Introduction

General stratigraphical succession for the

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Windermere Supergroup in its type area of the southern Lake District (after Kneller et al., 1994). The buff-coloured sections in the Formation/Member column show breaks in the preserved succession. P916053.

Langdale Fell, on the northern flank of the Howgill Fells, is underlain by Silurian strata from the upper part of the Windermere Supergroup. (P668926).

Selection of Ashgill shelly fossils from the Dent Group: a Brachiopod, *Rafinesquina* sp., internal mould of pedicle valve from the Kirkley Bank Formation (High Pike Haw Member, Cautleyan Stage) near Appletree Worth [SD 2465 9285] (RU 4075), x2; b & c Brachiopods, *Plaesiomys inflata* from the Kirkley Bank Formation (High Pike Haw Member, Cautleyan Stage) in the Coniston area - b = internal mould of transverse pedicle valve (Gsd461) x1.5, c = latex cast from external mould of brachial valve
(Gsd271) x1.5; d Brachiopod, *Fardenia* (cf. *transversaria*), internal mould of pedicle valve from the Kirkley Bank Formation (High Pike Haw Member, Cautleyan Stage) near Appletree Worth [SD 2508 9341] (Zw8345) x1.5; e Trilobite, *Mucronaspis olini*, small pygidium from the Ashgill Shale Formation (Troutbeck Member, Rawtheyan Stage) north-east of Appletree Worth [SD 2488 9309] (Zs430) x6; f Trilobites, *Staurocephalus* cf. *clavifrons*, internal mould of exoskeleton associated with a second, small individual and (top right) a pygidium of *Panderia*? from the Ashgill Shale Formation (Troutbeck Member, Rawtheyan Stage) at Boo Tarn [SD 2811 9673] (Zw9286) x5. (P711117).

Generalised distribution of the component groups of the Windermere Supergroup in its southern Lake District outcrop. P916054.


The cessation of Caradoc volcanism and granite intrusion was followed by thermal subsidence and a marine transgression across the eroded volcanic fields of the Borrowdale and Eycott groups. This
occurred despite a lowering of global sea level coincident with a late Ordovician ice age. The Windermere Supergroup encompasses the ensuing, mostly sedimentary and more-or-less complete succession that ranges up through the remainder of the Ordovician and the whole of the Silurian (P916053). It crops out across the southern Lake District, from Furness in the west to the Langdale and Howgill fells in the east (P668926).

Ordovician clastic and carbonate sedimentation was largely in a near-shore environment but with some of the basal strata showing fluviatile characteristics; two volcanic intervals represent the final throes of local Ordovician eruption. Marine deposition continued across the Ordovician–Silurian boundary despite the brief ice age at the end of Ordovician times, but the postglacial rise in global sea level produced a deepening depositional environment that allowed accumulation of mudstone and shale throughout the Llandovery. The overlying Wenlock sequence is dominated by laminated hemipelagic mudstone but with the proportion of turbidite sandstone increasing upwards. A calcareous siltstone unit spans the Wenlock–Ludlow boundary, marking a major marine regression, but the laminated hemipelagic mudstone reappears above it and continues upwards into the Ludlow, where it is increasingly swamped by the influx of turbidite sand.

The increase in the proportion of turbidite sandstone upwards into the Ludlow is dramatic, culminating in the deposition of a several-kilometre thickness of strata during the duration of three graptolite biozones (the Gorstian, nilssoni, scanicus and incipiens Biozones). This change in sediment accumulation rate has been ascribed to a rapid increase in subsidence brought about by the closure of the Iapetus Ocean and the collision of its marginal continents. As described in Chapter 1, collision between Laurentia (the northern continent) and Avalonia (the southern margin of Iapetus on which the future north of England was situated) resulted in the former over-riding the latter. It was this progressive loading of the Avalonian margin that produced the marked acceleration in subsidence rate and allowed accumulation of the thick turbidite sequence in what was effectively a foreland basin.

The later Ludlow and Pridoli succession reflects the matching of the subsidence rate by sediment supply rate and a commensurate filling of the sedimentary basin. It would seem that convergence between Laurentia and Avalonia slowed, the foreland basin failed to migrate southwards, and isostatic adjustments increasingly balanced the effects of loading. The middle to upper Ludlow strata are mainly low density, silt- and mud-dominated turbidites, but the youngest Ludlow and the Pridoli deposits include shallow-water sandstones and red beds.

**Stratigraphical framework**

In biostratigraphical terms there is one important difference between the Ordovician and Silurian parts of the Windermere Supergroup. The former contains a locally rich and varied shelly fauna (P711117) but, until recently, very few graptolites had been recorded; in contrast, the latter is largely graptolitic. Hence the basis of biostratigraphical correlation changes at the Ordovician–Silurian boundary, and the application of either scheme across that boundary is uncertain.

Windermere Supergroup strata crop out across a large swathe of the southern Lake District, from Furness in the west to the Howgill Fells in the east (P916054). Distinctive Ordovician successions form inliers in the Cautley and Dent areas, at the eastern margin of the Lake District outcrop, whilst inliers further east at Cross Fell comprise sequences ranging up from the Caradoc as high as the Wenlock. The onset of marine sedimentation was diachronous, with the oldest basal strata, of mid Caradoc age, seen in the north and east of the outcrop: calcareous mudstones of the Drygill Formation succeed the Eycott Volcanic Group in the north-east of the Lake District, whilst the lowest
(volcaniclastic, sandy siltstone) beds of the Dufton Shale Formation in the Cross Fell inlier lie unconformably on volcanic rocks assigned to the Borrowdale Volcanic Group (P916055). In contrast, in the south-west of the Lake District, the basal beds of the Windermere Supergroup, resting unconformably on both the Borrowdale Volcanic Group and (in Furness) the Skiddaw Group, are early Ashgill in age; they comprise the variously clastic or carbonate rocks of the Stile End and Kirkley Bank formations.

The upper Ordovician part of the Windermere Supergroup is a variable succession of mudstone, calcareous siltstone and impure limestone, sandstone and conglomerate. It is most complete and thickest (up to about 600 m) in the Cautley and Dent inliers of the eastern Lake District, but much thinner and interrupted by several non-sequences in the south-western part of the outcrop. In the latter area, it records the transition from shore-face through storm-dominated, mixed carbonate and clastic shelf to deeper shelf deposits. The deeper shelf environment was established earlier in the east allowing the more continuous deposition of the mudstone successions now seen in the Cross Fell inlier (Dufton Shale Formation) and the Cautley and Dent inliers (Cautley Mudstone Formation). Throughout the sequence there is a shallow-marine, shelly fauna that includes trilobites and brachiopods (P711117). This characteristic, together with the widespread (though by no means dominant) carbonate lithofacies, has justified the traditional, informal name ‘Coniston Limestone’ for the southwestern Lake District outcrop. Modern, formal stratigraphy designates the succession the Dent Group. Two episodes of silicic volcanism are recorded; one creating the ignimbritic Yarlside Volcanic Formation, and a subsequent, more widespread development of bedded tuffs high in the Cautley Mudstone Formation, and at subsequent, more widespread development of bedded tuffs high in the Cautley Mudstone Formation and at equivalent levels elsewhere (P916055).

At the end of the Ordovician, a combination of global sea-level rise and regional subsidence allowed a deep water, graptolitic lithofacies to be established across the whole region. The mudstone and siltstone of the Stockdale Group span the final graptolite biozone of the Ashgill and the whole of the Llandovery, but are no more than 100 m thick. The Wenlock and earliest Ludlow sequence is characterised by distinctively laminated, hemipelagic, carbonateous siltstones but includes intermittent turbidite sandstone units that presage the subsequent, major influx of sediment later in Ludlow times. These strata form the approximately 1000 m of the Tranearth Group and include, at the top of the Wenlock, two 15 m thicknesses of calcareous siltstone that establish a temporary shallowing of the depositional environment, probably in response to an eustatic sea-level change. The Stockdale Group extends across the whole of the Lake District outcrop and is also present in the Cross Fell inlier. The Tranearth Group is represented in Cross Fell only by its lowermost formation (Brathay), which is the highest unit of the Windermere Supergroup seen there.

A progressive increase in subsidence rate during the early Ludlow was caused by closure of the Iapetus Ocean and the resultant loading of the Avalonian continental margin by the overriding, leading edge of Laurentia (see discussion in Chapter 2). This increase, and the concurrent increase in the supply of coarse sediment, allowed a dramatic increase in sedimentation rate such that a large thickness, up to 2 km or more, of turbidite sandstone was deposited in the course of a single Gorstian graptolite biozone. The turbidite sandstones, and the intervening units of siltstone and hemipelagite, comprise the Coniston Group, the formalised equivalent of the traditional ‘Coniston Grits’. The ‘standard’ lithostratigraphy from the southern Lake District recognises three major sandstone-dominated formations separated by two siltstone formations, but there is some lateral variation in the relative positions of thick sandstone bodies within the siltstone background of the group, and so correlation at formation level is not wholly satisfactory. This is particularly true from the southern Lake District eastward to the Howgill Fells, where, in the latter area, the sandstone of the Screes Gill Formation may represent a diachronously old base to the Coniston Group, laterally equivalent to the top of the Tranearth Group further west. As an added complication, there appear to be more major alternations between sandstone-dominant and siltstone-dominant ‘formations’ in the
Howgill Fells than can be discerned further west.

The later part of Ludlow times saw continued turbidite deposition, but from flows with low density and volume. Over 4000 m of banded siltstone and mudstone (Bannisdale Formation) accumulated with sporadic intercalations of sandstone; a sparse graptolite fauna is present, mostly in thin interbeds of hemipelagite. The Bannisdale Formation is the lowest unit of the Kendal Group, the higher parts of which are still unsatisfactory in stratigraphical terms. Above it, a coarser-grained and more calcareous lithology, containing a shelly fauna, has been described as the Underbarrow Formation but the putative boundaries are certainly diachronous and lateral correlation of its supposed outcrop is highly dubious. The succeeding Kirkby Moor Formation is more securely established. It is largely composed of fine-grained sandstone distinguished by features indicative of a relatively shallow-water depositional environment; the sedimentary basin was by this time clearly being filled. In some places, the sandstones have suffered secondary reddening, whilst in others a distinctive siltstone lithofacies may have been deposited in a tidal environment. Both of these features have been cited in definitions of a Scout Hill Formation, but are probably more appropriately regarded as local variations of the Kirkby Moor Formation. Whichever lithostratigraphical name is preferred for the top of the Kendal Group, its age ranges up into the Pridoli.

Bibliography


