The Origin of the Brennand Stones feature in the Forest of Bowland, England.

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Abstract

The recognition of remnant corrie features in the Western Pennines at sites such as Whernside and Great Coum has prompted an interest in the feature known as Brennand Stones at the head of the Dunsop Valley in the southern part of the Forest of Bowland. Following this a study was initiated using GPS profiling to try to determine the type of feature that is observed. The results seemed to eliminate a corrie feature due to insufficient ice depth to generate the basal shearing forces necessary for such. The conclusion was arrived at that it was a *protalus rampart* that had developed into a *talus foot rock glacier*. After further desk studies a feature on one of the boulders was suspected to be *polygonal dessication cracks* supposedly only found in the Brennand Grit Formation. The cliff face above, assumed to be the source rock for the Stones is Pendle Grit. This new information prompted further studies to determine the rock type of the boulders. A collection of samples was therefore initiated. The results were inconclusive and also a search for the desiccation cracks type site at Little Moor Beck failed to produce results due to excessive water in the beck. The provisional conclusion was that protalus ramparts were formed but the site developed in the centre as a rock glacier.

Keywords

Protalus ramparts, talus foot rock glaciers, nivation hollows, Loch Lomond Stadial.

Introduction

Various workers in the north of England have identified corrie features in the Yorkshire Dales dating from the Younger Dryas Stadial (known previously in Britain as the Loch Lomond Readvance). Examples of such sites are the niche glacier on the eastern slopes of Whernside, Cautley Crag in the Rawthey valley, Combe Scar and Great Combe on the south slopes of Dentdale (Waltham & Lowe 2013). Whether such features extended as far south as this area is the question asked here. Mitchell (1991) suggests that snow blow is responsible for the above mentioned sites because of the extensive plateau lying upwind providing a source of driftable snow. The above could possibly be true for Brennand Stones with large areas of moorland to the west such as Marshaw and Hareden Fell with Whins Brow to the adjacent west..

The possibility that Brennand Stones is a *cirque* feature as defined in Benn & Evans (1998) that is a hollow bounded by a headwall but open downstream, arcuate in plan with a flat or overdeepened basin. The above is qualified by many combinations of type. The other possibility is that it is a hollow, possibly formed from a perennial snow patch with *pro talus rampart* features below. This is a transverse ridge formed at the foot of a slope and formed by frost detached debris that has travelled on an existing snow surface therefore has a longer reach than normal talus accumulation (Sissons 1980). A feature of the above is being composed of large blocks. Another possibility is that of a *rock glacier*. The scale of the feature seems to preclude a simple *nivation* hollow. The northwest of England has a number of such identified features e.g. the northeast slope of Ingleborough that also displays a large boulder landslip.

Concepts for a morphological approach

A general figure for the initiation of glacier flow is said to occur with an approximate overdurden pressure of 4 x 10^5 Pascals or in civil engineering parlance 400 kNm $^{-2}$ i.e. a depth of ice of approx 40-50 metres and a slope of 20^o. The yield stress of ice being circa 100kNm^{-2} or (10^5 Pascals). See the relevant shear stress formula below:-

$$\rho gh \sin a = \text{shear stress} \qquad (1)$$

where ρ = unit weight of ice, g = gravity figure, h = height of ice above, and a = angle of slope (Benn & Evans 1998).

The figure of circa 40 metres became a rough guideline for the beginnings of glacier motion without reference to slope angle in e.g. cirque formation. Also with small cirque glaciers the stresses are considered low enough for the ice to act like a rigid body but large enough to cause basal slip or shear. In larger cirques internal shear strain along the rotational surfaces accounts for the preservation or creation of the pattern of tilted layers (Waddington 2010).

Cirques and related features

A typical cirque has a flat floored or over-deepened basin connected to a steep backwall by a concave slope (Benn & Evans 1998). Mathematical expressions for the long profile have been used to describe the features, an example being k curves. These were derived from the formula

$$y = k(1 - x)e^{-x} \qquad (2)$$

Where derived values of k reflect the deepness of the curve i.e. the higher the k value the more developed the cirque e.g 2 = well developed, 0.33 = a gentle concave depression. (Benn & Evans 1998). Haynes (1968), the author of the above method, is not clear on how she related real data to her k-curves, it appears that the k-curves were generated independently and possibly compared graphically with the surveyed profiles.

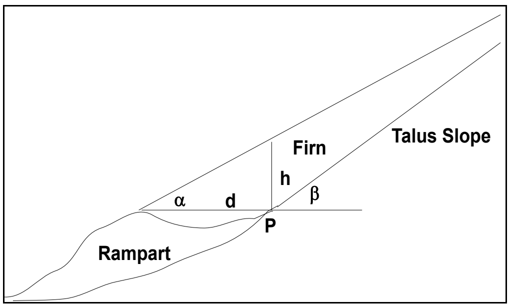
Polinomial expressions similar to the above have also been used by Hekkers et al (2014) using Excel to classify various cirque forms. The polynomial expression can be compared to an idealised cirque that gives: e.g.

$y = \mathbf{0.0019}x^2 - 0.8198x + 421.69$

ie. a higher **coefficient** for a deeper profile.

The Differentiation of Glacial and Peri-glacial landforms

To distinguish between genuine cirques i.e. those with glacial movement of the ice mass either by basal ice shear or internal deformation and static nivation hollows or pro-talus ramparts Ballantyne & Benn (1994) used measurements of the rampart crest to the foot of the talus slope to derive the point when static ice had to become moving ice.



<u>Fig.1 Parameters used by Ballantyne and Benn (1994). Diagram based on the above authors.</u>

Using the diagram (Fig.1) an expression was derived for calculating the **basal shear stress** τ_b from the value of **d**, first by calculating **z** the depth of ice normal to the talus slope **β** by the expression:

h = z/cos β so basal shear stress can be expressed as:

$$\tau_b = pgh \cos\beta \sin\alpha \qquad (3)$$

Following from this, to bring in the dimension **d** the relationship between **d** and **h** is:-

h = d tan α therefore basal shear stress can be expressed as

$$\tau_b = pgd \tan\alpha \cos\beta \sin\alpha \qquad (4)$$

The above formula can now be transposed to give:-

$$d = \tau_b / (pg \tan\alpha \cos\beta \sin\alpha) \qquad (5)$$

Some assumed parameters are now required:-

1. An average ice density of **800 kg** $\mathbf{m^{-3}}$ **for p.**
2. A figure for the critical value of **ά** for the cessation of gravitational transport over the ice at **circa 20°**.
3. A critical basal stress at **70–100 kPa.**

Also it was found by previous workers (Ballantyne & Harris 1994) that the difference in vertical height between **α** (i.e. the point at which this is measured) and **P** is rarely more than 2m.

The figures for **d** computed by [Ballantyne & Benn 1994) for slopes where:-

ά = **25° are 50-90m.**
30° are 40-60m.
35° are 25-40m.

It is now possible to calculate the shear stress τ_b of a historical feature by the measurement of the above parameters or to compute the likely dimension **d**.

The implications proposed by Ballantyne & Benn (1994) for the transition from a stationary firn field to a flowing glacier are that a protalus rampart cannot exist if the dimensions of **d** are greater than the above figures i.e. (30 – 70m). More precisely the conclusions arrived at are that for steep firn fields (35° surface gradient) **d** cannot exceed 30m and for gradients of 25° **d** cannot exceed 70m.

The **identification** of relict Younger Dryas features i.e. pro-talus ramparts, has been elucidated by Ballantyne & Kirkbride (1985) first by their location. The recorded examples lie within the area of the Late Devensian Glacial Maximum, so their formation post dated the decay of the last British ice sheet. Rampart formation requires the development of perennial snow-patches which implies a period of renewed cooling. The Younger Dryas being the only period of renewed cooling for which there is evidence in upland Britain. Also all the documented examples lie outside the mapped limits of the Younger Dryas Glaciation (Ballantyne & Kirkbride 1985). All the pro-talus ramparts and talus slopes studied by the above have partial or complete vegetation cover, little evidence of recent rockfall activity, this suggests that they are relict features formed between the retreat of the last ice sheet and the end of the Younger Dryas Stadial.

The **morphology** was described using the parameters:-

Rampart length along the crest **L**
Heights of distal and proximal slopes $\mathbf{h_1}$ and $\mathbf{h_2}$ resp.
Maximum rampart width **w**.
Horizontal distance from rampart crest to foot of the talus upslope **d**. n.b.(as used above by Ballantyne & Benn 1994)
Rampart thickness **z** derived from the above data.
Maximum gradients of the distal and proximal slopes $\mathbf{ά_{max}}$ and $\mathbf{β_{max}}$ resp.

Whether the rampart is arcuate or linear seems to depend on the topography e.g continuous cliff faces seem to produce linear ramparts. A linear depression between the rampart crest centre, not usually exceeding 3m, and the talus foot is also noted. Infilling of the depression by random deposition is assumed to be supranival and dumped as the snowfield decayed. Plotting of the **z, w** and **d** data gave linear relationships with **w and z**, **d and z** and **d and w**. These relationships seem to imply that the ramparts grew in size as the Younger Dryas stadial progressed and not that they were formed at the foot of stable snowfields. From the sediment point of view pro talus ramparts are generally composed of **angular blocks** with only **minimal** infill of fines. Although a surface soil and consequently vegetation may have formed it is shallow and the angular nature of the deposit is soon exposed.

Summary:-

1. Ramparts are situated at the foot of talus slopes overlooked by rock walls.
2. Length rarely exceeds 300 m.
3. Generally consist of a single ridge.
4. Distal slope angles are consistently steep c. 34^{o} .
5. Rampart size is related to the distance from the talus foot.
6. Ramparts are normally openwork deposits as opposed to moraine etc that are usually diamict.
7. Lithology identical to the rockwall source i.e. no eratics.
8. Clasts are angular and slabby unlike in diamict.

The difference between **talus foot rock glaciers** from the above can be difficult to ascertain but they may display flow structures such as transverse ridges, furrows, and a scalloped or crenulated plan-form. Also the feature can extend some 130-140 m from the talus foot.

The Study Area

The Geology

The highest features of the Brennand Stones is the horizontally bedded Pendle Grit, so situated because it is at the crest of the Sykes Anticline that trends in a northeast-southwest direction. Either side of the above is Swine Clough to the northwest and Hind Clough to the south east that cut deeply into the adjacent hillside. Both typically water worn valleys famous for their exposures of the Bowland Shales and particularly the Hind Sandstone said to be directly injected as sills and dykes before lithification (Kabrna Eds. 2011).

A Description of Brennand Stones

The feature known as Brennand Stones on the OS map OL 41 is of a boulder field (see Fig. 2) with a NNE aspect and a semi concave profile and a vertical but broken backwall 10 – 20 metres in height and circa 400 metres in extent. It could be described as having two bays the western being approx. twice the size of the eastern section. To both the west and east are two typically water cut V shaped valleys, Swine Clough and Hind Clough that form a striking contrast. Below the largest, western bay is a large raised area topped by boulders, the eastern side seems to have a more uniform profile. One side of the west bay has an outcrop like features i.e. a seemingly undisturbed short cliff face (see Fig.3).

As mentioned earlier the feature has large areas to the west and southwest that could supply windblown drift to

any snow feature that had become perennial. Observed at certain locations are ridge like features of higher relief with transverse depressed areas uphill between the talus slope and resemble the description of small protalus ramparts.
The weathering of many of the boulders (see Fig. 4) is quite pronounced perhaps described as subangular compared with recent rockfalls (see Fig.5 just below the cliff and with a well developed patina or oxidation similar to the fell top outcrops.

Methodology
An initial traverse was made from the centre of the western bay to a square wall feature on an alignment of 042 degrees true. GPS waypoints were logged at noticeable changes in slope gradient, a total of 19 being recorded with 2 manually inserted to cover the top and base of the cliff that proved difficult of access. This data was transferred to a navigational mapping software for appraisal. Following this Excel was used to calculate the altitude and distance travelled and a profile plotted both manually and by Excel. The manual method was used initially to check for any gross errors. A similar procedure was carried out for two more traverses, see fig.6, they being numbered 1 to 3. Features noticed on these traverses were numbered in relation to the traverses e.g. Rampart2Upper.

Random rock samples were also taken from boulders in the area of the Stones at a later date to try to ascertain the rock type. The location was plotted using GPS and a map prepared to appreciate the survey.

Fig. 2 View of Brennand Stones from the East

Fig.4 Typical boulder group (see pole for scale).

Fig.5 More recent debris from upper cliff area

The Results

Traverses 1, 2 and 3..

The GPS data was entered on an analysis form in Exel. This traverse data is shown in the appendix.

The traverse data lines were computed and profiles plotted by Excel. A cumulative horizontal total table was also extracted from the above to make the profiles possible.

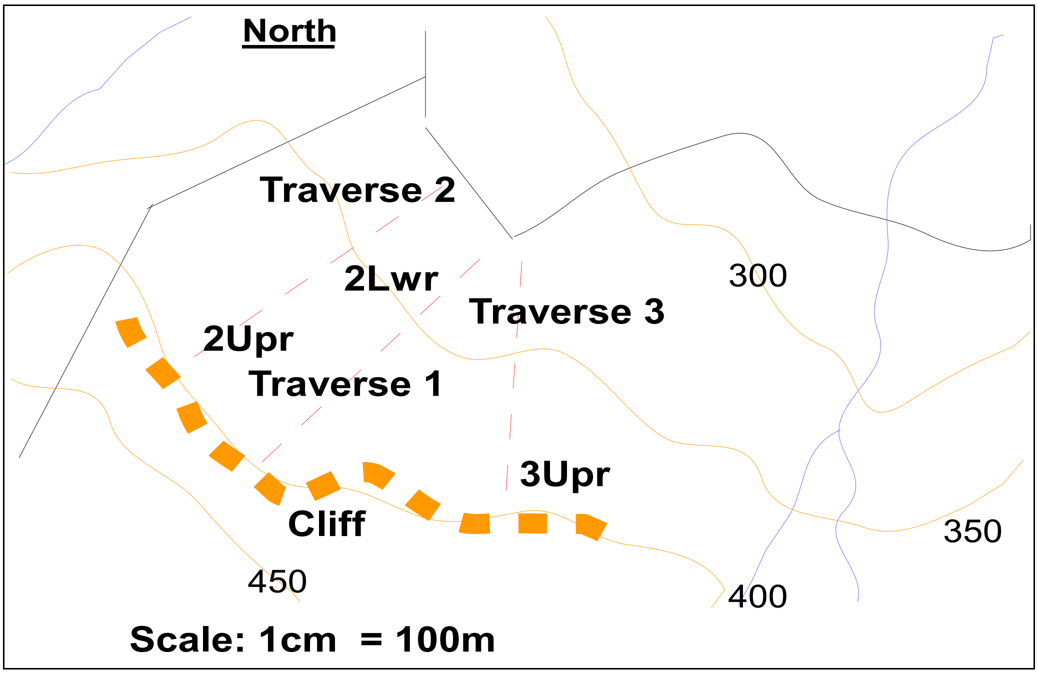


Fig 6. Sketch map of the Brennand Stones showing traverse lines

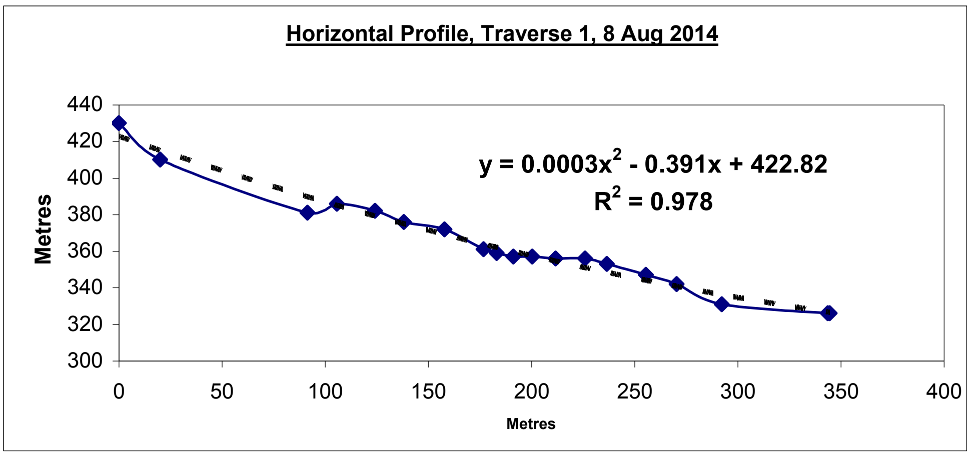


Chart 1.

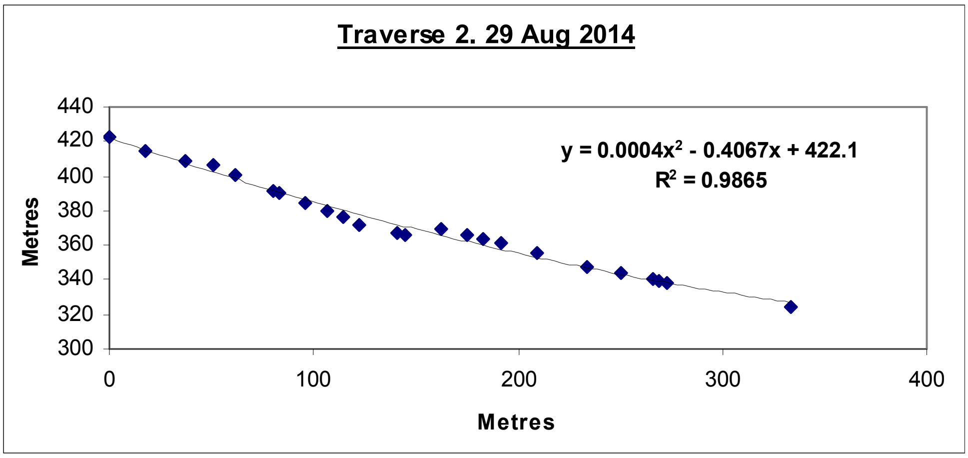


Chart 2.

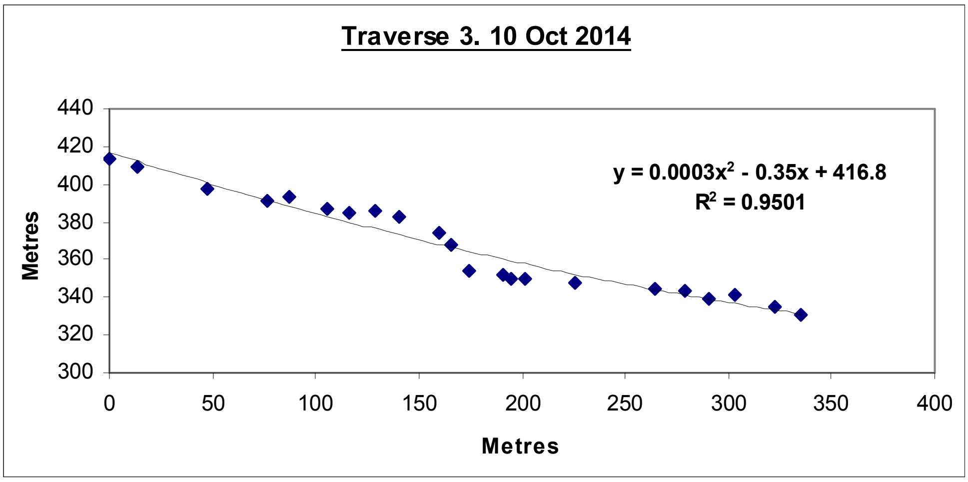


Chart 3.

The above three profiles help to identify the possible ramparts. The polynomial expressions are displayed top right of the charts

The collection of data from the possible rampart sites.

The sites of possible rampart features were identified as the profile traverses were undertaken, and on subsequent visits, to clarify the parameters used by Ballantyne and Benn (1994). These being:-

1. α Taken as the angle to the foot of the above cliff.

2. d The distance from rampart crest to talus foot.

3. The distal slope angle.

4. The proximal slope angle.

5. For additional information, the angle to the top of the cliff. (not used)

6. The angle β being derived from the traverse data.

For the results of the above parameters see table 1 below and their locations on fig 6 :-

Table 1. Results from suspect rampart sites

	α	d	β	Dist Slope	Prox Slope
Trav 2U	**27^0**	**14 m**	**34^0**	**31^0**	**00^0**
Trav 2L	**18^0**	**30 m**	**26^0**	**15^0**	**12^0**
Trav 3U	**11^0**	**25 m**	**14^o**	**28^0**	**15^0**

From the above results were computed the basal shear stresses.

The make up of the suspected rampart sites appeared to be "*open work"* (Ballantyne & Kirkbride p665, 1985) deposits composed of large angular boulders of >metre^3 to somwhat smaller sizes. No diamict deposits seemed to be in evidence.

During the above surveys a relict feature was seen at GR SD 64024/53486 (see photo Fig.7) and thought to be *polygonal desiccation cracks* that are said to be found in the Brennand Grit (Brandon 1998 p.49). The Brennand Grit is said to be a delta top deposit not a delta front/turbidite deposit that is the Pendle Grit, the assumed source rock for the Brennand Stones. This raises the question, are some of the Brennand Stones composed of Brennand Grit and not solely of Pendle Grit, that is said to be forming the cliff face above. The nearest Brennand Grit is in the area of Millers House, Threaphaw and Brennand Hanging Stones some 1 to 1.5 kilometeres north. In the light of the above, permission was obtained to take some small samples of rock from the boulders to ascertain if the rock could be typed. This resulted in 10 samples being obtained. See appendix for the location etc. Also a search for the desiccation cracks type site at Little Moor Beck was undertaken for comparison but was unproductive due to excessive water flow.

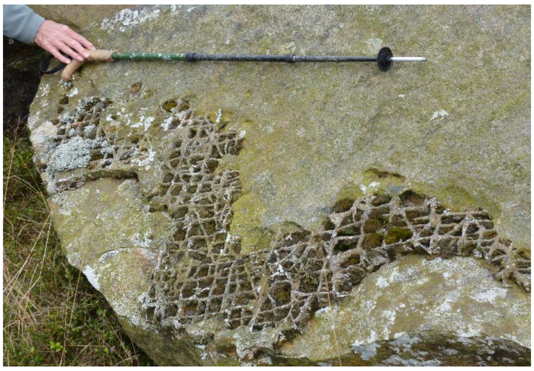


Fig 7. Suspected polygonal desiccation cracks.

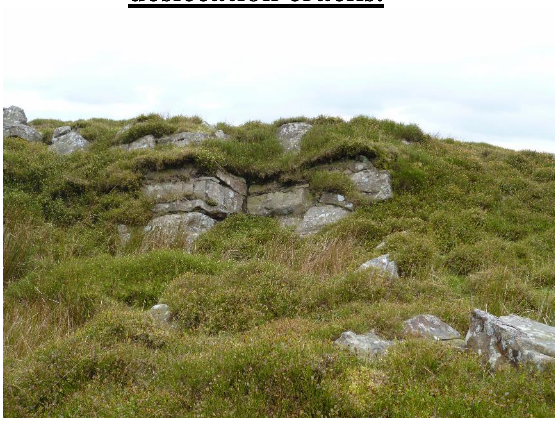


Fig.3 The outcrop type feature.

Discussion

Is it a cirque glacier?

Using the profile data from **Traverse 1, 2 and 3**., plotted graphically by a line drawn from the cliff top to the lowest point of the feature gives a max possible ice depth of **20 meters** circa 90 metres from the foot of the cliff. Entering this figure into **formula 1**. **ρgh sinα = shear stress** using an angle of 17^o for the shear plane we get: 800 x 9.81 x 20 x 0.292 = **45.6 kPa**.
The basal shear derived from **formula 4. τ_b = pgd tan α cos β sin α** were calculated and the results for suspect rampart sites were as below:-

Trav.2Lower. 21.256 kPa
Trav.2Upper. 21.047 kPa
Trav.3Upper, 7.498 kPa

These are all well below the usually accepted figure for possible ice basal shear of **100kPa**. On this basis it is not a cirque glacier.
Together with the curvature (polinomial) expressions, see profiles Charts 1, 2 & 3 above, we need to see a factor in the region of **0.0019** to generate a corrie profile.
The above all indicate that glacial flow was far from being achieved. It must also be said that a qualititive assessment of the site would probably also have given the same conclusion.

Are the mounds described possible protalus rampart features?
Using some of the morphological criteria of Ballantyne & Kirkbride (1985) the case of the **Traverse 2 Lower** feature does not display a steep distal slope (**15^o**) that would reflect an angle of repose commensurate with talus debris. There is also a possibility that the feature is an outcrop of the Pendleside Sandstone (see Fig.3) as the position would indicate this. This needs further investigation.
The **upper** feature noted on **traverse 2** has a steep distal slope (**31^o)** much more in keeping with rampart morphology and, despite the short **d** figure, is also composed of very blocky boulders.

The **Traverse 3 Upper** mound is linear, parallel with the cliff face (horizontal distance circa 50-70 metres), and has a distal slope of **28^o** so is a possible candidate for a rampart. n.b. It was noticed that a large boulder had fallen recently into the trough before the proximal slope indicating active talus accumulation.
No rampart type features were noticed for certain on the **Traverse 1** that goes down the centre of the Brennand Stones but hummocky terrain composed again of large boulders (often circa 1 cubic meter) that extend beyond the wall at the foot of the feature and into the improved pasture of Brennand Farm. From the evidence of **Traverse 1** are we looking at a rampart that has evolved into a fossil talus foot rock glacier (Ballantyne & Kirkbride 1985 p668)?
Productive work has been done on this subject by Wilson (1990) on the Errigal Mountain in Northern Ireland that confirms many of the parameters and morphology observed on the Brennand Stones. The Nahangian (Loch Lomond) Stadial is the period identified as being responsible, but the rock debris in the fossil rock glacier probably started to accumulate in the Lateglacial period. The above conclusion is derived from other sites where fossil corrie features developed e.g. the Wicklow mountains (Wilson 1990). One comparison that must be noted is that Errigal Mountain is a substantial peak of 752 metres but the range of the fossil rock glacier is from 450m – 150m but the height of Whins Brow the hill associated with Brennand Stones is 476m but the range of the postulated fossil rock glacier is 450m down to 300m O.D.
The last question to be considered is can *paraglacial* processes have contributed to the morphology of the Stones e.g. a large rock slope failure. The large stones or boulders on the lower slopes have weathering similar to the outcrops on the fell tops that are assumed to have been undisturbed throughout at least the last glaciation, till being absent from their environs. If the above is true it would indicate that the stones have come from a much older outcrop in place before the emplacement of such boulders. Wilson (2009) refers to "rock glacier mimics p134" formed by large-scale rock slope failures. The question also of the outcrop like feature that seems to face the "wrong way" relative to the presumed bedding that is found

midway down the western bay. A feature that will be difficult to identify one way or the other (see Fig.3).

Identification of the rock type.

The cliff face above from consultation of BGS map sheet 59 is of Pendle Grit, and described as "very coarse grained subarkose" (Brandon et al 1998) and the Brennand Grit as a medium to coarse grained sandstone. The Pendleside Sandstone appears to outcrop about halfway down the Stones according to sheet 59. This is described as "7m of coarse grained, poorly sorted sandstone" and also that "the lithologies of the sandstones vary little throughout the present area" (p8, 10-11 Hughes 1986). With the study of the samples collected and the above comments it is probably beyond this author's resources to reliably identify the source of the Stones by this method.

Conclusions

From the data collected by the author and from comparisons with other researchers consulted, the likely origin of the Brennand Stones feature is of a relict protalus rampart initiated at the start of the Loch Lomond Stadial but developing into a rock glacier that eventually extended circa. 200m below the talus foot. The rampart type features on the upper parts of traverses 2 and 3 surviving on the flanks of the rock glacier. This conclusion could possibly be confirmed or otherwise by an appropriate type of cosmogenic dating method. although the accuracy is only ± 1-2 ka over the Late Glacial period but if it falls wholly in the Holocene or in the LGM then processes can possibly be inferred (Wilson 2009 p.135).

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