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.

I thank Dave Milward who demonstrated the pre-cleavage age of the Eskdale granite to me, and many colleagues for discussion, particularly Kevin Pickering, and my research students Mike Branney and Neil Mathieson.

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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-

tion of that group and on the late Ordovician transgression is overstressed.

The Eskdale Granite, the exposed part of the largely concealed, early batholith cannot be directly related to the Borrowdale Volcanic rocks in the way that Soper suggests. The thick, acid, pyroclastic sheets he refers to are, generally, dacitic (SiO_2 66–68 wt%) and although they may represent plutons that rose to such high crustal levels that they explosively tore themselves apart, there was probably little left to form an intrusion of any size. Furthermore, a comparison of incompatible element geochemistry of rhyolitic rocks from the Borrowdale Volcanic Group with the Eskdale Granite shows the latter to be more evolved (O'Brien et al. 1985). Any relationships between the volcanic and plutonic activity must be seen as part of the long term evolution of magmas generated from sub-crustal and/or crustal sources within the destructive plate margin environment that existed in the Lake District during this period. All that can be argued is that repeated passage of magmas through the crust during the eruption of the Borrowdale Volcanic Group would produce a suitably annealed system of channelways to serve as sites for the rise of later, high-level intrusions.

Evidence for early (Caradoc) folding of the Borrowdale Volcanic Group centres on the Ulpha Syncline (see Soper & Moseley, 1978), which appears to have a more easterly trend than later folds of the main, early Devonian deformation phase and to be truncated by the late Caradoc unconformity at the base of the Windermere Group. However, anticlinal folds in the Borrowdale Group, like those in the overlying Silurian strata, are periclinal structures and thus the trend of the associated synclines can be anomalous. Our mapping shows that the axial plane trace of the Ulpha Syncline converges with that of the adjacent, more northerly trending, Black Coombe Anticline so that in the Duddon Valley, near Ulpha (grid reference SD 1993), these folds die out leaving no more than a sharp change in the strike of the volcanic rocks. There is, therefore, no good evidence to indicate that the orientation of early folds differed from that of later ones. We have yet to resurvey the Coniston/Torver area in the region of the pronounced overstep of the Upper Ordovician Coniston Limestone Formation onto the Borrowdale Volcanic Group, but there seems no reason to doubt the occurrence of periclinal folds in this area or that such folds are truncated by the unconformity. At present we are prepared to accept the existence of folds pre-dating the unconformity but consider these to be coaxial with those of the later, main deformation and see no reason to relate them to the Lake District batholith. Our recent field mapping does not support the suggestion by Firman & Lee that the Ulpha Syncline could be a drape structure developed during the intrusion of the batholith. In the Whitfell (SD 1593) to Buckbarrow (SD 1591) area the Ulpha Syncline is clearly truncated and, therefore, post-dated by the Eskdale granodiorite which is thought to be part of the early batholith.

We consider the Caradoc deformation to be unrelated to batholith emplacement and to be part of a prolonged, discontinuous deformation phase which commenced sometime between late Llanvirn and early Caradoc time. It was responsible for partial inversion of the earlier Skiddaw Group basins, causing the initiation of the main Lake District Anticline and the associated sub-Borrowdale Volcanic Group unconformity (Downie & Soper, 1972; Wadge, 1972). Minor structures relatable to this earlier episode have not been identified (pre-cleavage folds in the Skiddaw Group are earlier still). They are either very rare or coaxial with, and hence indistinguishable from, later structures of Caradoc or early Devonian age. Renewed development of the Lake District Anticline in Caradoc time would uplift the volcanics and produce a 'horst' without recourse to the intrusion of granitic magma at the same time. The intrusion would follow, as its radiometric age suggests, being emplaced early in the tensional regime under which the Silurian basins developed.

Soper suggests that the Caradoc compressional episode might represent a 'close encounter' between Avalonia and Laurentia rather than a true collision. The distinction is, perhaps, subjective. We would advocate such a 'close encounter' to initiate the Lake District Anticline in pre-Borrowdale times. This was followed by:

1. A tensional episode in which the Borrowdale Volcanic Group was erupted.
2. A compressional episode to produce the Caradoc folds and uplift.
3. A tensional episode in which the batholith was emplaced and the Silurian basins opened.
4. A compressional episode, the main, early Devonian deformation phase.

If the episode 4 represents the final docking of Avalonia into the re-entrant between Laurentia and Baltica (Soper & Hutton, 1984), then the earlier ones could represent transpressional and transtensional episodes as Avalonia slipped sinistrally along the irregular margin of Laurentia.

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Reply

It is apparent that the Lake District B.G.S. group (Webb *et al.*, above) do not accept our thesis, developed from that of