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CORRESPONDENCE AND NOTES

The Ordovician batholith of the English Lake District

SIRS – A paper of great interest to Lake District geology and Caledonide geotectonics generally has recently appeared in the Durham Symposium Volume in honour of Sir Kingsley Dunham (Firman & Lee, 1986). I would like to use the pages of the *Geological Magazine* to comment on Firman & Lee's model for the Lake District batholith and suggest how it may be extended.

In brief, the authors adduce evidence to suggest that the bulk of the concealed batholith (which is an order of magnitude greater in extent than the exposed granite bodies) is largely of Ordovician age; the largest exposed intrusion (Eskdale) was emplaced during the late Ordovician deformation which affected the Borrowdale Volcanic Group; the axis of uplift associated with this unconformity coincides with the axis of the concealed batholith, so its emplacement might well have been responsible for the uplift; and the subsequent Caradoc-Ashgill transgression records overstep onto this axis and its eventual inundation – a more realistic palaeogeographical interpretation than that previously proposed by Ingham & McNamara *in* Ingham, McNamara & Rickards (1978).

The authors' analysis of the control exerted by the batholith on late Ordovician sedimentation patterns sheds new light on Lake District geology, and their reliance on geological evidence for the age of emplacement of the Eskdale granite, rather than an apparently impeccable Rb/Sr isochron (Rundle, 1979), is to be commended. Before isotopic age determinations became available to complicate what appeared to be a simple issue, geologists working in the Lake District tended to divide the granitic intrusions into two groups. One group comprised Shap and Skiddaw, both coarsely crystalline with well developed contact aureoles and associated mineralization and, most importantly, a post-cleavage age of emplacement. The cleavage, then regarded as 'end-Silurian' but now known to be of mid- to late Lower Devonian age (Soper, Webb & Woodcock, in press), represents the main Caledonian deformation in the region and these granites were regarded as 'late orogenic plutons'.

The other group, Ennerdale, St. John's and Threlkeld, are pre-cleavage, of microgranitic texture, probably sheet-like in form and were emplaced near the base of the Borrowdale volcanic pile. These I regarded as subvolcanic intrusions and therefore of Ordovician age. In this simple scheme, pre-cleavage microgranites were emplaced at a shallow level during the volcanic activity, post-cleavage 'plutonic' granites were emplaced at a deeper level, in crust tectonically thickened during the Caledonian orogeny. Investigations of the Skiddaw and Shap aureoles (Soper & Roberts, 1971; Boulter & Soper, 1973) suggested that these plutons rose to their present levels during a relaxation of stress immediately following the main Caledonian deformation.

Because of its plutonic aspect I grouped the Eskdale granite-granodiorite intrusion with Shap & Skiddaw, and found Rundle's (1979) Rb/Sr age of 429 ± 4 Ma difficult to accept since it implied the emplacement of a large mass of buoyant material at a high crustal level during the early Silurian basin-deepening episode. To my shame, this was the one Lake District granite whose contact relationships I failed to check, and it was not until Dr P. M. Allen's investigation during the current British Geological Survey (BGS) resurvey that the pre-cleavage age of Eskdale was demonstrated. The intrusion must represent a deeper level of consolidation than the Ennerdale granophrye, even though it penetrates to a somewhat higher level in the volcanic pile.

Firman & Lee regard it as syntectonic with the Ulpha syncline, a fold which affects the Borrowdale Group in the southwest Lake District but which pre-dates the late Caradoc unconformity. This interpretation appears to be at variance with evidence that the final emplacement of the pluton post-dated the fold, since the granite contact cuts its axial trace. But leaving aside detailed problems of timing, I feel that the authors' scenario of uplift and eastward tilting of a horst due to the emplacement of the Caradoc part of the Lake District batholith is entirely credible.

Note the implications of this new interpretation for the late Ordovician history of the Lake District. The following events all took place largely within Caradoc time:

(1) Eruption of the Borrowdale Volcanic Group. Thirlwall & Fitton's (1983) Sm/Nd garnet age of 457 ± 9 Ma spans Llandeilo and Caradoc time on the McKerrow, Lambert & Cocks (1985) time scale, but new micropalaeontological evidence (S. G. Molyneux, pers. comm.) suggests that most of the volcanic pile was erupted during Caradoc time.

(2) Deformation to produce the Ulpha syncline and other major folds in the volcanic rocks such as the Nan Bield anticline (Soper & Numan, 1974). These structures could be largely of volcano-tectonic origin.

(3) Emplacement of the Ordovician component of the batholith, with attendant uplift of the volcanic horst and its erosion.

(4) Onset of the late Ordovician transgression across this horst, an important subsidence episode which led to Llandovery pelagic graptolite shale deposition.

I now draw attention to three points which arise from the recognition of this period of intense volcano-tectonic activity.

Firstly, the extrusive and intrusive activity, both now recognized as mainly Caradoc in age, must surely be related. In the view of M. J.Branney (pers. comm.), the batholith represents a large magma chamber which fed the voluminous acid pyroclastic deposits of the Borrowdale Group. This major volcanic event is part of the regional-scale magmatism which is recorded in the paratectonic Caledonides of England, Wales and Ireland in late Ordovician time, and which no longer seems to fit the simple space-time-composition pattern predicted by the Fitton & Hughes (1970) model of southerly subduction. It is tempting to relate this burst of magmatic activity and its attendant tectonism to the rapid displacement of southern Britain in late Ordovician time which Piper (1978) infers from the palaeomagnetic evidence. An understanding of this important event would shed much light on the current controversy of Ordovician vs. early Devonian closure of Iapetus.

Secondly, the Firman & Lee model might provide an

explanation for the late Caradoc-Ashgill transgression in the Lake District. The transgression appears to be independent of the eustatic changes which are recognized at this period (McKerrow, 1979), and its profound effect in the Lake District requires a local cause. I suggest that the cooling and contraction of the batholith and its volcanic superstructure over a period of about 10 Ma partly reversed the uplift and eastward tilt associated with its emplacement and could have produced the overstep pattern displayed by the Caradoc-Ashgill sediments as interpreted by Firman & Lee in their figure 4.

Thirdly, the corollary is that the bulk of the Lake District batholith was in place at a high crustal level before onset of the important Silurian subsidence episode which was associated with the deposition of some 5 km of Wenlock, Ludlow and Pridoli turbidites in the southern Lake District. In order to depress this relatively buoyant crust, a major geotectonic cause must be invoked, particularly as Silurian turbidite deposition is by no means confined to the Lake District but is characteristic of the paratectonic Caledonides generally. This is again of relevance to the question of late Ordovician vs. early Devonian closure.

A model I suggested in Leggett, McKerrow & Soper (1983) was that as the leading 'Lake District' margin of the southern Britain terrane (part of Eastern Avalonia or Cadomia in present terminology) approached the 'Southern Uplands' trench on the Laurentian margin, foreland basins developed ahead of the subduction-related thrust complex, and the Lake District basin started to receive sediment derived from the eroding Southern Uplands accretionary prism in late Wenlock time. The process was terminated by 'collision' in the early Devonian. An alternative model of Murphy & Hutton (1986) is based on Ordovician collision and invokes a Silurian transtensional episode to produce 'successor basins'. The main problem with this model is that it fails to account for the major orogenic events in the paratectonic Caledonides of early Devonian age – deformation and inversion of the Silurian basins, granite emplacement, erosion and molasse deposition and the stabilization of the Old Red Continent. A third possibility is that the Silurian turbidite basins represent residual seaways left after the incomplete closure of Iapetus at the end of the Ordovician period. The Caradoc tectono-magmatic event then records a 'close encounter' between Avalonia and Laurentia, not 'collision'. Integrated studies of the Silurian basins of Britain are needed to shed light on these problems.

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The Ordovician(?) batholith of the English Lake District

SIRS – As field geologists surveying in the Lake District for the British Geological Survey we would like to add our comments to those of Dr N. J. Soper. These concern the influence of the postulated Lake District batholith on the geological development of the area, as originally proposed by Firman & Lee (1986).

The evidence for late Ordovician or early Silurian emplacement of the major portion of the batholith is clearly strong but we feel that its relationship to the Borrowdale Volcanic Group, its possible influence on the early deforma-