Discussion on evidence for an unconformity at the base of the Eycott Volcanic Group in the English Lake District.

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A.H. Cooper and R.A. Hughes comment:

Millward & Molyneux (1992) have presented convincing evidence for the existence of a major unconformity between the Eycott Volcanic Group and the underlying Skiddaw Group. We agree with their conclusion that the new interpretation re-opens the debate about a pre-volcanic phase of deformation in the Ordovician of the English Lake District. The continuing British Geological Survey mapping programme has provided further evidence that there was such a phase. Its nature and products are crucial to the understanding of the deformation history of the Lake District Lower Palaeozoic inlier, particularly with respect to the structural complexity of the Skiddaw Group.

The uplift, tilting and erosion of the Skiddaw Group prior to the eruption of the Eycott and Borrowdale Volcanic Groups were considerable. These effects reflect the change from deep water, volcanically passive, ocean margin sedimentation to subaerial, subduction-related continental margin volcanism, as demonstrated by Millward & Molyneux, but need not necessarily represent basin inversion. Branney & Soper (1988) 'tentatively' attributed the uplift to 'buoyancy effects associated with the generation of andesitic melt by Iapetus subduction', but a compressive origin cannot yet be ruled out.

Different regional dip directions of the Skiddaw Group and the Eycott Volcanic Group clearly demonstrate tilting of the Skiddaw Group prior to volcanism. Furthermore, the sub-Eycott Volcanic Group unconformity cuts down through much of the upper part of the Skiddaw Group, and up to 1.5 km of the sequence has been removed in the Over Water area (by comparison with areas where the full Skiddaw Group sequence is known). Alternatively, if the Cambrian acritarchs within Skiddaw Group rocks at Eycott Hill are not re-worked from older strata into a late Arenig olistostrome, then pre-volcanic erosion might have removed a thickness of at least 5 kms of the Skiddaw Group between Over Water and Eycott Hill. Along the base of the Borrowdale Volcanic Group it can be similarly argued that up to 2.5 kms of the Skiddaw Group sequence may have been removed by erosion prior to volcanism. The accumulating evidence strengthens the arguments of Millward & Molyneux in favour of similar relationships between the Skiddaw Group and both overlying volcanic groups.

Although the pre-volcanic uplift, tilting, and erosion now seem well established, the factor crucial to the understanding of the structural history of the Skiddaw Group is whether the pre-volcanic event also produced tectonic folds with associated cleavage fabrics. Soper *et al.* (1987) attributed the main cleavage of the Lake District Lower Palaeozoic sequence, including the Skiddaw Group, to the Acadian (early Devonian) deformation. Considering the greater structural complexity of the Skiddaw Group compared to the Borrowdale Volcanic Group and the Windermere Group (with at least three cleavages in the Skiddaw Group and only one in the younger groups) it is tempting to attribute some of the complexity to the pre-volcanic

deformation event.

The recognition of pre-volcanic tectonic folds with associated cleavages in the Skiddaw Group is fraught with difficulty. The presence of widespread large-scale soft-sediment folding and olistostrome deposits in the Skiddaw Group mean that it was in parts already deformed prior to the eruption of the Eycott Volcanic Group. Any unconformity cutting across such a sequence might truncate folds and exhume locally inverted strata. Millward & Molyneux note that the Skiddaw Group at Over Water is steeply dipping and has yielded some way up evidence to suggest that it is inverted. It is possible that these rocks were inverted either by early soft-sediment deformation, pre-volcanic tectonic deformation or both. There is a weak bedding-parallel cleavage fabric in the Skiddaw Group here, but this has not been tied into a tectonic event and may only be a compaction fabric.

The structure of the Skiddaw Group is complex, but one line of evidence which might be thought pertinent to the problem of large-scale overturning was presented by Banham *et al.* (1981). They described the Gillbrea Nappe as a major structure formed in Arenig-Llanvirn times (i.e. pre-volcanic) which produced regional inversion in the Skiddaw Group. Dunning (1992) has reiterated the Gillbrea Nappe as a major structure of the Skiddaw Group. Unfortunately, the re-survey of the Skiddaw Group by the British Geological Survey has shown that this structure does not exist. The work of Webb & Cooper (1988) and the map covering much of the area (British Geological Survey, 1990) show a more plausible interpretation based on a complete re-survey rather than the scattering of exposures used by Banham and his co-workers.

On the specific evidence cited by Banham *et al.* (1981) we make the following comments: large scale overturning of the sequence is not a feature of the area between Scawgill and Watch Hill as shown in their Figures 1 & 4. Much of Harrot (their Figure 1) is inverted, but the structure is that of a tight anticline overturned to the south-east; it contains numerous minor folds. The lowest exposure on the hill side, in the wood behind Gillbrea Farm [NY 1560 2704], is largely the right way up; it includes an anticline overturned to the south-east with an inverted limb younging to the south-east. This is a structure impossible to reconcile with the postulated Gillbrea Nappe. At Harrot there is no plane of inversion running along the 200m contour. Sole structures and graded beds in sandstones in the Watch Hill area show that the Watch Hill area is the right way up, not inverted. No inverted beds were found at Scawgill anywhere between the quarry and the stream. No reliable way up evidence was found at Embleton Quarry and the apparent fold in the north of the exposure was partly a result of quarry collapse.

A brief summary of the Skiddaw Group structure as we understand it is given here. In the south-west of the main inlier there is good evidence for major slumping and olistostrome generation during the late Arenig (Webb & Cooper, 1988). This event produced folds and intensely disrupted deposits on a km scale, best seen in the vicinity of Buttermere; these folds are post-dated by tectonic folds and their associated cleavages. The Buttermere deposits are separated from the northern part of the Skiddaw Group by the Causey Pike Fault (Cooper & Molyneux, 1990) and the Crummock Water Aureole which follows the same line (Cooper *et al.* 1988). North of this line the structure, outlined below, is more like that described by Rose (1955) and does not resemble that described by Banham *et al.* (1981). There is inconclusive evidence of an early phase of thrusting (see below). The major folds have a wavelength of 3-6 kms and vary from the upright isocline of Sale Fell to the open folds of the Lorton-Barf and Grasmoor anticlines (British Geological Survey, 1990). The Loweswater anticline is near isoclinal,

recumbent and lobate in form with a basal thrust fault directed to the south-east (Webb & Cooper, 1988). It has been suggested by Webb & Cooper (*op cit*.) that this structure originated as a slump fold early in the deformation history of the Skiddaw Group. Re-interpretations by the BGS mapping team of fold-cleavage and minor fold vergence relationships within this structure suggest that this fold is of true tectonic origin. It is also possible that it has been refolded into its more northerly orientation by sinistral drag on the Causey Pike Fault structure. The structures that are present in this northern part of the Skiddaw Group do not include the Gillbrea Nappe.

The Gillbrea Nappe therefore cannot be cited as an example of a product of pre-volcanic compression, and conclusive evidence for such structures remains wanting. The distribution of the minor intrusions of the Embleton diorite set, east of Cockermouth, on both the hanging-wall and foot-wall of the Watch Hill Thrust (BGS, 1991) suggests that the thrust pre-dates the intrusive age of 458 +/- 9 Ma (Rundle, 1979). This is, to date, the only evidence of a pre-volcanic compressive event, and is admittedly equivocal.

Millward & Molyneux have re-opened the debate on a pre-volcanic deformation event in the Lake District. That such an event took place is beyond doubt, but the question which remains unanswered is can the greater structural complexity of the Skiddaw Group (by comparison with the Eycott and Borrowdale volcanic groups and the Windermere Group) be due in part to tectonic folding and cleavage development during this event? It is hoped that the current re-survey by the British Geological Survey of the 1:50,000 Keswick sheet, which involves further study of sections through the Skiddaw Group- Borrowdale Volcanic Group unconformity will answer this question once and for all.

References

BANHAM, P. H., HOPPER, F. M. W. & JACKSON, J. B. 1981. The Gillbrea Nappe in the Skiddaw Group, Cockermouth, Cumbria, England. *Geological Magazine*, **118**, 509-516.

BRANNEY, M.J. & SOPER, N.J. 1988. Ordovician volcano-tectonics in the English Lake District. *Journal of the Geological Society*, **145**, 367-376.

BRITISH GEOLOGICAL SURVEY. 1990. *Lorton and Loweswater Sheet NY 12.* Solid and Drift 1:25 000 (Southampton: Ordnance Survey, for the British Geological Survey).

BRITISH GEOLOGICAL SURVEY. 1991. 1:10,000 Series sheet NY 13 SE (Embleton). Keyworth: British Geological Survey.

COOPER, A. H. & MOLYNEUX, S. G. 1990. The age and correlation of Skiddaw Group (early Ordovician) sediments in the Cross Fell inlier (northern England). *Geological Magazine*, **127**, 147-157.

COOPER, D. C., LEE, M. K., FORTEY, N. J., COOPER, A. H., RUNDLE, C. C., WEBB, B. C., and ALLEN P. M. 1988. The Crummock Water aureole: a zone of metasomatism and source of ore metals in the English Lake District. *Journal of the Geological Society of London*, **145**, 523-540.

DUNNING, F. W. 1992. Structure, In *Geology of England and Wales*. (eds. P. McL. D. Duff & A. J. Smith), pp. 523-561. Geological Society, London.

MILLWARD, D. & MOLYNEUX, S. G. 1992. Field and biostratigraphic evidence for an unconformity at the base of the Eycott Volcanic Group in the English Lake District. *Geological Magazine*, **129**, 77-92.

ROSE, W. C. C. 1955. The sequence and structure of the Skiddaw Slates in the Keswick-Buttermere area. *Proceedings of the Geologists' Association*, **65**, 403-406.

RUNDLE, C.C. 1979. Ordovician intrusions in the English Lake District. *Journal of the Geological Society of London,* **136**, 29-38.

SOPER, N.J., WEBB, B.C. & WOODCOCK, N.H. 1987. Late Caledonian (Acadian) transpression in north-west England: timing, geometry and geotectonic significance. *Proceedings of the Yorkshire Geological Society*, **46**, 175-92.

WEBB, B. C. & COOPER, A. H. 1988. Slump folds and gravity slide structures in a Lower Palaeozoic marginal basin sequence (the Skiddaw Group), NW England. *Journal of Structural Geology*, **10**, 463-472.

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