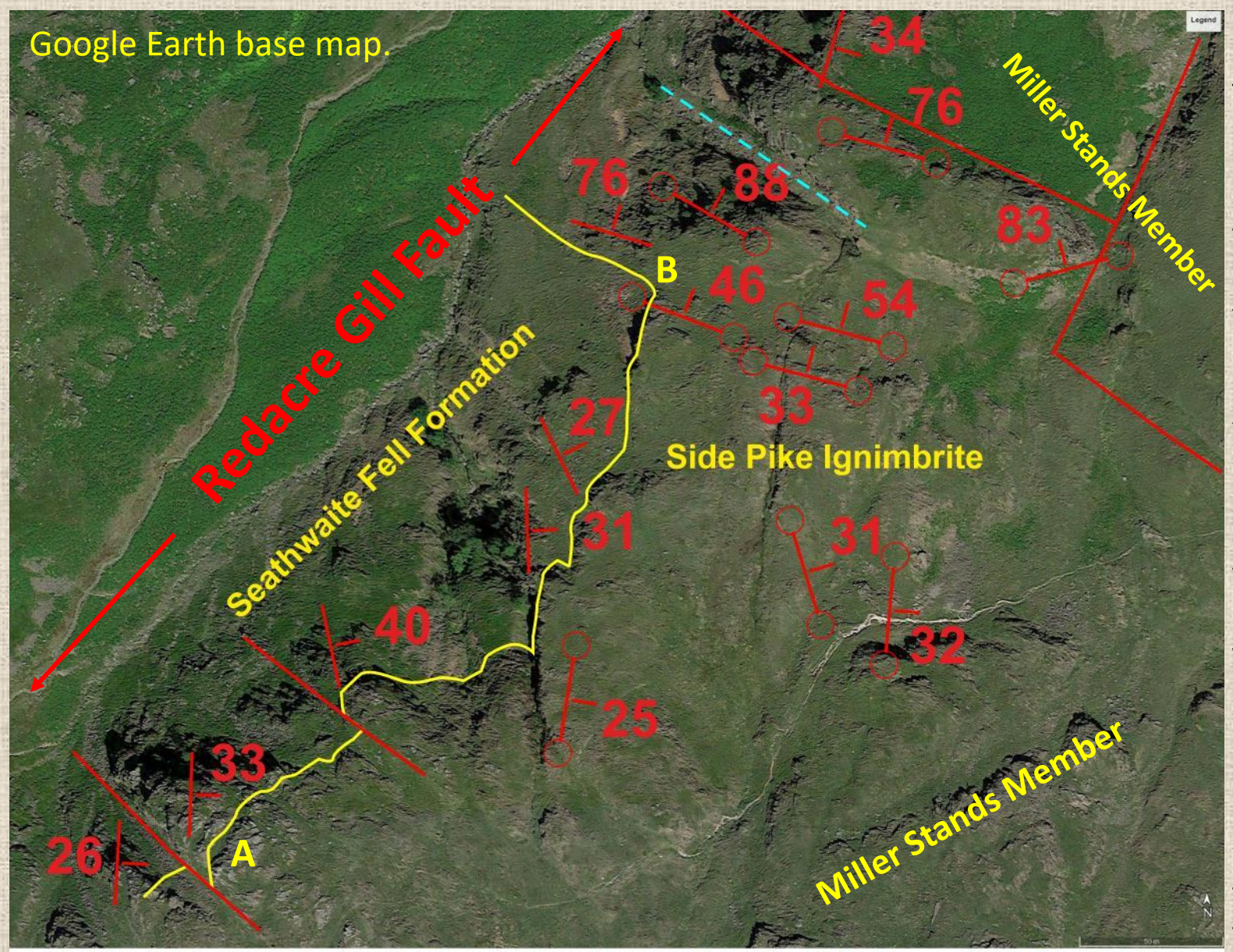
A boulder conglomerate from the pre-inundation deposits that immediately overly the in-situ welded ignimbrite. The boulders are mainly of welded ignimbrite and the welding fabrics are variably orientated from boulder to boulder. Careful examination is necessary to identify the boulder/matrix contacts.
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.



A traverse can be made from Locality 10 towards Bleaberry Knott to demonstrate the sequence in the “western area”. This clearly shows the relationship between the Seathwaite Fell Formation of the Scafell Caldera and the overlying Langdale Caldera elements. Starting in the Seathwaite Fell Formation a traverse in the dip direction at first demonstrates the overall sequence in the dominantly turbiditic caldera-fill deposits. Of significance is the pumice rich horizon [NY 28268 03969] which was probably formed by a subaqueous silicic eruption within the lake. Essentially conformable attitudes between the units of the Scafell and Langdale calderas are evident. The traverse takes an along-strike dog-leg to avoid an area of poor exposure and continues through the Side Pike Ignimbrite, the Miller Stands Member to the Tilberthwaite Formation.



Pumice clasts [P] several tens of cm in size in the pumice breccia, Seathwaite Fell Formation. The same horizon is found on Long Crag



LOCALITY 11: Volcanotectonic-Monocline

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 is 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 discreet volcanotectonic fracture. 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.

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