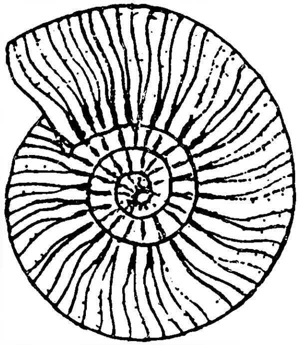
THE CUMBERLAND GEOLOGICAL SOCIETY



PROCEEDINGS

Volume 5 | 1990-91 | Part 3

THE CUMBERLAND GEOLOGICAL SOCIETY

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Volume 5 **Part 3**

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EDITOR'S NOTES

This volume of the Proceedings is dedicated as a memorial to the Society's Life President, Edgar Howard Shackleton, who died on 14 March 1991. Appreciations of his many contributions to the work and life of the Society are provided by Tom Shipp and Mervyn Dodd.

Two new publications by the Society merit special mention. "**The bibliography of the geology & geomorphology of Cumbria**" by R.A. Smith provides a comprehensive list of published material on Cumbria over the 15 years since the first edition of the bibliography was published in 1974. The volume includes over 560 references, reflecting the significant surge in research activity on Cumbrian topics during recent years. Copies of the bibliography and of earlier editions of the Proceedings may be obtained from the Publication Secretary: Mr.T.P.Loftus, 9 Jackson Road, Carlisle CA3 0NW (Tel.0228 45807).

"**Lakeland Rocks & Landscape: A Field Guide**" is published in April 1992. This stimulating field guide with eighteen geological excursions covers all the main geological features of Cumbria. The book with its introduction to Lake District geology and glossary makes it suitable for beginners in geology as well as the more experienced geologists. Copies are available to Society members at a concessionary price from Publication Secretary; Other orders at £7-99 per volume to the publishers: Ellerbank Press, The Laithes, Selby Terrace, Maryport, Cumbria CA15 6LX (Tel. 0900 8178773).

I would like to thank all who have contributed articles, provided excursion and lecture notes or have assisted in the preparation of the Proceedings. The art-work has again been undertaken by Mr. J. D. Hinde while Dr. D. Edwards has greatly assisted with computer facilities, to both of whom I extend thanks on behalf of the Society.

The Proceeding is a biennial publication that caters for papers on the geology and geomorphology of Cumbria and Northern England. Contributions are welcome and should be submitted to the Editor.

Eric Skipsey, Editor.

DINANTIAN CARBONATE CYCLES OF WEST CUMBRIA

G. A. L. Johnson

Abstract

The pioneer work of Kendall (1895), Edmunds (1922), Earle (1922) and the British Geological Survey in the 1930s on the Lower Carboniferous (Dinantian, Holkerian to Brigantian) rocks of West Cumbria gave much detail on the subdivision and correlation of the succession and the fossils it contains. This data was reviewed by Shackleton in the 1960s who produced a valuable field guide and popular accounts of the regional geology. Since then much work has continued in the region associated with marine geophysics and hydrocarbon exploration in the Irish Sea, producing results on the structural framework of north-west England and the Irish Sea and the history of basin development in the region. The Dinantian of West Cumbria is proved to have been laid down on a positive structural ridge between the active Carboniferous Solway and Manx-Furness basins. Over this Ramsay-Whitehaven ridge, Dinantian downwarping was rather less than in the basins to the north and south. Evidence for Dinantian shallow water deposition in West Cumbria is assessed and periods of emergence of the carbonate shelf are attributed to irregular uplift of the adjacent Lake District core. Collateral evidence for a Dinantian Lake District Island is seen to be strong. The major differences between the Dinantian succession of West Cumbria and the sequences developed elsewhere in Northern England is shown to be due to structural considerations and location.

Introduction

The west side of the English Lake District tends to be remote, missed by the main lines of communication and by the tourist routes. It has been well known geologically for many years, however, because of its mineral resources. Coal mining in the West Cumberland coalfield started in about the middle of the 16th Century and by the middle of the 17th Century coal was being shipped extensively from Whitehaven. Haematite mining from the altered Dinantian limestones boomed from the mid-19th Century when the local iron ore proved to be ideal for the newly developed acid Bessemer convertor. Mineral resources brought the region to geological notice and the whole of West Cumbria was mapped by the Geological Survey with maps published in the 1890s. The Dinantian succession was studied in detail during the development of haematite mining and in particular Kendall (1885) produced a full account of the sequence and lithology. The names of limestones and the intervening shale and sandstone bands introduced by Kendall (*ibid*), the First to the Seventh limestones in descending order, are still in general use. The sequence is illustrated in Figure 1.

The biostratigraphical division of the Dinantian early in the 20th Century allowed more precise subdivision of strata and opened up the possibility of lateral correlation of Dinantian sequences. Garwood (1913) produced a scheme of biozones for NW England and these division were correlated with West Cumbria by Edmonds (1922) and Earle (1922). These authors recognised that the First Limestone of West Cumbria was the Great or Main Limestone of East Cumbria and the Pennines and that, using fossil markers, it was possible to correlate the underlying succession between the two areas. The work of Charles Edmonds on the Dinantian fossils and marker bands of West Cumbria is especially noteworthy and his work was later substantiated by the Geological Survey. During the 1920s West Cumbria was re-surveyed by the Geological Survey and the new biostratigraphical data on the Dinantian was incorporated in the Maryport, Whitehaven and Gosforth memoirs published during the 1930s. After a gap, owing to the war, geological investigation in West Cumbria restarted in the 1960s with the development of the Cumberland Geological Society. Under their President Edgar Shackleton the Society continued the study of Dinantian successions and and a detailed description was produced (Shackleton, 1962).

Although distinctive upper and lower Dinantian faunas have been known for over 150 years and zonal schemes using fossils were set up by Garwood (1913) and Vaughan (1905), no uniform pattern of zones (biozones) could be applied to the whole of the British Isles. The cause of this was the disconformities or breaks in deposition occurring within the Dinantian successions. Zones or parts of zones are absent in

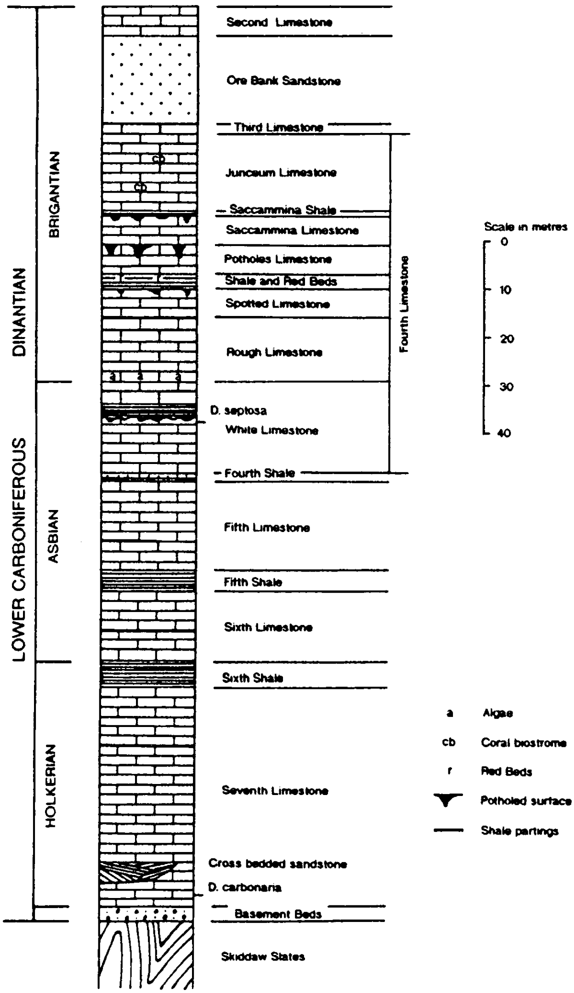

Figure 1- Dinantian succession in the Clints Quarry area, Egremont, after E.H.Shackleton F.G.S. (Redrawn from the West Cumbria Field Meeting Guide, 1980, The Carboniferous Group of the Palaeontological Association-Leaders: E.H.Shackleton & M.Mitchell

apparently continuous sequences of strata. A Dinantian Working Group was brought together in the 1970s to look into this problem and they recommended that six new regional stages be set up for the correlation of the British Dinantian (George *et al.*, 1976). In defining the stages only the base of each has to be fixed, the top being the base of the overlying stage. The location and exact horizon of the boundary at the base of each of the six stages is given in George's paper and the new regional stages were applied to the West Cumbria succession (Fig. 11F, p. 38 in George's paper). Only the three upper stages are present in West Cumbria, the Holkerian, Asbian and Brigantian in ascending order; these are broadly equivalent to the S_2, D_1 and D_2 zones of Vaughan and Garwood. The fossil criteria used to identify the stages is the same as those used to identify the zones. The difference is that the base of each stage is standard and linked to an agreed boundary stratotype section rather than zones (biozones) whose boundaries have been chosen arbitrarily and at slightly different horizons in various parts of Britain. Using the stages, a correlation of the Dinantian round the margin of the Lake District was published by Mitchell, 1978.

Structural Setting

The Lower Palaeozoic core of the Lake District is the product of earth movements during the end-Silurian climax of the Caledonian orogeny. Compression gently folded and fractured the Ordovician and Silurian rocks while further alteration was caused by the intrusion of the Lake District granite batholith early in the Devonian. The principal result of the Caledonian movements was to form a large emergent continent stretching from North America to what is now Russia west of the Urals. Britain was at the centre of the southern shoreline of this continent. The Lake District formed part of a considerable mountain range during the Devonian and subaerial erosion proceeded rapidly so that the granite batholith was unroofed before the end of the Period. At least one and probably several kilometres of cover rocks were removed from the Lake District at this time but the only stratigraphical record of this episode is the Mell Fell Conglomerate, a series of coalescing alluvial fans formed below high ground by mountain torrents. The abundance of Silurian greywacke in the conglomerates indicates that this formation was once much more widespread over the

Lake District than it is at the present day (Capewell, 1955; Kimber and Johnson, 1986).

Intrusion of low density granite below the Lake District and erosion of a substantial thickness of cover rocks overlying the batholith induced long-term positive structural trends over the region. The Lake District has tended to rise and form high ground even to the present day; Scafell Pike (978.4 m) is the highest mountain in England. By the end of the Devonian however denudation had proceeded far enough to produce a subdued rounded topography although it had not been reduced to a level plain as had been suggested by some previous workers. This eroded upland was invaded by the Carboniferous sea. Marine conditions reached the south and south-east of the Lake District first and here the earliest Courceyan Stage has been recognised (Johnson and Marshall, 1971). Later Dinantian Stages successively form the base of the Carboniferous northwards, with onlap on a basement slope, until the Holkerian forms the base on the northern and western rim of the Lake District. During the early Dinantian an archipelago of islands, formed from the cores of the denuded Devonian uplands, stood out of the Carboniferous sea and the Lake District formed part of one of the larger islands. In West Cumbria, on the western side of this island, subaerial conditions were maintained and the Devonian denudation episode continued until the Holkerian when the Seventh Limestone was laid down over the eroded Lower Palaeozoic floor. Traces of the products of erosion, conglomerate, sandstone and shale, underlie the Seventh Limestone and are called the Basement Beds or Seventh Shale.

The Lower Palaeozoic core of the Lake Districts has been proved by geophysical investigations and offshore drilling to extend south eastwards across the Irish Sea to the Isle of Man (Bott, 1964; Bott and Young, 1971; Wright *et al.* 1971). This Ramsay–Whitehaven ridge separates the Carboniferous and Permo-Triassic Solway basin to the north from the similar Manx-Furness basin in the south (Coultar and Barr, 1975; Skipsey, 1988). Exploration of the eastern Irish Sea has been active following the discovery of exploitable concentrations of hydrocarbon gas in the Manx-Furness basin off Morcambe (Jackson *et al* 1987) and the Carboniferous has been sectioned in offshore boreholes below thick Permo-Triassic deposits. The Ramsay-Whitehaven ridge is a seawards continuation of the basement high developed in West Cumbria and Carboniferous cover rocks, both Dinantian and Silesian, also persist seawards. At the western end of the ridge, in the north of the Isle of Man, Carboniferous sediments were proved by boreholes for haematite beneath drift and Permo-Triassic deposits in the early 1920s. The Dinantian succession is very similar to that of West Cumbria with a series of limestone bands recognised as the First to Seventh limestones (Smith, 1927). Though few fossils were recorded, the lowest or Seventh Limestone was believed to be S_2 in age, as in West Cumbria. The thickness of the Dinantian succession, 285 m in the north of the Isle of Man, is similar to the 274 m in West Cumbria. The Ramsay-Whitehaven Ridge is a Palaeozoic structural lineament and a continuation into the Irish Sea of the Devonian Lake District uplift. The ridge persisted as an elongated emergent land surface separating the Solway and Manx-Furness basins during the early Dinantian but was submerged by the Carboniferous sea in the Holkerian. Post-Dinantian deposition confines the Dinantian limestone outcrop in West Cumbria to a narrow belt skirting the margin of the Lake District uplift. The Namurian and Westphalian have a wide subcrop beneath the Permo-Triassic onshore and in the Solway and Manx-Furness basins.

A faulted margin between the Carboniferous and Permo-Triassic sediments and the Lower Palaeozoic rocks of the Lake District is almost continuous in West Cumbria. Called the Lake District Boundary Fault it has a proved throw of more than 61 m to the west in the Gosforth area but the throw decreases northwards. This fault line probably has a long history of movement, not always confined to downthrow to the west.

Dinantian Succession

The Dinantian rocks of West Cumbria are dominated by limestones with the succession containing much less classic sediment than other regions in northern England. Conditions of deposition were different from other areas and this is one of the features of the region that will be considered. The sequence of seven limestone bands divided by generally thin shales and sandstones, originally described by Kendall (1885) from the haematite orefield, has been accepted by all later workers and is the standard lithostratigraphical division of the Dinantian to lower Namurian succession. The base of the Namurian is taken at the base of the First Limestone (= Great Limestone of the Northern Pennines) on reliable fossil evidence (Johnson *et al.* 1962). The First Limestone is thus Pendleian (Lower Namurian) and lies above the Dinantian, but it forms the natural top to the West Cumbria carbonate succession and so will be included in this account. The sequence of seven limestones will be briefly described from the base upwards in the sections that follow where much of the quantitative data quoted has been derived from Edmonds (1922) and the Cockermouth, Maryport, Whitehaven and Gosforth Geological Survey memoirs.

<u>The Basement Beds</u> The Basement Beds or Seventh Shale are a series of shales, sandstones, grits and pebble conglomerates of irregular thickness and composition that overlie the platform of folded and cleaved Lower Palaeozoic rocks. The marked angular unconformity is an eroded landscape surface with hollows in which the Basement Beds are thicker. The surface is part of a wide platform in the northern Lake District where the products of denudation of Lower Palaeozoic core accumulated. By the end of the deposition of the Basement Beds, most irregularities in the land surface had been filled and this subdued, but not level, plain was eventually covered by transgressing Carboniferous sea.

The thickness of the Basement Beds varies considerably in West Cumbria with a general thickening southwards. South of Egremont, in the concealed haematite orefield, Basement Beds are up to 12 m thick. They average about 3.3 m at Egremont and 2.7 m at Clints, slightly to the north. Still further north the Basement Beds are thin and, derived from the underlying Skiddaw Slates, their base is difficult to identify. Lavas occur within the Basement beds in the Cockermouth area, outcropping over a distance of 13 km from Cockermouth to Bothel. These are tholeiitic basalts and andesites with maximum thickness of about 100 m in the Cockermouth area (Macdonald and Walter, 1985). Five or six separate lava flows have been distinguished on the basis of topography and the presence of scoriaceous flow tops. Basement Beds above the lavas are over 15 m thick at Ghyll Wood, Blindcrake, and are composed of interbedded mudstone, limestone and pebbly conglomerate with fossils to within about 6 m of the top of the lavas (Moon, 1965; Shackleton, 1966). Fossils include *Modiola* and ostracods towards the base of the section, suggesting brackish water near-shore conditions, but higher in the section pectenids, productids and bryzoans, indicating full marine conditions prior to the deposition of the Seventh Limestone. The age of the Cockermouth lavas and the Basement Beds have been determined from spore assemblages obtained from above and below the lavas, both of which indicate the CM Zone, Courceyan Stage (Mitchell, 1978, p. 171). Evidence from index fossils shows that the overlying Seventh Limestone is Holkerian and so two Dinantian stages, the Chadian and Arundian, are missing with a disconformity present below the base of the Seventh Limestone.

The Basement Beds are marine and brackish water deposits in the Cockermouth area, but south of Lamplugh they appear to be subaerial accumulations containing plant fossils (Edmonds, 1922). The subaerial origin of the Basement Beds in the south is supported by red staining of the deposits and the underlying bedrock, reported to have been deeply weathered under continental conditions (Eastwood *et al.* 1931).

Seventh Limestone Like most Dinantian limestones of northern England the Seventh limestone is grey coloured and divided into beds by thin dark shale partings. The limestones are fine-grained packstones, wackestones and mudstones with some coarser bioclastic grainstones. Cross-bedded sandy limestones and calcareous sandstones are often present as are bands of dolomitic limestone. Nodular anhydrite has been recorded near the top of the limestone in a borehole near Egremont and the same facies from elsewhere (Llewellyn *et al.* 1968; Stabbins 1969). The anhydrite occurs one metre below the top of the limestone in a band about 0.17 m thick in dolomitic matrix. The evaporate band is believed to indicate formation under supratidal conditions in a sabkha environment such as is found in the Persian Gulf today. The combination of features shown by the Seventh Limestone suggest deposition at or near to sea-level in a near-shore setting.

The Seventh Limestone varies between 100 m thick in the Cockermouth region to the north and 29 m thick at Lamplugh. Part of this variation is an easterly thinning of the limestone against the Lake District core, but lateral variation along the strike also takes place. Index fossils from the Seventh Limestone include *Lithostrotion vorticale* and *Davidsonina carbonaria* indicating the Holkerian (S_2).

Sixth Shale This horizon consists of black shale and limestone varying between 2 m and 11 m thick, only known from boreholes in the haematite orefield. Exact boundaries are uncertain because the overlying Sixth Limestone and underlying Seventh Limestone are interbedded with similar shale bands.

Sixth Limestone A dark thin-bedded nodular limestone, with shale partings, about 14 m thick. Fossils include *Dibunophyllum bourtonense* and *Gigantoproductus maximus* indicating Asbian (D_1) age.

Fifth Shale including the Chonetes Shale This horizon consists of a succession of fossiliferous dark shale and limestone bands about 5 m thick, often with a variable sandstone near the top. A shale parting with many shells of *Chonetes hardrensis* group is often developed near the base while plant fossils occur towards the top.

Fifth Limestone A thick bedded limestone about 18 m thick, dark grey in the lower part and pale grey in the upper, with pseudobreccia bands and thin shale partings; fossils include *Dibunophyllum bourtonense*, *Palaeosmilia murchisoni* & *Lonsdaleia melmerbiense* [Asbian (D_1) age].

Fourth shale Unfossiliferous fine-grained sandstone with variable thicknesses of mudstone above and below; under 2 m thick at Clints Quarry, Egremont.

Fourth Limestone A complex, but laterally persistent sequence of limestone and shale bands with thin sandstone horizons. The standard sequence from the base upwards is as follows:

White Limestone - Pale limestone about 19 m thick with pseudobreccia bands and thin shale partings. Fossils include *Lonsdaleia duplicata*, *Davidsonina septosa*, *Daviesiella comoides* & *Gigantiproductus maximus*, indicating Asbian (D_1) - equivalent to the upper part of the

pale Melmerby Scar Limestone of the northern Pennines.

Rough Limestones - Dark grey wavy bedded limestone about 13 m thick including a thin micritic limestone containing algal *Girvanella* bearing nodules (*Osagia sp.*). This horizon is correlated with Garwood's Girvanella Band at the base of the Brigantian and the change at this horizon from pale to dark limestone supports this correlation. Index fossils recorded include *Dibunophyllum bipartitum*, *Lonsdaleia (Actinocyathus) floriformis* and *Gigantoproductus giganteus*, indicating Brigantian age. The Rough Limestone is equivalent to the Peghorn & Smiddy limestones of northern Pennines.

Spotted Limestone - Pale limestone with dark spots interbedded with dark grey limestone, top surface eroded and potholed; limestone 6 m thick. Fossils include *Saccamminopsis* and this limestone is equivalent to the Lower Little Limestone of the Pennines.

Shale - A persistent horizon of limestone or sandstone and shale bands overlies the eroded top of the Spotted Limestone and is about 3 m thick. *Stigmaria* occurs in the sandstones and abundant plant impressions may be present in the shales. Red beds occur towards the top of the sequence near Clints Quarry.

Potholes Limestone - Pale grey limestone about 6 m thick with strongly eroded top surface, potholes up to 2 m deep and broad channels. Index fossils include *Nemistium edmondsi*, *Orionastraea edmondsi*, *O. phillipsi* and *O. placenta* indicating equivalence with the Jew (= Hardraw) Limestone of the Pennines. This is one of the most persistent limestone bands in the Brigantian succession and it is recognised with confidence through the Pennines, Northumberland (Oxford Limestone) and south Scotland (Hurlet Limestone). Shale and sandstone fill the irregular top surface of the Potholes Limestone and forms a thin parting between it and the overlying Saccammina Limestone.

Saccammina Limestone - Thinly bedded pale grey limestone about 6 m thick, similar to the underlying Potholes Limestone. Top eroded with potholes reported to be up to 2 m deep. *Saccamminopsis* is usually abundant with index fossils including *Dibunophyllum*, *Lithostrotion portlocki*, *Orionastraea garwoodi* & *Gigantoproductus* spp. A nodular

limestone in clay matrix overlies the Saccammina Limestone and at this horizon Hudson (1929) recognised his *Erythospongia* Band, but the identity and continuity of this band is uncertain.
The strongly eroded top of the Potholes Limestone indicates a disconformity, emergence and erosion having removed part of the succession. The overlying Saccammina Limestone is probably a condensed sequence that includes the equivalents of the Tyne Bottom and Single Post limestones of the Pennines; *Orionastraea garwoodi* occurs in both of these limestones in the Pennines.

Junceum Limestone and Cherty Limestone - A lower pale rubbly limestone overlain in some places by a dark thin bedded limestone with eroded top. Chert nodules developed throughout and fossils are partly silicified. This limestone is about 16 m thick in the Clints Quarry area near Egremont. Bands of *Siphonodendron junceum* occur in the lower part of the limestone and *Londsaleia duplicata alstonensis* has been recorded towards the top. The subspecies *alstonensis* is believed to have a geographical rather than biostratigraphical range (Mitchell, 1989), but it is recorded from the Alston area of the Pennines and occurs at the same horizon in West Cumbria. The Junceum and Cherty limestones are correlated with the Scar and Five Yard limestones of the northern Pennines.

<u>Third Shale</u> A variable thickness of shale overlain by sandstone is developed above Junceum and Cherty limestones, from 0 to 20 m thick.

<u>Third Limestone</u> Light and dark grey crinoidal limestone with rather rare corals and brachiopods, 2 m thick at Clints Quarry, Egremont, and increasing to 5 m in the Lamplugh area; correlated with the Three Yard Limestone of northern Pennines.

<u>Orebank Sandstone Group</u> A variable series of lower shale, middle sandstone and upper shale is persistent throughout the area. It is 18 m thick at Clints Quarry and reaches 29 m elsewhere.

<u>Second Limestone</u> A rather unfossiliferous, dark grey thick bedded limestone about 14 m thick in the Egremont area; equivalent to the Four Fathom or Undersett Limestone of the northern Pennines.

First Shale A lower black shale becoming sandy upwards and passing into a light coloured sandstone. An upper shale may be developed with a thin coal seam. The First Shale is 4 m thick in the Clints Quarry area, but increases to more than twice this figure elsewhere.

First Limestone Fossiliferous dark grey limestone about 12 m thick in the Egremont area, lower part massive and thinly bedded towards the top. Fossils recorded from the First Limestone include *Actinocyathus floriformis laticlavia*, a large subspecies that was first described from the Great Limestone of the Pennines and Northumberland and the other fauna found in the two limestones is very similar. The First and the Great Limestones are equated with confidence.

Dinantian Deposition

The dominance of carbonates in the Dinantian succession of West Cumbria and the minor role taken by clastic sediments are features that distinguish this sequence from those other regions to the north and east. Attention was drawn to this by Rowley (1969) who showed that in the Brigantian nearly 80% of the West Cumbria succession is carbonate with under 40% in the northern Pennines and under 20% in the Northumberland basin. He found that the thickness of Dinantian limestone deposited in northern England during the Brigantian remained relatively constant, between 91 m and 107 m. In contrast the thickness of clastic rocks varied widely, from under 30 m in West Cumbria to about 167 m in the northern Pennines and nearly 400 m in Northumberland. The general interpretation that there was a common source of sediment to the north and east supplying mud and sand to the basin and to the Pennine blocks is widely accepted as part of a palaeogeographical framework of a shoreline with interior hinterland to the north and east and open water with full marine conditions to the south and west (Johnson, 1982; Hodge and Dunham, 1991).

The reduced thickness of clastic sediment interbedded among the Brigantian limestones of West Cumbria is partly due to the distance from the source of sediment supply as is the case with the Derbyshire sequence further south. Possibly more important is that West Cumbria was on the western seaward side of the Dinantian Lake District Island.

Clastic sediment reached the eastern side of the Lake District during the Brigantian in some quantity. Rowley (1969) records over 130 m in the River Leith section near Shap, but sediment seems to have been trapped in the basins to the north and east of the Lake District and it was not carried in quantity to West Cumbria. Quantities of clastic sediment derived from the Lake District Island itself would be expected to be small, owing to luxuriant growth of tropical vegetation giving dense ground cover (Kimber and Johnson, 1986). A case can be made for most of the small thickness of clastic sediment in the Dinantian sequence of West Cumbria to have come from the island to the east. The Basement Beds or Seventh shale are certainly derived from the Lower Palaeozoic rocks of the island and there is no reason why most of the other bands of shale and sandstone could have come from the same source, although the thicker Ore Bank Sandstone Group may have been enriched with sediment from elsewhere.

The widespread occurrence of plant impressions in many shale and sandstone bands of West Cumbria suggests near shore conditions and proximity to land vegetation. The records of*Stigmaria* in the thin shale and sandstone succession above the Potholes Limestone and coal seams in the First and Sixth shales shows that the clastic sediments became emergent and supported a land flora that persisted long enough for a peat layer to form. When the clastic sediments built up above sea level, land vegetaion spread seawards from the island. Common plant impressions in the shales and sandstones as compared to the rarer coal seams suggests that the upper part of the clastic horizons may well have suffered erosion before the deposition of the overlying limestone. In this way other thin coal seams may have been lost as happened elsewhere in Dinantian coal-bearing successions.

The faunal succession in the West Cumbrian limestones is identical to that in the northern Pennines and elsewhere in northern England, allowing reliable correlation with other areas (Mitchell, 1978). Limestone deposition took place in clear water, shallow seas that persistently re-occurred over the region from the Holkerian to the end of the Brigantian. There is no evidence of deeper water episodes, but much indication of shallow water deposition, emergence and erosion of the carbonate surface during the Dinantian. Most conspicuous is the development of erosion channelling and potholes within and at the top of limestones. The Pothole Limestone has either an even top or channelled surface with deep potholes infilled with mudstone and sandstone. Similar erosion surfaces are found in the Fifth, White, Rough, Spotted, Saccammina and Third Limestones. According to Stabbins (1969), erosional features are best developed and most removal of previously deposited carbonate took place in the south of the region between Lamplugh and Egremont, with repeated slight emergence of the carbonate platform and subaerial erosion occurring. Potholes reported to be 2 m deep in the Fifth, Potholes and Saccammina limestones gives the minimum height of emergence of the carbonate platform, but of course it may have been rather greater than this. Supporting the shallow sea to low land setting, evaporites found in the Seventh Limestone are said to indicate supratidal sabkha conditions of deposition.

The Lake District Island

There is much evidence that the Lake District was an emergent upland and island from the Devonian through the Carboniferous and the Permian, but direct geological proof of the island is long lost owing to erosion (Kimber and Johnson, 1986). The Dinantian of West Cumbria is on the west and north-west flanks of this island and it gives independent evidence of near shore, shallow water conditions of deposition adjacent to emergent land to the east. Thus the Dinantian sequence has been proved by boreholes in the haematite orefield to thin eastwards (Eastwood *et al* 1931), no doubt with onlap on to a gentle ramp slope of Lower Palaeozoic basement. The succession was laid down in shallow water with a shoreline that fluctuated backwards and forwards to the east and west of the present Dinantian outcrop and stratigraphical evidence also suggests that a nearby shoreline lay to the south. Conditions of deposition seem to have been shallower than elsewhere in northern England.

The lack of outliers of Carboniferous rocks on the west side of the Lake District is significant and indicates that extensive post-Carboniferous denudation effected the region. Despite major block faulting and faults of large throw, only one Carboniferous outlier is known. The Wilton outlier (NY 049110), east of Egremont, is a mass of Seventh Limestone about 0.8 km long resting on an eroded surface of Ordovician andesites and faulted against Skiddaw Slates and Triassic deposits. The rocks of the outlier outcrop at Mouse Gill Quarry where about 45 m of limestone is exposed. The limestone is fossiliferous with *Linoprotonia corrugato-hemisphericus* group and *Lithostrotion vorticale* indicating Holkerian (S_2) age.

The preservation of the Wilton Dinantian outlier is due to large pre-Triassic faults, with downthrow east, that dropped the Seventh Limestone against the Skiddaw Slates. Prolonged pre-Triassic regional denudation removed all the Carboniferous cover on the western flank of the Lake District except for the deeply downfaulted Wilton outlier which is preserved simply because of its great depth of burial. The outlier proves that Dinantian limestone was laid down to the east of the present outcrop and east of the Lake District Boundary Fault, but all traces of the eastern shoreline margin have been lost due to pre-Triassic erosion.

Conclusion

The thin carbonate-dominant Dinantian succession of West Cumbria formed under special conditions of deposition over the Ramsay-Whitehaven ridge, a well documented positive structural lineament between sedimentary basins in the north Irish Sea and continuous from the Lake District to the Isle of Man. Over this ridge slow Dinantian deposition allowed carbonate to form, broken by disconformities and by minor intervals of clastic deposition. The limited amounts of clastic sediment entering the area are thought to have been derived at least partly from the Lake District Island immediately to the east. West Cumbria was sheltered by the island from regular influx of mud and sand from a known distant major source to the north and east. Disconformities in carbonate deposition, indicated by subaerial potholing and channelling of the limestone, indicate emergence of the carbonate shelf and lowering of sea level by a minimum of 2 m. These events could have been caused by minor uplift of the Ramsay-Whitehaven ridge. The ridge was coupled to the Lake District block so that both ridge and block may have been unstable and tending to rise during the Dinantian, a continuation of the long period of uplift over the Lake District that took place during the preceding Devonian. Instability and uplift would be caused by the major Devonian age granite batholith underlying the Lake District that had not at this time reached equilibrium. Irregular pulses of uplift could be expected and some of these events spread westwards over the Ramsay-Whitehaven ridge to cause emergence of the carbonate platform and subaerial erosion. Evidence for Dinantian uplift of the Lake District is not unexpected. Prolonged and active uplift took place throughout the Devonian and again uplift and rapid denudation effected the region prior to and during Permo-Triassic deposition. It is possible that uplift of the Lake District core persisted throughout the Carboniferous Period and that this maintained the identify of the Lake District island.

In marginal marine regions of shallow deposition, such as the Dinantian of West Cumbria, small changes in the conditions of deposition can be detected in the stratigraphic succession. Thus the minor episodes of uplift found in West Cumbria adjacent to the Lake District core have not been detected elsewhere in places of apparently more continuous deposition in rather deeper water. If the minor periods of uplift were insufficient to raise the platform of deposition above sea level, no signal was left in the stratigraphical sequence. Only in West Cumbria where deposition was persistently under very shallow near-shore or shoreline conditions was there potential to preserve evidence of these small uplift episodes.

The shallow water environment of the upper Dinantian succession of West Cumbria with no evidence of change other than slight submergence and low emergence of the sea floor, rules out the occurrence of any major sea-level changes during this period of deposition. This is a significant finding because upper Dinantian deposition in northern Britain is celebrated for long sequences of sedimentary cycles or cyclothems of the type 'limestone, shale, sandstone, seatearth and coal', often called the "Yoredale Series". These sequences have been described by many authors for more than 150 years and regularly, in one way or another, eustatic sea-level changes have been invoked to explain the marine to subaerial cyclothems, since this was suggested by Wanless and Shepard (1936). It is unnecessary to have repeated eustatic sea-level changes to account for the formation of Yoredale cyclothems and a better explanation is that they are formed under tectonic and sedimentation controls within the basin of deposition (Johnson, 1984). Interpretation of the Carboniferous carbonate sequence of West Cumbria bears on this problem because it provides independent evidence that significant world-wide eustatic sea-level changes did not take place during the upper Dinantian when the Yoredale cyclothems were being laid down.

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G.A.L.Johnson, D.Sc.,
Department of Geological Sciences,
University of Durham,
Science Laboratories,
South Road,
Durham DH1 3LE.

QUATERNARY LANDSCAPE EVOLUTION IN THE LAKE DISTRICT - A DISCUSSION

J. Boardman

1. Introduction

The recent increase in knowledge of global climate change has provided a stimulus to Quaternary geology. With a firm time scale for climate change, particularly from oxygen isotope studies of deep-sea sediments (Shackleton and Opdyke, 1973), the challenge is to link this information to the fragmentary terrestrial record in order to understand the development of the landscape. This paper discusses the evolution of the English Lake District with particular reference to the influence of temperate, glacial and periglacial processes during the Quaternary. Much is, of necessity, speculative and many questions remain unanswered - thus the plea to regard this as 'a discussion'.

2. North-west England

In the region between the Scottish border and the Cheshire-Shropshire plain the Quaternary succession is relatively simple with sediments of the last glacial stage, the Devensian, blanketing much of the landscape (Johnson, 1985). These represent the last major ice sheet advance from the uplands of northern Britain, an advance which reached the vicinity of Wolverhampton. The advance and retreat of the Late Devensian ice sheet occurred between 26,000 and 13,000 years B.P., a period known as the Dimlington Stadial; it reached its most southerly position about 18,000 B.P.

Pre-Devensian sediments are very rare in the north west, the exception being at Chelford and Four Ashes on the Cheshire- Shropshire plain (Worsley, 1985). On the West Cumbrian coastal lowlands several sites have yielded undated pre-Late Devensian material (Huddart *et al.*, 1977). At Scandal Beck in Ravenstonedale, Late Devensian till is underlain by a peat bed with an infinite radiocarbon date and below that there is a lower till (Letzer, 1981). Apart from these records, the sedimentary evidence for landscape evolution during the Quaternary in north west England is very limited.

3. The Lake District

The landscape of the Lake District is widely accepted as being largely the product of surface processes that operated during the Quaternary. Scepticism regarding Tertiary erosion surfaces and a belief in the efficacy of glacial processes have lent support to this view. Almost axiomatically the Lake District is regarded as a glaciated landscape. This view that active ice has created many of the region's major landforms has been propounded by authorities such as Linton (1957) and supported by Boulton *et al.* (1977). Thus the conventional view is that the region has been glaciated and not merely glacierized (i.e. covered by ice). There is also a belief in the relative youth of many of the landforms; two recent reviews have referred to the forms of glacial erosion as being a product of Late Devensian processes (King, 1976; Moseley, 1978). Clark (1990) refers to the amount of glacial erosion and deposition in the Late Devensian as testifying to 'the vigour of glacial processes'. It has even been suggested that the development of many of the corries occurred during the Devensian Late glacial period between c 13,000 and 10,000 years B.P. (King, 1976, p. 102)! These are assumptions and not 'self evident truths': the evidence should be viewed critically (Boardman, 1988).

As a counter to these views, Clark (1988) argues strongly that the major valleys of the Lake District are adjusted to geologically old lineaments and are Tertiary in age: 'the main valleys and principal watershed pre-date the Pleistocene glaciation' (Clark, 1988, p.23). While Clark's views are well supported by the evidence that he presents, in terms of landscape dissection they are unquantified and therefore questions regarding Quaternary evolution are unanswered. For example: how much of the dissection occurred during the Quaternary; when during the Quaternary was erosion concentrated and what processes were responsible? It is these issues that we intend to discuss in this review.

Quaternary erosion occurred, broadly speaking, in three distinct environments each with characteristic sets of processes, see Table 1.

Table 1 **Quaternary environments in the Lake District.** Based on subdivisions of glacial/interglacial cycle (128,000 to 10,000 BP) shown on Figure 1.

ENVIRONMENT	PROCESSES	TIME
Glacial (ice sheet)	erosion & transport including meltwater effects	13%
Periglacial +/- restricted glaciation (<+3^{0}C M.A.T.)	frost weathering, cryoturbation, solifluction, fluvial erosion & transport	58%
Interglacial & Temperate (>+3^{0}C M.A.T.)	weathering & soil formation	29%

It would be of value to sub-divide the Quaternary into intervals dominated by specific environmental conditions. While this is feasible for parts of the late Quaternary, there remain large areas of doubt. In the lowlands of England fossil beetle and pollen evidence has been used to reconstruct temperatures and in France and the Low Countries soil features and ground ice structures are being used to the same end (Van Vliet-Lanoe, 1986). Much of this work is based on ^{14}C dating and the approach is therefore limited to deposits of the last 30,000 years; correlation of pollen diagrams with the oceanic oxygen isotope record takes the record of inferred climatic change back to 125, 000 B.P. Little information of this type is available in the uplands, partly because of the dominance of erosional processes and a scarcity of fossil-bearing deposits, and environmental conditions have to be inferred from evidence in the lowlands.

An attempt is made in Figure 1 to subdivide the last 130,000 years into ice-sheet, periglacial and interglacial environments while an allocation of time to these environments is proposed on Table 1. There are some periods of considerable doubt with reference to upland sites in northern England, notably Oxygen Isotope stages 5a and 5c. Application of a lapse rate to the data on Figure 1 suggests that high altitude sites (>400 m) would be periglacial in character during these periods. It is also likely that, given sufficient precipitation, some parts of the Lake District would have nourished glaciers in Oxygen Isotope stage 5b and at the beginning of Stage 3.

The relative effectiveness of geomorphological processes under glacial, periglacial and temperate conditions during the Quaternary in the Lake District will now be considered.

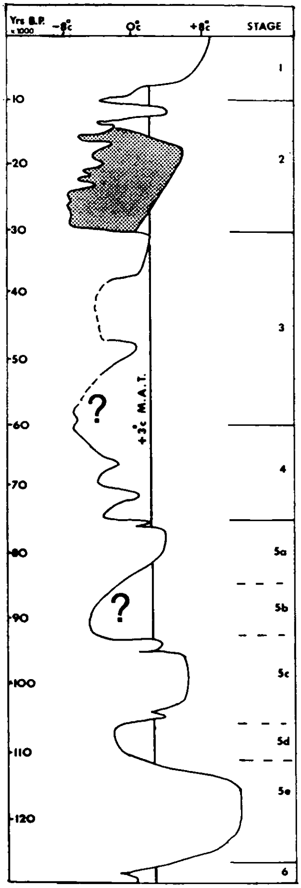

Figure 1

Tentative climate curve for the last 125,000 years. The curve is based on Van Vliet-Lance, 1987 (Figure 8) using pedological & ground-ice structure data.

The original refers to sites in Belgium & N. France with a present day Mean Average Temperature of about 9°C. This is also the M.A.T. of Keswick, a low altitude site in the Lake District. The shaded area represents ice sheet growth & decay in the Lake District. +3°C line is used to define arbitarily periglacial phases (French,1976). Correlation with Oxygen Isotope Stages is shown. The possibility of restricted glaciation in Stages 5 b and 3 is indicated.

3.1 Glacial environments

Evidence for glaciation comprises the deposits of three glacial events and some erosional features. The depositional record is as follows:

1. Sediments of the Loch Lomond Stadial (10-11,000 years B.P.), a period of small valley and corrie glaciers in the Lake District (Sissons, 1980).
2. Sediments of the last major regional glaciation during the Dimlington Stadial.
3. Sediments of a pre-Devensian glaciation.

In the valley of Mosedale Beck in the northeastern Lake District (NY 355240), the relationship of the three glacial formations (Boardman, 1991) can be demonstrated (Figure 2). The Thornsgill Till outcrops over an area of about 8 km^2 and is the result of an extensive glacial episode, which in this area consisted of ice from the Central Lake District moving east. The sediment is deeply weathered (the Troutbeck Paleosol), to a depth and severity suggesting a period or periods of temperate conditions (interglacials) of 100,000 to 150,000 years duration (Boardman, 1985a). This implies that the Thornsgill glacial event probably occurred during Oxygen Isotope stage 10 or 12. Bowen et al (1986) show that a major glacial event affected Britain in stage 12.

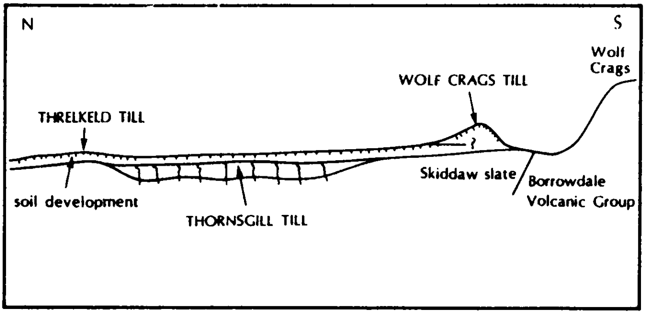

Figure 2 Profile of the Mosedale Beck valley to show the relationship between the three tills (Boardman, 1988).

The Thornsgill Formation is overlain by the Threlkeld Till of Dimlington Stadial age. This glacial sediment is the equivalent of those covering much of the lowlands, e.g. the Stockport Formation of the Manchester area. On the steeper slopes of the Lake District till has been redistributed by solifluction or was never laid down.

During the Loch Lomond Stadial a small glacier occupied Wolf Crags corrie and was responsible for the construction of a moraine ridge of bouldery till, the Wolf Crags Till (Figure 2), and also for the outwash which formed the higher terraces of the Mosedale Beck valley.

The depositional evidence for a sequence of glacial episodes is therefore more extensive in the uplands than in the lowlands of north west England but nevertheless is rather meagre. The three formations could well represent little more than a few hundred years out of a total of something less than two million years of Quaternary time. Extrapolation from Table 1 suggests that ice sheet conditions may have existed for 260,000 years and periglacial climates, which would include periods of restricted glaciation, for 1,160,000 years. The existence of the Troutbeck Paleosol, however, implies that at least in that area there was a long period in the late Quaternary, between Oxygen Isotope stage 12 and the Dimlington Stadial, when major erosion of the area did not occur. Phases of minor erosion and deposition by glaciers cannot be ruled out though the evidence is lacking. We shall return to the implications of the depositional evidence shortly.

The erosional evidence for glaciation in the Lake District is much more difficult to interpret. There are three underlying problems:

1. The assumption that a landform is the product of a set of unique (and identifiable) processes is at best an over-simplification. Hanging valleys, for example, are also characteristic of many river systems (Kennedy, 1984).
2. Since the glacial component of the landscape cannot always be identified, there is great difficulty in assessing the form of the landscape at the onset of glaciation. Hence the total amount of Quaternary erosion cannot be estimated.
3. Erosional forms are difficult to date and it is usually very difficult to connect the fragmentary sedimentary record with episodes of glacial erosion.

Thus we are confronted by three classic geomorphological problems: the often ambiguous relationship between process and form, or at least one which we have great difficulty in deciphering; the dating of change; and need to reconstruct landscape evolution from meagre evidence.

3.1.1 Ice sheets

The problems referred to above are central to any consideration of the origin of the major valleys of the Lake District. This first substantive topic illustrates the depth of our ignorance with regard to the impact of glacial erosion. If we make the not unreasonable assumption that a major valley system existed in some form at the beginning of the Quaternary (Clark, 1988), then we can propose two very different conditions under which erosion occurred. Firstly, within ice sheets faster moving ice streams are known to occur along valley routes. Due to the greater thickness of ice and higher pressure at the base, ice may be at pressure melting point and therefore able to slide, erode and transport debris. Thinner ice on the interfluves may be frozen to bedrock and ineffective as an erosional force. This scenario has been proposed by Sugden (1968) to explain landscapes of 'selective linear erosion' in, for example, Greenland and northeast Scotland. Secondly, deepening may occur when the valleys are occupied by individual glaciers perhaps fed by ice from small ice caps and corries. We have at present no means of assessing which of these conditions has been dominant; it seems likely that both have occurred during the cold periods of the Quaternary.

Boulton *et al* (1977, Figure 17.1) classify the Lake District as a zone of maximum glacial erosional intensity and comment that conditions under the centre of an ice-sheet would not be conducive to erosion by any process. They therefore conclude that erosion was achieved not primarily during glacial maxima but in periods of more limited glacierization.

There is no doubt that towards the end of the Dimlington Stadial the valleys acted as routeways for the passage of ice: this is indicated by the trends of drumlin fields (e.g. Boardman, 1982; Vincent, 1985; Waters, 1976). Computer modelling of glacial maximum conditions, based on geological evidence, suggests that maximum ice thickness in the Lake District was of the order of 1700 m (Boulton et al., 1977). Such an ice sheet would have the ability to move independently of all but major topographic controls. However, the quasi-radial valley system coincided with flow directions which would result from an ice dome centred on the highest ground. For this reason breached watersheds, on the scale of those of western Scotland and Snowdonia, are not a feature of the Lake District landscape. Examples such as Dunmail Raise are relatively small-scale. There are however some cases of glacial modifications of the drainage pattern.

If we assume a broadly radial pre-glacial drainage pattern then glacial modification is apparent in the northeastern Lake District. It seems likely that drainage from the Thirlmere basin via the Vale of St John's (NY 315230), and the Vale of Threlkeld was to the northeast and north past Mungrisdale (NY 363305). This drainage is now reversed with the Glenderamackin flowing westwards through the Greta Gorge (NY 290246) to Keswick. The reversal is likely to have been the result of glacial overdeepening of the Vale of Threlkeld and overflow of an ice-dammed lake to produce the Greta Gorge (Boardman, 1982). The overdeepening was not a Dimlington Stadial event: at that time erosion in the Vale was very limited. It was the result of earlier glacial events presumably also responsible for the truncated spurs of Blencathra (NY 320263). Overdeepening of the order of 100 m is required to effect drainage reversal along relatively erodible Skiddaw Group rocks that lie south and east of the more resistant slates of the Skiddaw Granite metamorphic aureole. It is interesting to note that the map used by Linton to illustrate the radial drainage of the Lake District omits the markedly anomalous west flowing Greta leaving all its headwaters unconnected to any river system (Linton1957, Figure 7).

The character and survival of the Troutbeck Paleosol is remarkable: soft sediments are not expected to survive the passage over them of at least one major ice sheet. However it is located within the buried bedrock valley of a former Mosedale Beck. Sites in Thornsgill Beck are less easy to assess as the bedrock topography is not known. Weathered bedrock assumed to be a result of the same weathering episode is found in the Thornsgill valley and in a gully adjacent to Wolf Crags (Boardman, unpublished). The number of sites where the paleosol outcrops suggests that bedrock protection is only part of the explanation for its survival. It appears that Dimlington Stadial glacial erosion along the Vale of Threlkeld was insufficient to cause more than the removal of 1 or 2 m of the paleosol. Sheared blocks of the soil are seen in the Devensian till. The explanation for this lack of erosion is not obvious. It has been suggested that the ice sheet may have been cold-based and non-erosive (Boardman, 1984); this seems surprising in the base of a major outlet route for ice and close to areas where basal sliding is indicated by the presence of drumlins. What seems to be required is a lack of erosion while an ice sheet moved across the area during the Dimlington Stadial, as suggested by Boulton et al. (1977), rapidly changing to conditions favouring deposition as the ice sheet thinned, at which time drumlins were formed. It may be that, by this time, major elements of the Lake District landscape were adjusted to the passage of ice and that minimal erosion resulted. The fact of limited Late Devensian erosion on the southern flanks of the Vale of Threlkeld persists, even though the explanations are speculative. More general problems are posed by the paleosol. The deep weathering of sediments (up to 14 m) must have affected other superficial deposits and bedrock in the Lake District: the late Devensian glaciation - or other unknown events - appears to have stripped this off since unweathered bedrock is the norm in exposures where bedrock is seen below Devensian till.

Few clues to the history of the Lake District's major valleys have been found although this is at least partly because they have not been examined in any detail. Even in such a classic steep-sided trough as Wasdale the evidence for the amount of glacial erosion is equivocal (Boardman, 1988). The maximum depth of the lake is 76 m reaching 15 m below sea level. Thus a *minimum* of 15 m of glacial overdeepening is indicated although it is likely to be more. The present depth of the lake appears to be due to rock basin excavation and glacial deposition at its western end. The hanging relationship of the Mosedale valley (Wasdale) (NY 100180) *may* indicate about 40 m or erosion. A maximum amount of 600 m is indicated by the difference between the summit height to north and south of the lake and the valley bottom but 600 m of glacial erosion is very unlikely since the existence of the present major valleys prior to glaciation seems probable.

Current rates of erosion by valley glaciers are of the order of 1 mm per year (Embleton and King, 1975, p.312). These high rates result from favourable conditions: basal sliding, abundant meltwater, and reworking of previously deposited sediments. With such rates substantial valley incision could be achieved in the Quaternary. However, these figures are unlikely to be representative of ice-sheet conditions or of ice flow in well developed glaciated valleys and troughs where the efficient adjusted form minimised erosion (Sugden & John, 1976, p.205).

In view of these difficulties the answers to some very basic questions about the role of glacial processes in the formation of the major valleys of the Lake District remain speculative. Reviews have tended to emphasis the ability of glaciers to erode at high rates e.g. 50-1000 mm per 1000 years (Andrews, 1975), or 1000 to 5000 mm per 1000 years (Embleton and King, 1975). The cutting of major landforms such as Sognefjord with 1100 m or erosion is regarded as feasible during Quaternary time (Andrews, 1975, p.122). It remains a possibility that substantial glacial erosion occurred in the valleys of the Lake District but the evidence suggests that such erosion has not occurred in the north east during the later part of the Quaternary.

3.1.2 Restricted glaciation

In the Lake District, an unresolved problem is the extent of glaciation in the long cold, non-ice sheet parts of the Quaternary, for example from 75,000 to 30,000 years B.P. Evidence from elsewhere suggests that much of this interval was cold enough for permafrost to form (Van Vliet-Lanoe, 1987). Unless conditions were extremely dry it is likely that glaciers existed in the Lake District. The lack of evidence for a major ice sheet, particularly on the surrounding lowlands, suggests that it is reasonable to assume that the glaciers remained small and confined to upland valleys and corries.

Climate modelling suggests that there have been two relatively stable states in the British uplands: one without an ice sheet and the other with a massive ice sheet, with only a small change in climate necessary to cause a switch between the two (Lockwood, 1982). The change envisaged is a burst of high precipitation lasting perhaps 100 years. During cold periods such as that from 75,000 to 30,000 B.P. this does not seem to have occurred and therefore restricted glaciation appears to have been the norm.

There are three further lines of argument which support the suggestion that the norm for long periods of the Quaternary was the existence of glacial ice masses in corries and valleys of the central Lake District i.e. a restricted glaciation. Firstly, a model for this type of glaciation is provided by the Loch Lomond Advance, and the existence of corries, the most unequivocal of glacial landforms, implies repeated episodes of this character. Secondly, the existence of between 90 and 200 corries, depending on definition, implies that regional glaciation has been rare, ineffective or confined to the early Quaternary allowing for the development of corries at a later stage, which seems unlikely. Thirdly, and more speculatively, it might be suggested that the rock basins of the valleys of the central Lake District, some of which are occupied by lakes, represent a mean minimum extent of valley glaciers. During times of ice sheet glaciation, fast moving ice streams would have occupied the valleys and enhanced the deepening (Sugden, 1968).

It is worth noting that the distribution of ice masses in the Loch Lomond Stadial was a function of the distribution of corries resulting from previous episodes of similar climatic character. The pattern of glacier distribution would have become more firmly established with each succeeding episode of cold climate. These episodes need not have been identical and would have varied considerably in length but once established there would have been a strong tendency for the survival and development of inherited glacial forms, the corries and glaciated valleys.

The arguments for regarding restricted glaciation with corrie glaciers and perhaps valley glaciers as a 'norm' for cold climate conditions in the Lake District are enhanced by Porter's (1989) suggestion that Younger Dryas (=Loch Lomond Stadial) ice extent represents an average Quaternary glacial condition. Restricted glaciation would occur during periods when the landscape beyond the corries and valleys of the central Lake District was periglacial in character (Table 1).

How adequate a model is the Loch Lomond Advance for previous episodes of restricted glaciation? Sissons' (1980) maps of the extent of glaciers during this phase show that at their maximum some glaciers extended beyond their source corrie (e.g. glacier 57 at Blea Water), whereas others occupied only a part of the corrie (e.g. glaciers 2, 4 and 20 in the Buttermere and Grasmoor areas. Dr I Evans (personal communication) has pointed out that of the 81 glacier sources on Sissons' maps, 71 are corrie sources, that there are 12 corries containing snow, and 50 corries with neither ice nor snow. On balance, therefore, the Loch Lomond Advance would seem to represent a rather poorly developed example of the type of restricted glacial event necessary to create the suite of Lake District corries.

Clough's (1977) observation that the last glaciers to occupy many of the corries had a slightly different orientation to that of the main corrie form is pertinent to such an argument: the corrie form as it now exists is the resultant of many changing climatic and glaciological conditions. Some of these episodes are likely to have been colder and longer than the Loch Lomond Stadial but the relative impact of low temperature, snowfall and duration is unknown.

What effect have periods of restricted glaciation had on the landscape? The primary effect as indicated above is the formation of corries. Estimates of rates of formation are speculative for several reasons. Studies of present day corries suggest that rates of formation are strongly influenced by climate and that they may well have varied through time. Problems of dating erosional forms have already been referred to. Larsen and Mangerud (1981) calculated the erosion rate for a small corrie on the Norwegian coast during the Younger Dryas (=Loch Lomond Stadial). This is based on the volume of eroded sediments in the end moraine, in a small lake and in a delta, and gives an erosional rate of 0.5 and 0.6 mm yr^{-1} assuming an erosion period of 700 years. With a constant rate of erosion the corrie could have formed in 83,000 to 125,000 years. This implies that long periods of time are not necessary for restricted glacial conditions to produce corries. Nevertheless, it is noteworthy that Younger Dryas glaciation was responsible for excavation of about only 0.4 m compared with 50 to 75 m of total corrie excavation that has occurred at this site (Larsen and Mangerud, 1981). Rates of corrie formation in dry, cold arctic environments such as Baffin Island appear to be at least an order of magnitude less than those of maritime Norway, and such rates may apply to some periods during the Quaternary in the Lake District. Therefore, although there may have been long periods such as the mid-Devensian with restricted glaciation in the Lake District, rates of corrie formation may have been low.

There are several different ways of estimating the volume of corries and the rate of excavation. An example is given in Table 2 for the Wolf Crags corrie. Pennington (1978) shows that during the Loch Lomond Stadial Wolf Crags corrie was occupied by ice for about 250 years. The larger corries such as Blea Water were occupied for 1000 years. This four-fold discrepancy in the time of occupancy, if typical for other periods, would go a long way to explain the size contrasts in corries. It also suggests that the small corries at low altitudes or in other ways in unfavourable positions (e.g. in receipt of less snow), would require long periods of cold conditions to develop because they were less frequently occupied by ice. Rates of excavation per unit area are likely to be less for small corries than for larger ones because of contrasts in shear stress related to ice thickness and velocity.

Table 2 **Wolf Crags corrie**

Morphology:	Height of backwall	150 m
	Length of backwall	1100 m
	Area of backwall	0.165 km^2
	Area of corrie floor	0.118 km^2

Area of floor & backwall in contact with ice = 0.283 km^2

Assume lowering (i.e. erosion) of 0.5 mm yr^{-1} = 0.0005 x 283,000
material eroded = 141.5 $m^3\,yr^{-1}$

During Loch Lomond Stadial corrie occupied by glacier for 250 years (Pennington, 1978) : material eroded = 35,375 m^3

Estimate of excavated volume of corrie = 0.25 x Area x Height
= 4,425,000 m^3

At erosion rate of 141.5 $m^3\,yr^{-1}$ the corrie would be excavated in
<u>31,272 years</u>

Erosion of material from corries during the Loch Lomond Advance involved the reworking of unknown amounts of Late Devensian till and accumulated slope, lacustrine and fluvial deposits. This applies also to the site investigated by Larsen and Mangerud (1981). At Wolf Crags the moraine ridge contains not only crudely rounded and angular material from the backwall and floor of the corrie but also erratics of Threlkeld Microgranite which can only have reached the site through the agency of a previous regional glaciation. Rates of excavation based on material moved out of Loch Lomond age corries are therefore likely to be far higher than in cases where bedrock erosion is occurring. In North Wales, at Cwn Idwal and Llyn Llydaw, striations formed by Loch Lomond Advance ice, within and on the lips of the corries, are seen to cross pre-existing striations of Dimlington Stadial age (e.g. Sharp *et al.*, 1989). This emphasises the lack of impact on bedrock surfaces achieved by ice which occupied such sites for a few hundred years. Erosion cannot have exceeded a few millimetres at these sites.

Sharp *et al.* (1989) explain the relative lack of impact of a Loch Lomond Stadial glacier on a bedrock surface in terms of thin, slow-moving ice, erosional processes limited to abrasion, and the inhibiting effect of roughness elements of the bedrock topography formed by earlier ice moving in a different direction. The rates of bedrock erosion at this site by the Loch Lomond Stadial glacier are very low (cf Larsen and Mangerud, 1981), although the removal of pre-existing till, prior to bedrock abrasion, cannot be ruled out. The evidence suggests that erosion rates vary by at least two orders of magnitude depending on whether unconsolidated materials or bedrock is being eroded, although contrasts in shear stress between the corrie basin and lip should also be noted. The assumed erosion rate in Table 2 is probably too high if bedrock is being eroded, and therefore a longer time is required to excavate the corrie.

In this section emphasis has been placed on corrie development because in a sense these are 'manageable' landforms. Problems of identification and process are far less than with the larger form of the glacial trough. The Loch Lomond Advance is also an essential part of any discussion because of the relative abundance of information about the event. During phases of restricted glaciation corries developed at various rates dependent on climatic and glacial conditions and on the materials available for excavation. As with glacial troughs there is the strong possibility that excavation rates declined through time as equilibrium forms have developed. Lake District corries may have required periods in excess of 100,000 years of favourable conditions for their development. These conditions undoubtedly included the supply of supra-glacial debris from frost weathering processes operating within the periglacial landscape around the corrie. In short periods such as the Loch Lomond Stadial high rates of excavation were the norm because of the availability of debris in the corries. These rates would decline during longer periods of occupancy. Rates of formation of corries are therefore likely to have been higher during the Loch Lomond Stadial than during other periods of restricted glaciation, for example, 75,000 to 30,000 B.P. There is also the probability that other cold periods were appreciably drier than the Loch Lomond Stadial (see below). During periods of regional glaciation corries appear to have suffered little degradation although there is some evidence of overriding by ice and modification of the form especially in the Central Fells (Dr I Evans, personal communication).

3.2 Periglacial environments

Periglacial processes have operated within the Lake District landscape for long periods of glacial stages which have been devoid of glaciation or with restricted glaciation. The substantial effect of periglacial processes on the Lake District landscape is indicated by the thickness of frost-shattered debris on many slopes. This debris post-dates glacial deposits of the Dimlington Stadial. At numerous exposures scree material can be seen to overlie till of that age (e.g. Boardman, 1985b). The surface of these debris sheets is usually vegetated and stable with a well developed soil profile. This suggests that there has been little addition of frost shattered material under the temperate conditions of the last 10,000 years. There are exceptions to this: for example parts of the screes of Wastwater are active at present with 'slight weathering' occurring on the free face (Andrews, 1961).

These observations imply that periglacial slope processes were extremely active between c15,000 and 10,000 B.P. Since there is evidence that the period 13,000-11,000 was warm enough for the establishment of birch forests in the southern Lake District the interval of severe periglacial conditions is further reduced. The period 15,000-13,000 B.P. appears to have been relatively dry (e.g. Coope and Brophy, 1972), which would inhibit periglacial activity. In the southern Netherlands this period was semi-arid (Vandenberghe, 1987). The available evidence therefore suggests that thick periglacial slope deposits accumulated in the Loch Lomond Stadial. During this period mean July sea level temperatures in the Lake District were about 7.5^{o}C with winter temperatures below -15^{o}C (Sissons, 1980; Ballantyne, 1984). The lack of vegetation and the likely existence of frozen ground have important geomorphological implications. The development of ground ice is indicated by the presence of fragic horizons in soils of the Penrith area (Matthews, 1976) and in the central Lake District. It seems likely that these are Loch Lomond Stadial features especially where they are developed in fine scree materials (Boardman, 1988). Sissons (1980) has argued that the presence of rock-glacier-like forms in the Lake District requires annual average temperature at least as low as -1^{o}C and discontinuous permafrost during the Loch Lomond Stadial. The amount of precipitation is likely to have been little different to the present (Sissons, 1980) and a brief summer snow-melt period would have been hydrologically very effective. The hydrological importance of this period for both lowland and upland rivers is discussed by Rose and Boardman (1983).

Three aspects of the periglacial environment should be emphasised. Firstly, the production of angular rock debris by frost weathering appears to have been very effective. Secondly, much of this material travelled short distances downslope and now covers both hillslope and footslopes: these have for the past 10,000 years acted as storage sites. Thirdly, much of the debris reaching stream channels was transported to storage sites such as alluvial fans, flood plains, river bars and lake basins, and some of the coarser material remains at these sites.

The movement of large quantities of glacially produced debris by proglacial and later, temperate fluvial processes, has been termed the 'paraglacial model' (Church and Ryder, 1972). Large scale sediment transport results in the formation of alluvial cones and fans.

Conditions in the Lake District at that time were somewhat different as frost weathering, snow melt, fluvial and slope processes, operating in proglacial and periglacial environments, were responsible for the transport of material to storage sites, including reworking of glacial sediments. Transfer of material from these sites, under temperate conditions with relatively complete vegetation cover, has been slow.

Rates of periglacial landscape change have been estimated for two sites in the Skiddaw Slate rocks of the northern Lake District. This fissile rock appears to break down readily under frost weathering. At Greta Bank Farm, Keswick, (NY 273241) scree at least 13 m thick overlies till. Using Rapp's (1960) figure for the annual average increment to the scree surface at Karkevagge, a present day periglacial environment, the scree would have taken about 850 years to accumulate. This would seem to be a reasonable estimate based on the assumption that these are Loch Lomond Stadial features (Boardman, 1985b). The scree is composed almost entirely of angular gravel-size chips of Skiddaw Slate: there is very little erratic material. This suggests that the origin of the scree is upslope frost weathering ofbedrock, not glacial till. Rates of accumulation therefore approximate to rates of bedrock weathering. At Sandbeds fan (NY 234291), an estimate of the volume of stored material gives a mean figure for ground lowering during the Loch Lomond Stadial of 0.58 m in this small, high-gradient catchment (Boardman, 1985b). This translates to a mean rate of surface lowering of 0.58 mm yr^{-1} based on 1000 years for fan formation. However, the upper beds on the fan are of late Flandrian age and probably represent reworking of the higher parts of an old fan. Fine material which has moved through the fan and into the Bassenthwaite Lake basin is not included in the calculation; the estimated rates of transport of weathered debris could well be equivalent to ground lowering of 1 mm yr^{-1}

It is likely that the Loch Lomond Stadial provided optimal conditions for rock weathering and the transport of debris to storage sites. Studies of frost action in contemporary cold montane environments e.g. the French Alps, have recorded rates of rock wall retreat of about 3 mm yr^{-1} at north-facing sites, where temperatures regularly drop below -8^{o}C (Coutard and Francou, 1989). Such temperatures would have occurred frequently in the Loch Lomond Stadial and resulted in high rates of rock wall retreat (Ballantyne, 1984).

There is no reason to believe that the sites investigated in the northern Lake District are unrepresentative of the Skiddaw Slate landscape as a whole; moderate and steep slopes frequently have a scree cover of 1-2 m depth (e.g. much of the Thornthwaite Forest area (NY 2125) and Dodd (NY 2427) with much greater thicknesses on footslopes. Many footslope and fan sites remain uninvestigated. Numerous exposures on forestry roads on Dodd show that the thickness of scree cover is variable; the smoothness of the Skiddaw Slate hillslopes is a result of mantling of a very irregular bedrock topography by slope deposits. Areas of Borrowdale Volcanic Group rocks rarely have good exposures of superficial deposits but the impression is of thinner debris mantles on a less frost-susceptible lithology. However, the thickness of scree composed of very large blocks, such as that below Falcon Crag (NY 272205), is unknown.

The efficacy of run-off under periglacial conditions is indicated by the thickness of stratified scree on the Skiddaw Slates; and by the formation of large alluvial fans which appear to have been inactive during the Flandrian and also appear to be widespread in the Lake District. Studies elsewhere in Britain emphasise the importance of rock weathering, fluvial transport and fan aggradation in the Loch Lomond Stadial (Sissons, 1979).

Table 3 Sediment transport by high gradient streams in the Lake District

	Catchment (km^2)	Mean channel gradient ($m\ m^{-1}$)	Bedload yield ($t\ km^{-2}\ yr^{-1}$)
present day *			
Beckthorn	0.5	0.40	70
Coledale	6.0	0.11	50
Lanthwaite	4.0	0.14	29
Loch Lomond stadial **			
Sandbeds	0.3	0.51	918

* data from Newson & Leeks (1985) ** data from Boardman (1985b)

A comparison of rates of movement of material in high gradient Lake District streams at the present time and under Loch Lomond Stadial conditions is given in Table 3. Present day rates are likely to be untypically high for interglacial conditions due to landscape disturbance by man and domesticated animals. An order of magnitude difference is indicated by the data. Church and Ryder (1972) point out that the difference in sediment yield for the paraglacial phase and 'normal' conditions is about an order of magnitude.

3.3 Interglacial environments

The interglacial contribution to landscape change can be dealt with briefly. This is because in well vegetated landscapes most surfaces are stable and rates of movement of materials are low. Exceptions to the rule are along stream channels, sea coasts and on steep, bare slopes.

From 7500 to 5000 years B.P., during the post-glacial climatic optimum, rates of erosion and sediment transport to lake basins were minimal (Pennington, 1981). It is believed that forest cover extended to about 850 m at this time. Rates of sediment output from small basins were probably similar to those for forested ecosystems in the eastern USA at the present time, about 4t km^2 yr^{-1} of particulate matter (Bormann et al., 1974).

Deforestation over the last 5000 years, and the more recent introduction of sheep, have meant an increase in erosion and transport rates compared with those of the early Flandrian and previous interglacials. About 5000 B.P. the influence of the first farmers is seen in sediments in the lake basins; this is due to local forest clearance, increase in run-off and downcutting of streams into mineral soils leading to an increase in the rate of lake sedimentation (Pennington, 1981). Extensive upland forest clearance, settlement and farming occurred in the Bronze Age, the Romano-British period, and as a result of Viking immigration and the introduction of sheep farming about 1000 years ago. By analogy with the Howgill Fells, deforestation and the introduction of sheep by Norse settlers may have initiated a phase of valley side instability, gullying and fan formation in the Lake District (Harvey, *et al*, 1981). In the last two hundred years erosion rates in the British uplands have increased greatly.

The dominant geomorphological processes in the interglacial landscape of the Lake District are pedogenesis, soil creep, and transport of sediments in river channels (Table 4). Lake basins have been infilled and flood plains developed. On bare slopes there is some rockfall activity and on gentler gradients at high altitude superficial sorting and creep of scree materials occur. These processes have little impact on the large scale inherited elements of the landscape.

Table 4 Principal weathering & erosion processes & rates (if known) for the Flandrian in the Lake District

Pedogenesis	Soil profiles 1-2 m deep
Soil creep	0.5 - 2.0 mm yr^{-1}*
Low angle scree movement	5 - 10 cm yr^{-1}**
Rockfall: accumulation on scree	Very limited (e.g. Wasdale); Hard rock cliff retreat: 0.1 mm yr^{-1}*
Debris flows	Active on some steep slopes (no data)
High gradient stream transport	see Table 3

* estimate based upon Saunders & Young (1983) ** from Caine (1963)

Even though upland interglacial landscapes have been somewhat disturbed and destabilised by mans' activities in the last 5000 years, the available data emphasise their relative quiescence in comparison with conditions in the preceding periglacial phase of the Loch Lomond Stadial (e.g. Table 3).

There is no evidence in Britain that the landscapes of previous interglacials were significantly different from those of the early Flandrian. Stable inactive landscapes dominated by slow weathering processes would have been the norm in the Lake District forests to over 850 m altitude.

4 Discussion

4.1 Glacial, periglacial and interglacial environments

The relationship and comparative effectiveness of glacial and interglacial processes operating within the same environment is a theme which has been little explored through lack of evidence. Some tentative comments can be made with respect to these processes during the Loch Lomond Stadial in the Lake District.

Rates of frost weathering can be estimated from the volume of material emplaced in storage sites; these would appear to be equivalent to about 1 mm yr^{-1} of surface lowering. The character of the material suggests that this is largely the result of the weathering of bedrock rather than superficial deposits. Rates of glacial erosion of bedrock are likely to be well below 0.5 mm yr^{-1}. The rates would increase with the presence of superficial deposits because the latter contribute to most measures of 'glacial erosion'. All estimates of glacial erosion based on the volume of moraines, the sediment deposited in lakes and the sediment content of outwash streams reflect the fact that a substantial proportion of debris reaches the glacier surface from weathering processes and rock failure on valley sides. The importance therefore of periglacial slope processes in contributing to rates of 'glacial erosion' is emphasised. Catastrophic slope failures, well known from alpine glacial environments, may contribute more material to the glacier surface in a day than that which is normally transported over many years (e.g. Gordon et al., 1978).

This review of the comparative effectiveness of geomorphological processes in different environments, hedged as it is with many qualifications, points to the importance of periglacial weathering and transport processes. These are likely to have operated for long periods of Quaternary time during phases of restricted glaciation. On steep slopes, and with efficient snow-melt transport available, the inhibiting effect of a negative feedback mechanism due to the thickening of weathered mantles is unlikely to have been operative. The major role of ice sheets is seen to be one of removal from the uplands of large quantities of periglacially weathered debris as well as interglacial soil profiles. Interglacial pedogenesis would seem to have contributed little to preparation of material for transport since most profiles are developed in superficial deposits, which, weathered or unweathered, are relatively easy for ice sheets to transport.

The importance of periglacial processes is further emphasised by the data in Table1. If almost 60% of Quaternary time in the Lake District has been periglacial in character then these processes have been dominant in a temporal sense. It is unlikely that conditions throughout this time period were as geomorphologically effective as during the Loch Lomon Stadial. Indeed, there is some evidence that the Loch Lomond Stadial was climatically atypical compared with earlier periglacial periods. Sissons (1980) suggests that precipitation in the central Lake District was in the range 2700-4000 mm and that this was sustained by vigorous cyclonic activity with snow-bearing winds from the south and south-east. These conditions were a result of the boundary of polar and warmer waters (North Atlantic Drift) being in the vicinity of south west Ireland (Sissons, 1980; Ruddiman et al., 1977). In contrast, the period prior to and during the Dimlington Stadial was relatively dry and cold in lowland England with limited amounts of snow (Williams, 1975). The climatic conditions envisaged are those of the blocking anticyclone over Western Europe dominating winter weather with the Polar Front in the latitude of Portugal.

The conclusion is that during periods such as the Loch Lomond Stadial a much snowier climate existed; this, together with low winter temperatures, gave rise to conditions which would maximise geomorphological activity - in contrast to cold drier conditions during (some?) earlier periods, for example, much of the interval 75,000-30,000 B.P. As a corollary, it seems reasonable to postulate the corrie formation would accelerate during snowier periods. Estimates of the length of time necessary to excavate corries based on Loch Lomond Stadial rates (Larsen and Mangerud, 1981), are therefore likely to be under estimates.

4.2 Regional implications

Evidence from other parts of the British Isles supports the tentative conclusions reached here with regard to the evolution of the Lake District landscape. In the Yorkshire Dales dating of speleothems from abandoned cave passages using the Uranium series method provided information on the formation of the major valleys. Waltham (1986) showed that the maximum possible mean valley floor excavation rate is 0.12 m per 1000 years. It must be emphasised that this is a maximum rate and would be lower if some cave passages are older than is indicated by the age of the oldest dated speleothem. Limitations of

dating method mean that speloethems greater than 350,000 years cannot be dated and therefore cave passages with speleothems dated at >350,000 years may be a great deal older. Waltham acknowledged that valley lowering is likely to have been accomplished by episodes of glacial erosion. He assumed three episodes in the last 300,000 years which gave a rate of about 0.2 m per 1000 years of glacial time (Waltham, 1986, Figure 28.5). Bowen *et al.* (1986) suggested that in the last 300,000 years there were only two major glaciations in the English lowlands, those in Oxygen Isotope stages 3 and 8. This could increase Waltham's glacial erosion rates but they remain 'maximum possible' rates. The relevance of the work on speleothems is that it emphasised that relatively minor amounts of valley floor lowering can be accounted for by recent ice sheets. A maximum of about 30 m of erosion appears to have been accomplished by two or three major ice sheets. Waltham (1986, p. 549) concluded:
'As the Yorkshire Dales are typically around 150 m deep, their history appears to span at least a million years, and a large part of their excavation appears to pre-date the recognised glaciations of the Devensian, Wolstonian and Anglian'.

Atkinson *et al.* (1978) had previously concluded that the main phase of valley deepening of perhaps 75 m had been achieved, presumably by glacial erosion, prior to 400,000 B.P. This would not now be in conflict with a major glacial event in the Anglian in Oxygen Isotope stage 12 between about 428,000 and 480,000 years ago (Bowen *et al.* 1986), but equally the erosion could have occurred much earlier.

The argument advanced in this review is that the major relief features of the Lake District landscape represent an unknown amount of modification of pre-glacial river systems. Linton (1957) pointed out that the radial drainage pattern had been emphasised by the formation of lake basins: these basins add to the impression of a radial pattern. Several of the lake basins are clearly glacial in origin.

If it is accepted that the Thornshill Till in the northeastern Lake District is most likely to be of stage 12 age, then it follows that the major relief elements, the glaciated valleys, may have existed in much their present form at that time. The lack of large scale recent glacial erosion is supported by the speleothem studies. Bowen *et al.* (1986) review the evidence for five separate glacial events in the Early Pleistocene. Ice sheets and/or meltwater were responsible for the transport of large quantities of erratic material from Wales and the Midlands to the Thames basin. Erosional processes must have had a significant impact on uplands at this time. Glaciation of Wales is likely to have been contemporaneous with glaciation in the Lake District and Scotland.

The fact of large scale glacial (and fluvioglacial) transport of sediment from uplands to lowlands does not in itself require large scale glacial erosion. In eastern Scotland thick weathered profiles of Tertiary age are known in areas which escaped glaciation or in which erosion has been limited (Hall, 1985). However, the scarcity of such materials in Wales and the Lake District suggests that Early Pleistocene glaciation has removed them: this may be the origin of much glacially transported material. It would be surprising if as many as five glaciations had not substantially eroded bedrock as well as superficial deposits.

In global terms the amounts of glacial erosion that are argued for here, in the Lake District and in the Yorkshire Dales (Waltham, 1986), are rather modest. In the Appalachians, for example, Braun (1989) suggests Pleistocene glacial erosion of 120 - 200 m is necessary to account for the volume of glacially derived ocean sediment. This requires average erosion rates of 0.5 to 0.8 m per 1000 years (cf the adjusted maximum rate of 0.2 m per 1000 years from Waltham's study). However, the latter figure relates to the last two glacial episodes and it is entirely reasonable to expect higher rates in earlier glacial stages. Warnke (1970) suggested that in Antarctica glacial modification of the land surface was more rapid in the earlier than in the later part of its present glacierization, see Figure 3.

Recent evidence from oxygen isotope studies indicates that accumulation of ice on the northern hemisphere land masses and consequent glacial erosion started about 850,000 years ago. Warnke argued for the stripping of pre-glacial weathered mantles and also for the formation during early glacial episodes of equilibrium forms adjusted to efficient transport of ice and debris. This model is applicable to the landscape of Britain (Rose, 1988), and to the Lake District. It is apparently an anomaly that glacial-interglacial climatic cycles have become, in the second half of the Quaternary, better defined as the impact of glacial processes on the landscape has declined. Warnke's model appears to explain adequately the anomaly.

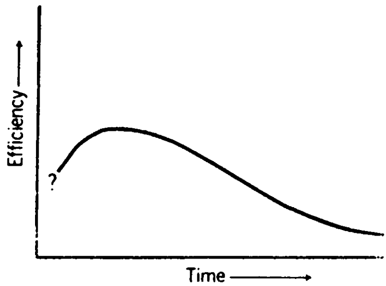

Figure 3

Schematic representation of efficiency of glaciers as eroding agents. Slope of curve to left of efficiency peak unknown (Warnke,1970).

5. Conclusion

The evidence for glacial erosion in the Lake District is, with the exception of the corries, rather meagre. There is strong circumstantial evidence for the modification of a quasi-radial pattern of drainage by glacial processes in the Quaternary. In the northeastern Lake District little glacial erosion occurred during the Devensian and also probably during a major glacial event which most likely occurred in Oxygen Isotope stage 12. A series of earlier Quaternary glaciations were responsible for modification of the landscape including valley deepening. The amount of modification is unquantifiable but may be in the range of 50-150 m of localised deepening. The role of ice sheets at this time was to strip Tertiary weathered mantles, and to a lesser extent interglacial soils, from the landscape. No sedimentary remnants of the phase of Tertiary pedogenesis have been described from the Lake District.

Phases of restricted glaciation are likely to have existed for at least 60% of the Quaternary. Corries have been formed and the valleys of the central Lake District deepened. The Loch Lomond Advance provides a model by which to assess the impact of this type of event. In spatial and temporal terms it was very limited but the effectiveness of geomorphological processes during the short time is evident. Many similar periods must have occurred in order to produce the suite of corries. However, cold climate conditions during the Quaternary were frequently drier, less snowy and therefore geomorphologically less effective.

The major impact of periods of restricted glaciation was due to their periglacial character. Frost weathering and snow-melt interacted to produce major landscape change. These processes were controlled by climatic factors and were effective because of the presence of frost-susceptible rocks, steep slopes (partly the result of glaciation), frozen ground, a lack of vegetation and the availability of debris inherited from previous glacial episodes. The evidence suggests that this constituted the most effective group of processes in terms of landscape change to have affected the area in the Quaternary. These periods may, however, have been relatively short lived and similar to the Loch Lomond Stadial in character.

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J. Boardman, Ph.D.,
School of Geography,
University of Oxford,
Mansfield Road,
Oxford OX1 3TB.

SELLAFIELD GEOLOGICAL INVESTIGATION: A DEEP SITE INVESTIGATION FOR A POTENTIAL RADIOACTIVE WASTE REPOSITORY

C. J .Thompson

Introduction

UK Nirex Ltd has the responsibility for establishing a facility for the disposal of low and intermediate level radioactive waste. A nationwide geological review identified both Sellafield in Cumbria and Dounreay in Caithness as potentially suitable sites for the deep disposal of this waste. Geological investigations were initiated at these sites in 1988 and 1989 respectively. This paper summarises the progress of the Sellafield investigation as at November 1991.

UK Nirex Ltd appointed BNFL to act as their site agent at Sellafield. The first phase of the investigation was intended to confirm the initial model of the geology and hydrogeology of the area and to generate a 3-dimensional geological model. This model would be suitable for use in modelling of groundwater flows that could contact material in a repository. The overall area of investigation was approximately delineated by surface water catchment areas around the Sellafield site and the outer limits of potential radionuclide release pathways from the repository back to the surface environment.

Nature of the Investigation

The initial phase of the investigation consisted of the following work:

1) Conducting a number of regional geophysical surveys
2) The drilling of 2 deep boreholes.
3) Surface geological mapping.

Regional Geophysics

The Regional Geophysical Surveys were intended to cover as much of the area of investigation as the individual techniques permitted. The following surveys were undertaken October 1989 - August 1991.

1) Onshore, offshore and transition zone (coastal and tidal areas) seismic reflection surveys over an area extending from St Bees to Ravenglass, up to 10 km offshore and into the Lake District to the east.
2) An Airborne (helicopter) survey comprising magnetic, radiometric and VLF (Very Low Frequency) measurements, both onshore and offshore.
3) A gravity survey, both onshore and offshore (on the marine seismic vessel).
4) Trial electromagnetic (Audio Magnetotelluric and Transient Electromagnetic) surveys over a small area to establish if the techniques were of use in the area.

Each of these data sets was intended to complement the others and to allow resolution of any ambiguities that might arise from the use of a single data set. The interpreted data sets were to be integrated with the deep borehole data and other available information to generate the 3-D model of the area.

Deep Boreholes

The initial phase of the investigation required the drilling of deep boreholes to confirm the prognosed geological sequence in the area and to calibrate the regional geophysical surveys (particularly the seismic data). It was apparent from existing data there were significant changes in the geological sequence between the edge of the Lake District massif and the coast. The interpretation of seismic data acquired in the vicinity of the Sellafield site in 1988 supported this. It was therefore proposed to drill one hole close to the coast to penetrate the most complete stratigraphic sequence in the area and a second some 3 km inland in an area where the proposed repository host rock, the Borrowdale Volcanic Group (BVG) was known to be present closer to the surface.

Borehole 1 This was located on the Sellafield site close to the coast (Figure 1). Only one location was available and since the seismic interpretation indicated the presence of a significant normal fault directly below this surface location (Figure 2) it was necessary to deviate the hole to reach the intended bottom hole location.

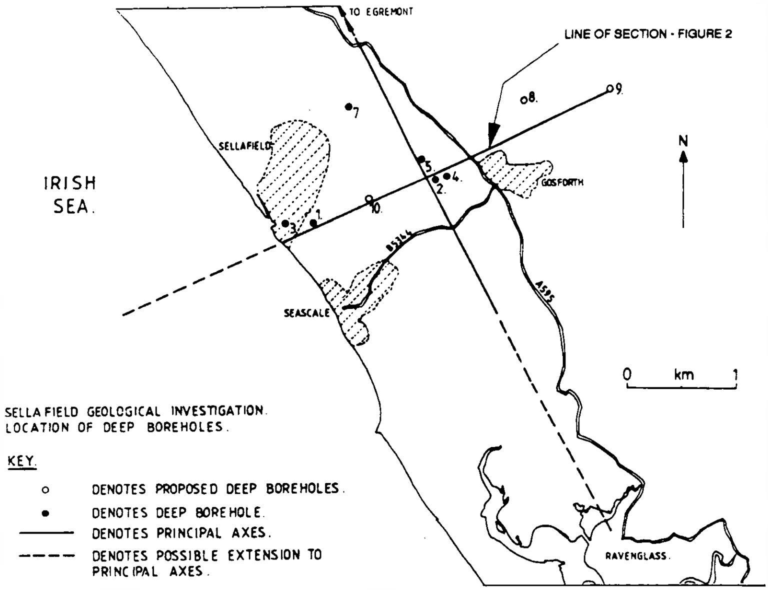


FIGURE 1 - DEEP BOREHOLE LOCATION MAP

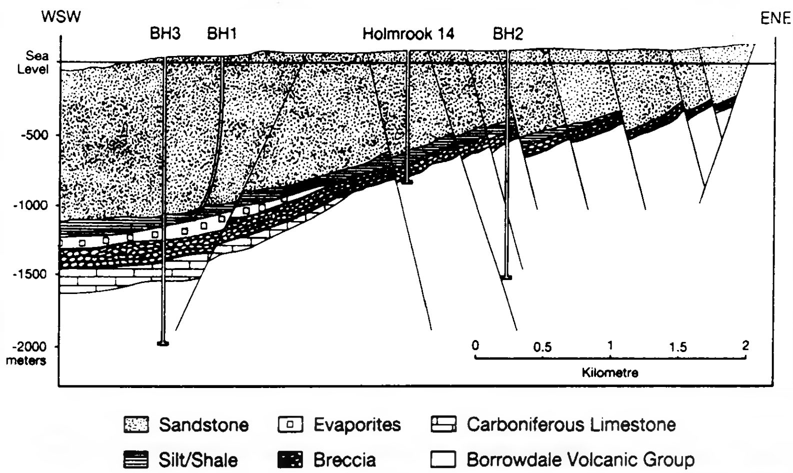


FIGURE 2 - SCHEMATIC CROSS SECTION - SELLAFIELD AREA

(UK NIREX JULY 1991)

The objectives of Borehole 1 were to:

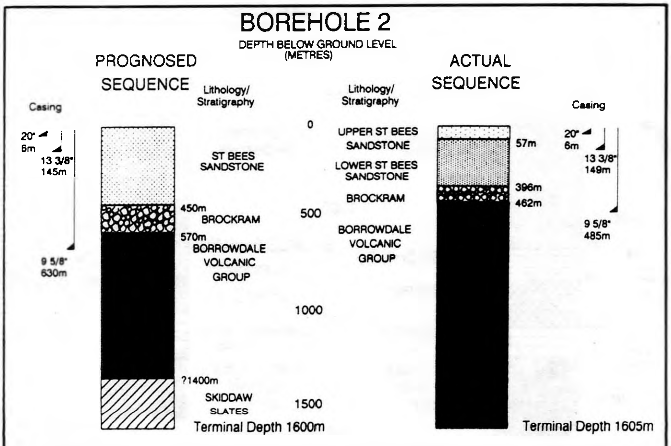
* Establish the geological sequence in the coastal area
* Obtain core from as much of the sequence as possible
* Obtain data from downhole geophysical logs to determine various characteristics of the formations and to calibrate the regional geophysical data
* Obtain detailed information on the hydrogeological properties of the rocks and collect groundwater samples

Borehole 1 commenced on 25 August 1989 and reached a drilled depth of 772 m in the Lower St Bees Sandstone when the drillstring became stuck. During attempts to free the drillstring it broke; subsequent attempts to recover the pipe left in the hole were unsuccessful. A decision was taken to drill another hole (Borehole 1A) from the same surface location and using the vertical portion of Borehole 1.

Information obtained from Borehole 1 indicated that drillpipe rotating in the deviated section of the hole had worn a groove in the borehole wall and this had resulted in excessive wear to and final failure of a section of drillpipe. This problem was exacerbated by the slow rates of progress associated with coring operations. Borehole 1A was therefore rotary drilled over most of the St Bees Sandstone section in an attempt to minimise this problem. Drilling with occasional coring was undertaken to a drilled depth of 1143 m where the top of the St Bees Shales were encountered. The St Bees Shales were cored to a depth of 1189 m where drilling stopped and geophysical logs and hydrogeological tests were conducted. However, following the completion of this work problems were encountered whilst increasing the size of the hole to accept casing, with the pipe again becoming stuck. After an extended period of operations to recover the drillstring this was finally achieved but due to the deterioration of the borehole a decision was taken to suspend the hole. Operations on Borehole 1A ceased on 7 November 1989.

Borehole 2 was located approx. 1.5 km west of Gosforth (Figure 1). Published data indicated that the BVG could be expected at a depth of about 500 m below ground level. The objectives of Borehole 2 were essentially similar to Borehole 1 but with more emphasis being placed on obtaining geotechnical information on the BVG in an area where the basement rock was expected to be present at depths suitable for repository construction.

Borehole 2 was drilled as a vertical hole employing a wireline coring system which enabled 6 m lengths of core to be retrieved from the hole without removing the drillstring, thus minimising damage to the borehole wall, improving core quality and reducing the time taken to recover the cores. Environmental Pressure Tests involving the use of a packer system were conducted over the lowermost 50 m of the hole at 50 m intervals with the purpose of determining hydrostatic pressure heads throughout the sequence. Borehole 2 commenced on 25 August 1990 and was completed on 9 April 1991 at a depth of 1605 m below ground level. The borehole was very successful, meeting and in most cases exceeding the data acquisition objectives. Both the Brockram sequence and the Borrowdale Volcanic Group rocks were encountered shallower than prognosed from the seismic data (Figure 3). Nearly 1100 m of BVG were encountered, consisting predominantly of intermediate tuffs with occasional thin intrusives and sediments. Borehole 2 both confirmed the stratigraphy of the inland area and provided hydrogeological data, which confirmed the very low hydraulic conductivity (permeability) of the Brockram and the BVG.



BOREHOLE 2 - COMPARISON OF PROGNOSIS AGAINST SECTION ENCOUNTERED

Figure 3

Borehole 3 was drilled as a replacement for Borehole 1 with the location (Figure 1) selected to ensure that a vertical hole would meet the objectives. The prognosis indicated the presence of five markedly different formations. In order to test these formations individually and meet safety requirements, a large number of casing strings were required to isolate successive sections of the borehole as the hole was drilled. This necessitated the use of special (10 3/4" and 8 5/8") casing sizes not available in the UK, which had to be ordered from the US. As a result the borehole design was probably the most complex ever proposed in the UK.

Borehole 3, with objectives similar to Borehole 1, commenced on 5 December 1990 and reached a terminal depth of 1947 m below ground level on 27 July 1991. All the objectives were achieved but the stratigraphy encountered in the pre-St Bees Sandstone sequence was however significantly different to that prognosed (Figure 4). The development of the St Bees Evaporites is restricted to a 4 m thick anhydrite bed underlain by 43 m of dolomite. This sequence overlies a very thick (157 m) breccia, very similar to the Brockram. This breccia

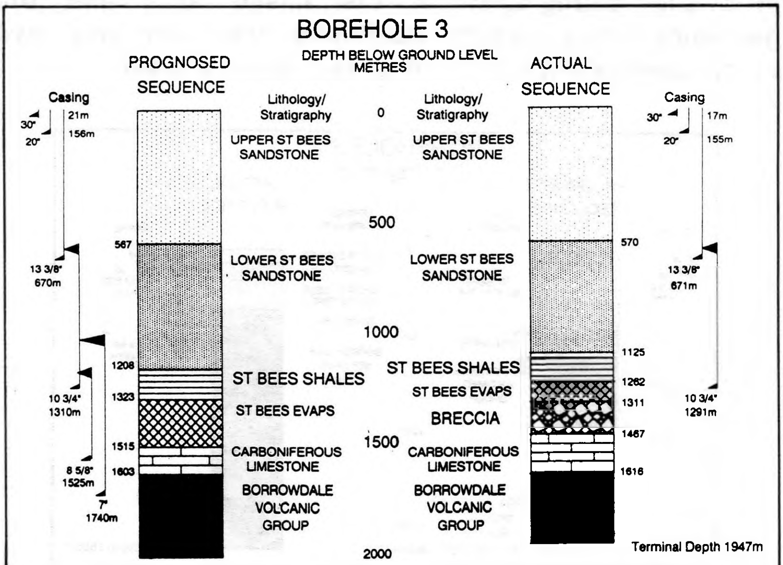


Figure 4 BOREHOLE 3 - COMPARISON OF PROGNOSIS AGAINST SECTION ENCOUNTERED

is underlain by 149 m of unweathered Carboniferous Limestone, containing saline groundwater, which in turn overlies the BVG rocks. One feature of the pre-St Bees sequence as a whole was the lack of any significant weathering zones at the unconformities separating the lithological units. No significant drilling or formation problems were encountered and following geophysical logging and testing Borehole 3 was completed on 6 September 1991.

Further Boreholes

Following the successful completion of Borehole 3, the initial phase of the Sellafield investigation was essentially complete. However the site was then sufficiently well understood that it was possible to identify and proceed with further investigations. Subsequent deep borehole sites will be required to characterise the regional hydrogeology by drilling a series of deep boreholes along the line perpendicular to the coast (the line of postulated regional groundwater flow from the Lake District to the coast) on which boreholes 1, 2 and 3 have been drilled, and on a line parallel to the coast (see Figure 1). The first of these boreholes (Borehole 4) has been completed and has confirmed the lateral continuity of the BVG and also the low hydraulic conductivities indicated by Borehole 2. The close proximity of this hole to Borehole 2 (approximately 100 m apart at surface) is intended to facilitate cross-hole testing. Borehole 5, some 700 m to the north of Borehole 2, is currently drilling (November 1991). This is the first of a series of holes that are likely to be required along the line parallel to the coast.

Planning consent has been obtained for Borehole 7, close to Calderbridge, this hole will commence in early December 1991. Planning applications have been submitted for a further 3 borehole sites. Two of these (8 & 9) are situated in the National Park and located either side of the junction of the BVG with the overlying sediments. These are required to determine the nature of groundwater recharge, both directly to the BVG and to the thin sedimentary sequence overlying the basement rock. Borehole 10 will establish the nature of the pre-St Bees Sandstone sequence between Boreholes 2 & 3. Planning permission has also been granted for 4 shallow borehole sites which will provide details of drift deposits in the immediate vicinity of Sellafield site.

Surface Mapping

As part of the detailed geological study of the area the BGS were contracted to undertake a detailed surface mapping study of some 450 km^2, covering the western part of the Lake District and the coastal plain. The area is essentially that defined by the BGS 1:50 000 Gosforth/Bootle sheets and the southern portion of the Whitehaven sheet. This work was conducted between September 1990 and April 1991. Field mapping was on a scale of 1:10 000 with emphasis being placed on structural mapping and the sub-division of the Borrowdale Volcanic Group. Final maps of this area were produced at a scale of 1:25 000. A 1:50 000 compilation map of a larger area extending from Egremont to Bootle and eastwards to Ambleside was also produced.
[The geological mapping is discussed in the paper on 'Recent BGS work in Cumbria' by B. Young and in the notes on the lecture 'Nuclear waste disposal and Ordocivian volcanics' by M.G.Petterson, both members of BGS staff. - Ed.]

Regional Hydrogeology

An initial study of the regional hydrogeology and geochemistry of the Sellafield area involved the evaluation of all the available relevent data. Further work comprising the field investigations necessary to improve the information on the principal aspects of the hydrology, hydrogeology and geochemistry of the site is being planned.

Future Progress

On 23 July 1991, UK Nirex Limited announced that Sellafield was its preferred site for further investigations into its suitability for the construction of a deep repository.

Interpretation of the data produced from the regional surveys and from Boreholes 1 - 3 is now underway. The interpretation will provide the information for input to the computer generated 3-D groundwater flow model for the area. This will allow comparison of the performance of the repository with the safety principles and requirements set by the Department of the Environment (Reference) and will form the basis of the geological information that will be submitted to a Public Inquiry should the Sellafield area prove suitable. The model will be used to provide data on the quantities of groundwater that will flow through the repository over geological timescales and the time that this will take to emerge into the biosphere.

Further deep boreholes will be drilled to determine the characteristics of any features which are likely to be important in terms of repository development and to provide further refinements to the groundwater flow model. The latter are likely to be along the 2 axes described above and may result in a total of at least 20 deep boreholes being drilled. Dependent upon the results of the initial shallow boreholes a significant number of shallow boreholes may also be drilled to characterise the nature and variability of the superficial (drift) deposits within the catchment area.

Acknowledgements

The permission of UK Nirex Limited and British Nuclear Fuels plc to publish this paper is gratefully acknowledged. Thanks are also due to staff of Sir Alexander Gibb and Partners, Geoscience and John Arthur and Associates (The Gibb Deep Geology Group) who are the consultants for the investigation work at Sellafield.

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C.J.Thompson, BSc, FGS.
[redacted]

Figure 1. Features of glaciation in the Solway area.

KEY

Edge of Lockerbie-Langholm upland.

Ice flow direction at maximum.

Ice flow direction at drumlin stage.

H1 Readvance limit (Huddart).

H2 Later margin (Huddart).

Ice divide

R? Readvance limit (this note).

Nithsdale post-readvance ice margin.

Esker locations.

Main meltwater discharge routes.

Alignment of ice-moulded landforms.

A POSSIBLE LATE INCURSION OF SCOTTISH ICE INTO NORTH CUMBRIA

A short communication by R.Clark

The possibility of a movement of ice from southern Scotland into northern England late in the Upper Devensian glaciation was suggested by Trotter (1929). More recently Huddart (1971,1973) and Huddart *et al* (1977) presented further evidence from Cumbria for such an ice readvance but less extensive than initially suggested, see Fig.1. However, Pennington (1978) discounted the evidence for such an episode, seemingly in consequence of somewhat ambiguous and unelaborated comments by Evans and Arthurton (1973). Thomas (1985) doubted the importance of any readvance of ice into Cumbria, commenting that evidence for a readvance ice margin need demonstrate neither extensive ice advance, large-scale previous ice margin retreat nor any significant climate deterioration such as thought by Huddart *et al* (1977) to have driven the Scottish readvance into Cumbria.

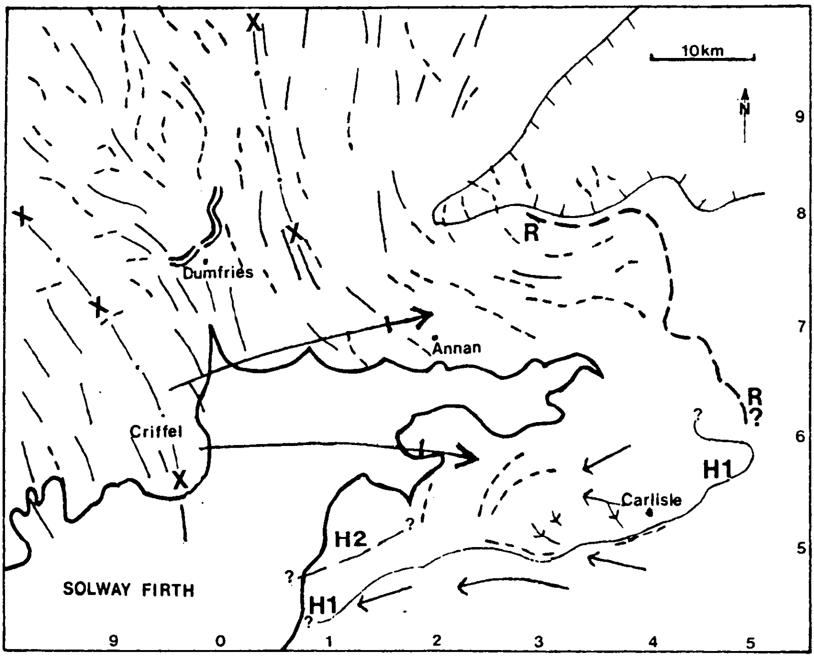

Figure 1. Features of glaciation in the Solway area.

Features on the Scottish side of the Solway, however, do lend support to the likelihood of a readvance. Ice-moulded landforms and east-directed marginal or sub-marginal meltwater discharge channels indicate the establishment of eastward and southeastward falls of ice surface slope from Nithsdale to lower Eskdale. The altitudes of the outermost channels show that event to have post-dated the abandonment of the Gilsland col meltwater channel, itself later than the cessation of vigorous ice movement east into the Tyne basin (Clark, 1990, 1992). The channel pattern suggests the thickest part of the associated ice mass was in the area of the present Solway Firth and the eastern limit of the ice followed the Esk valley between Canonbie and Longtown; there may have been an extension over the low ground north and northeast of Carlisle. Such a margin is compatible with that identified south of the Solway (Huddart 1971). In consequence of the form of this ice surface, meltwater from east of Nithsdale would have converged upon the Longtown-Carlisle area and, for as long as the Solway area was occupied by thick, coherent ice, water would have been diverted south to the Cumbrian side.

During dissipation, the ice lobe appears to have retained quite regular and distinct margins to its shrinking central zone of thicker ice, at least until it lay west of Annan. Sufficient ice then remained in the Nith catchment for the younger marginal features - channels and glacifluvial deposits - to have been constructed in the Nith valley north of Dumfries (Stone 1959). As the readvance ice thinned and became stagnant on the Scottish side of the Solway, large volumes of meltwater converged in the lowland areas, laying down extensive glacifluvial deposits. The following set of events are tentatively proposed for the area during that part of the glaciation which includes this readvance (Clark 1990).

1) initiation of ice flow from north Cumbria and Dumfriesshire into the Irish Sea basin - cessation of last ice movement east into the Tyne basin; stagnation of ice in the Brampton area and from there south to near Renwick,
2) drumlin formation south of the Solway by ice moving to the Irish Sea basin; thinning of ice in Liddesdale and the Vale of Eden; weakening of ice flow over the lowland south of the Solway,

3) extension of ice east from Nithsdale and Annandale on to the drumlin tract south of the Solway to the readvance limits, perhaps commencing during waning of the drumlin event; strong contemporary southward iceflow out of the Dee valley, buttressing Nithsdale ice to the east; movement of meltwater to major channels leading west from the Carlisle area,
4) formation of the Thursby eskers (Huddart 1971); development of meltwater routes southwest from the Burgh-by-Sands area; withdrawal of the ice margin to the Holme St Cuthbert locality; loss of last Scottish ice from Cumbria.

It should be noted that the extent of the suggested readvance may be related to dimensions of the ice supply region on the Scottish side, almost 70 km wide at its mountainous inner limit 50 km north of the present coastline, much larger than the whole of the Lake District. Ice from the interior passed south across a tract little more than 30 km wide, from the east of Criffel to the hills east of Lockerbie, before spreading over the Solway lowlands.

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R. Clark, D.Phil.,
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RECENT B.G.S. WORK IN CUMBRIA

B. Young

The Newcastle Office of the British Geological Survey was opened ten years ago and Cumbria has been one of its main theatres of activity. This seems, therefore, to be an appropriate time to outline the main areas of research and to review some of the results of this considerable volume of work.

In 1981 a start was made on re-mapping the Ordovician and Silurian sediments of the Troutbeck and Kentmere areas. The following year saw the establishment of the Lake District Regional Geological Survey, one of several large multi-disciplinary research projects initiated at this time by BGS. The study embraced a variety of research topics including:

* sedimentology, palaeontology and structure of the Skiddaw Group
* geochemistry, volcanic stratigraphy & volcanotectonics of the B.V.G.
* petrological and geochemical studies of the intrusions
* stratigraphical, palaeontological and structural studies of the Windermere Group
* detailed reinterpretation of geophysical, particularly gravity, data.

One of the principal aims was the 1:10 000 scale geological mapping of the Lower Palaeozoic rocks of the Lake District. Work was initially concentrated on the Keswick and Ambleside Sheets though work was also undertaken on areas of critical importance on other sheets. As the project has developed, mapping contracts were awarded to geology departments at Sheffield, Leeds and Liverpool universities. This work has been undertaken both by academic staff and research students, the latter as part of their PhD studies. Other pieces of collaborative research have been carried out with the universities of Newcastle, Nottingham, Lancaster and London.

Work on the Upper Palaeozoic rocks of Cumbria began in 1985 in response to a commission of the Department of the Environment (DOE) to revise the geological maps of parts of the west Cumbrian coalfield. In addition to new 1:10000 scale maps this work led to the preparation of suites of thematic maps showing such diverse features as rockhead elevation, drift thickness, areas of shallow mining, swallow holes, made and disturbed ground, structure and mineralisation. Three separate DOE-commissioned projects have covered parts of the Whitehaven, Cockermouth and Maryport sheets. Partly as a result of work started for these projects the complete revision of these 1:50 000 sheets is now in hand.

In addition to work directed towards field mapping of the Lake District and adjacent areas, BGS has undertaken work on the regional geochemistry and mineral resource potential of parts of the area. As part of the BGS Mineral Reconnaissance Programme investigations have been mounted on mineralisation in the Black Coombe, Wasdale and Cockermouth areas.

Recent years have seen the beginning of detailed investigations for a deep repository for radioactive waste in the Sellafield area. Not only have staff been involved in a wide variety of detailed studies and reviews of the area's geology but a considerable effort has been, and is still being, expended in examination of the deep boreholes currently being drilled as part of this investigation. The wealth of detail obtained from this work allows important revisions to the Gosforth and Bootle 1:50 000 sheets, new editions of which are in preparation.

In addition work is in hand to produce an Ambleside memoir, the writing of which is due for completion in 1992, a memoir describing the major revisions to the Eycott Volcanic Group and a similar publication describing the economic geology of the Caldbeck Fells.

This is a brief outline of work to date and in hand. Already much has been published in earth science journals and as BGS publications (details are listed in the Society's "Bibliography of the geology & geomorphology of Cumbria:1974-1990" by R.A.Smith). With any project of this sort the lead time needed to see the first published maps is considerable. However the first maps have appeared and will soon be joined by several others which are nearing completion.

Maps already published or in press are as follows:-

1:10 000 scale:
published: (NY) 02 NW, 02 NE, 02 SE, 03 NW, 03 NE, 03 SE, 03 SW, 12NW, 12 SW, 12 SE, 12 NE, 13 NW, 13 SE; (NX) 92 NE & 93 SE.
in press: (NY) 05 SE, 15 SW, 04 NE, 04 SE, 14 NW, 14 SW.

1:25 000 scale: NY 12 (Lorton and Loweswater), SD 19 (Devoke Water and Ulpha)

1:50000 scale maps due to be completed and published within next two years.

* 22 Maryport
* 23 Cockermouth
* 37 Gosforth
* 38 Ambleside
* 47 Bootle

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B. Young, B.Sc., C.Eng., F.I.M.M.,
British Geological Survey,
Windsor Court, Windsor Terrace,
Newcastle upon Tyne NE2 4HB.

EXCURSIONS

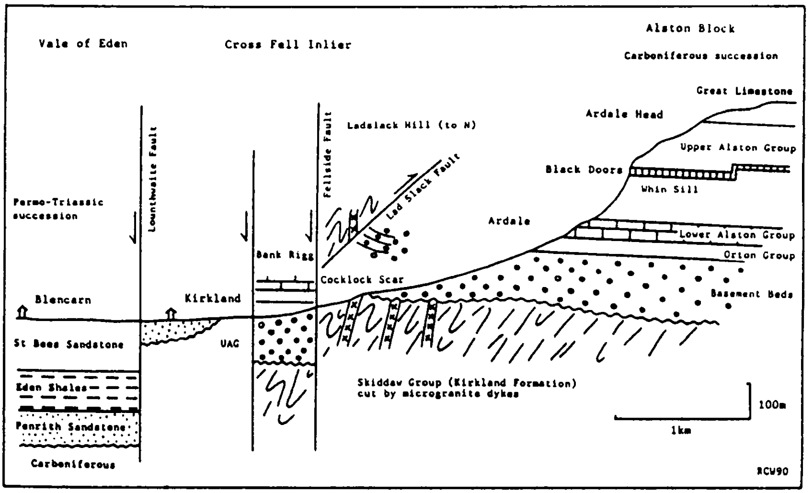
THE GEOLOGY OF THE WESTERN SLOPES OF CROSS FELL

Leader: Dr.R.C.Wright

29 April 1990

Members and friends met in the hamlet of Kirkland (NY 646,325) at the foot of the western slopes of Cross Fell and 13 km. east of Penrith. The leader summarised the geological evolution of the area and drew comparisons with the Dufton/Murton area to the south, visited by the Society on a previous occasion (Wright, 1988).

The excursion route from Kirkland northeast into Ardale traverses the Cross Fell Inlier and the Lower Carboniferous succession on the western flank of the Alston Block. The inlier comprises a variety of



Diagrammatic E-W cross section of western slopes of Cross Fell

rock units ranging from Ordovician to Permian in age that lie along the Pennine Fault Zone between the downfaulted Permo-Triassic succession of the Vale of Eden to the west & that of the Carboniferous on the Alston Block to the east. The inlier includes not only the rocks of the fault blocks but also the adjacent outcrops of Ordovician (Skiddaw Group) rocks that are exposed to the east beneath the Carboniferous cover at the western edge of the Alston Block. The fault zone has had a 400 Ma history since the emplacement of the Weardale Granite led to crustal inhomogeneity between the Alston Block and surrounding areas. The low density granitic core of the Alston Block created a positive and buoyant area that has persisted through subsequent geological time and whose existence is reflected in both depositional and tectonic histories. In Carboniferous times, sedimentation began earlier and successions were thicker in basins adjacent to the block; in Permian times, the Vale of Eden marked the site of an intermontane basin of deposition between areas of the Pennine and Lake District blocks. During periods of tectonic activity, the Alston Block retained a more rigid structure whilst deformation was concentrated in the basin rocks and particularly along the margins of the block, eg. the Pennine Fault Zone.

Triassic St Bees Sandstone outcrops in the villages of Skirwith and Blencarn west of the Lounthwaite Fault, which has a throw of at least 300 m, while Kirkland lies on upfaulted Permian Penrith Sandstone that rest unconformably upon an irregular surface of Carboniferous rocks. The party followed the fell road eastwards from Kirkland. An outcrop of purple, pebbly sandstones of the Lower Carboniferous Basement Beds was seen on the north bank of Kirkland Beck (654,328) while on Bank Rigg to the north, limestones of the overlying Lower Alston Group occur in old workings (652,331 and 650,336). These outcrops are downfaulted to the west by the Fellside Fault, with an estimated throw of 200m, which is crossed at the fell road bridge over Kirkland Beck. From a suitable vantage point (657,334) along the fell road, the relationship between the diggings in the Lower Alston Group Melmerby Scar Limestone at 652,331 and the same limestone high on the escarpment where it forms the crags of High Cap and Wildboar Nook could be seen.

East of the Fellside Fault are Skiddaw Group rocks, which in the Cross Fell Inlier are divided into a lower Murton Formation (seen on Murton Pike 735,232) and an upper Kirkland Formation. These are unconformably overlain by the Lower Carboniferous Basement Beds but much is obscured by drift in the immediate area of the traverse. The Kirkland Formation comprises mudstones with interbedded tuff and 'spilitic' lava horizons. The harder volcanic rocks do give rise to outcrop, best seen in the crags of Wythwaite Hole (661,327) to the south and in the south bank of Ardale Beck (650,342) to the north (Burgess & Wadge, 1974). Graptolites from the Kirkland Formation indicate an Ordovician (Llanvirn) age, allowing correlation with the Eycott succession of the northern Lake District.

After the fell gate (657,336), the party turned west into an imposing glacial meltwater channel alongside Cocklock Scar, part of an extensive system of glacial drainage that developed along the flanks of the Pennines and floor of the Vale of Eden during the wasting of the Late Devensian ice-sheet. The Cocklock Scar channel with a humped long profile is an excellent example of a channel cut beneath the ice with water locally flowing uphill under hydrostatic pressure. The cross profile of the channel has been modified by hillslope processes. Blocks of conglomerate within the channel record rockfalls and a linked slump scar and lobe are evidence of debris flows. Streamlining of the debris at the toe of the lobe indicates that some slumping occurred before the channel ceased to carry water. Prominent rock outcrops of pink, porphyritic microgranite in the the valley sides form dyke-like bodies which intruded Kirkland Formation mudstones. Vein quartz pebble conglomerates of the Carboniferous Basement Beds occur on the eastern flank of Cocklock Scar (654,339) and extrapolation of their outcrop pattern indicates that they unconformably overlie the microgranite dykes. A post-Caledonian deformation, pre-Carboniferous age for dyke emplacement is consistent with observations on similar bodies elsewhere in the inlier. Chemical analyses suggest that these microgranites are related to the Weardale Granite (Arthurton & Wadge, 1981). However more extensive mass movement has occurred down the gully of Lad Slack (652,342) which is eroded along the Lad Slack fault. This post-Carboniferous reverse fault has carried Kirkland Formation mudstones eastwards over the Basement Beds of Ardale Side (see fig.1)

A steepening of bedding planes in the Basement Beds was noted as the party moved into Ardale. Waterfalls in the first section of Ardale Beck (654,344), show cycles of conglomerates and sandstones passing upwards into siltstones which characterise the Basement Beds. Cross bedding in this fluviatile sequence indicates a current direction towards the east. The middle section of Ardale Beck is drift-covered and eventually a halt was made for lunch at the site of a long-abandoned shieling. The asymmetry of Ardale was noted and the much modified south-facing side compared with the more uniform north-facing one.

Limestones, sandstones and siltstones of the Orton Group outcrop in Ardale Beck (661,349) approximately 150m upstream of its confluence with Ranscleugh Sike. Brachiopods occur in the limestones and plant debris and trace fossils in the siltstones. The facies is transitional between the underlying fluviatile Basement Beds and the overlying marine beds of the Lower Alston Group. The latter are not exposed in the floor of Ardale, although the major limestone, the Melmerby Scar Limestone, was seen in a cliff on Ardale Side to the north and in the wall of Ranscleugh Sike to the south, and near High Cap during the return journey.

While the Asbian Lower Alston Group is dominated by limestones, the Brigantian Upper Alston Group is dominated by clastic sediments with limestones making up less than 25% of the sequence. Nevertheless the limestones are important marker horizons and alternate with deltaic clastics in the classic Yoredale cyclothems : limestone overlain by mudstones becoming less fossiliferous and more ferruginous upwards and in turn overlain by siltstones and more massive sandstones with a seatearth and thin coal at the top beneath the next limestone. The sequence records the advance of a delta lobe into a shallow sea. Major cyclothems imply widespread sea-level changes which may reflect variation in sea-floor spreading rates whilst minor cycles may relate to more local delta switching or variation in the rate of sediment supply.

A section in the tributary coming into the upper section of Ardale Beck from the east (663,352) displayed the major cyclothem from the Smiddy Limestone to the base of the Lower Little Limestone. This cyclothem includes a 5m thick sandstone, the Smiddy Ganister, which forms a prominent feature all along the escarpment. The party then ascended the slopes at the head of Ardale to the spectacular outcrop of the Whin Sill forming the cliff of Black Doors (665,354) across the head of the valley. Here the Whin Sill is 18m thick and its dark, near vertically jointed crags contrast starkly with the paler, near horizontal, bedding plane dominated outcrops of the sedimentary rocks. Here the sill intrudes the Copper Hazle sandstones which lie within a variable sequence of rocks forming up to seven cyclothems between the Tyne Bottom and Scar Limestones, known as the Alternating Beds (Burgess & Wadge, 1974). The Single Post Limestone within these beds crops as distinctive white crags on the slopes below the Whin Sill on the north side of the stream. A thin coal within the Alternating Beds was located on the south bank of the stream.

The lower contact of the Whin Sill showed a chilled margin to the dolerite resting on a hornfelsed sandstone; weathering made them look superficially similar close to the contact. The sill transgresses down the succession southwards to intrude below the Tyne Bottom Limestone at High Cup Nick (710,305). It rises to higher stratigraphical levels northwards and at Brampton it intrudes rocks of the Coal Measures. The Whin Sill extends to the Farne Islands off the Northumbrian coast and its total volume of 200 km^3 is thought to have been emplaced as a number of pulses of mantle-derived magma (Thorpe & MacDonald, 1985). Dolerite pebbles in Permian brockram conglomerates at George Gill, near Appleby (Holmes & Harwood, 1928), supports a late Carboniferous radiometric age of 295 Ma (Fitch & Miller, 1967) for the date of intrusion of the Whin Sill.

Ascending the gully above the Whin Sill, the party noted the extensive *Lithostrotion* coral colonies in the Scar Limestone and crossed the outcrop of the High Brig Hazle sandstone to emerge on the escarpment. An extensive area of disturbed ground was seen 300m to the northeast on the north side of Gregory's Sike at Ardale Head (669,357), remains of extensive opencast extraction of an iron ore deposit which occurred as a 'flat' replacing the Great Limestone at the base of the Namurian. A well-graded extractors' road contours southwards from the workings to join the Cross Fell path at 672,348. A 300m detour was made to the south to locate old (ca.1800) coal shafts and pits (669,345) in a seam below the Scar Limestone. A limekiln and an elongated quarry (662,346), 700 m to the west on the edge of Ardale, provided evidence of the nineteeneth century uses of the Lower Alston Group limestone resources. Other local limekilns lie on the western front of High Cap (661,340) and a rather magnificent double bay example at the foot of the Ladslack track in Ardale (646,344). The party continued down the Cross Fell path to Kirkland where the leader was warmly thanked for an enjoyable excursion.

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METAMORPHIC ROCKS OF THE SKIDDAW GRANITE AUREOLE

Leader : Mrs.A.C.Marchant

6 June 1990

14 members met at the Blencathra Centre, Threlkeld, where the leader summarised the geological evolution of the metamorphic rocks in the Skiddaw area. The Skiddaw granite was emplaced into the Skiddaw Slates close to the Skiddaw Group/Eycott Group boundary. The granite is exposed only in three small outcrops, in the vicinity of the junction between Grainsgill Beck and the River Caldew in Mosedale , a larger one 1 km. to the south-west along the River Caldew valley and in Sinen Gill above the River Glenderaterra.

The Skiddaw Slates consist of a succession of turbidite mudstones, greywackes and sandstones which have undergone mild regional metamorphism to greenschist grade. The intrusion post-dates folding and cleavage in the Skiddaw Slates. The width of the metamorphic aureole resulting from the intrusion of the granite is some 800 m. with characteristic zoning while the extent of the aureole suggests that it underlies an area of 25-30 km^2 at depths of less than 1 km. Recent geophysical work (Lee,1984) indicated that the granite is a relatively flat-topped, steep-sided intrusion elongated in a NE-SW direction. Much information on the petrology and mineralogy of the granite emerged from investigations forming part of an appraisal of geothermal potential of selected Caledonide granites (Webb & Brown, 1984). The present excursion followed the route of a previous Society excursion (Shipp, 1977, vol.3.4), examining metamorphic minerals in the Skiddaw granite aureole. After lunch the party investigated the evidence of mineralisation in the old mine workings in the Glenderaterra valley.

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BORROWDALE VOLCANIC ROCKS OF THE SEATHWAITE AREA.

Leader : Dr.R.A.Smith

23 June 1990 - Joint Meeting with Westmorland Geological Society.

The party of 25 members and friends from both Societies met at Seathwaite Farm, Borrowdale. Most of the day was spent examining rocks of the Borrowdale Volcanic Group (B.V.G.) exposed along the footpath ascending the course of Sourmilk Gill and up the flanks of Base Brown.

Dr. Smith described how the B.V.G. rocks could be divided into lower and upper sub-groups, reflecting different types of volcanic processes. The lower group was dominated by basic and intermediate effusive activity which produced chiefly andesite lavas and sills. In contrast, the upper group was an explosive episode with the dominant products being pyroclastic fall, flow and surge deposits. A review article in a previous Proceedings (Petterson, M.G. 1989, vol. 5.2) described these volcanic processes.

The Seathwaite succession is summarised below :

Simplified Stratigraphy

UPPER B.V.G.	Seathwaite Fells Formation	
	Airy's Bridge Formation	Crinkle Tuffs
		Long Top Tuffs
	Whorneyside Tuff Formation	Whorneyside Bedded Tuffs
		Whorneyside Lapilli Tuffs
LOWER B.V.G.	Birker Fell Andesites	

The first stop at the foot of Capell Gill (241,123) east of the farmhouse, where examples of the Whorneyside lapilli tuffs were seen.

Rills and gullies in the ashfall deposits must have been formed during eruptions since they were draped by succeeding tuff layers. Impacted blocks in the deposits showed their relative proximity to the vent.

The fellside along Sourmilk Gill is composed of the Whorneyside Bedded Tuffs. A short distance above the valley floor (232,122) they consisted of pyroclastic deposits containing large angular clasts up to 2m. set in a matrix of finer material. These rocks represented debris flows (lahars) sliding down the slopes of the volcanic pile, carrying large blocks. Many examples of soft sediment deformation structures were noted, such as local highly contorted pockets of sediment overlaid by further debris flows, minor faulting and accumulations of rip-up clasts. Bedding planes with both well formed ripple markings & polygonal patterns were seen in the waterfall section. Alternative theories of dessication cracks or earthquake-generated fissuring were advanced in explanation. Rocks of the Whorneyside Tuff Formation extended to the break in slope (approx. 227,121) above the wall crossing the path where the base of the Airy's Bridge Formation was seen. Rocks of Long Top Tuffs consisted of surge deposits which had rapidly spread lapilli material outwards in an "ash hurricane". These deposits consisted of very coarse bedded tuffs up to some 40m. in thickness. The upper member of the Formation, Crinkle Tuffs, was seen near the Hanging Stone (228,119) and marked the highest point reached on the excursion. These rocks consisted of light coloured, fine grained, eutaxitic ignimbrite flows with strong columnar jointing.

During the descent Dr. Smith pointed out the geomorphological characteristics of Gillacombe, describing the analysis by Sissons. The combe showed few of the characteristics listed by Clough as typical of corries, being both elongate and without an existing tarn although there had undoubtedly been standing water in the past.

The final exposures north of Sourmilk Gill (228,124) consisted of andesite sheets with strong joint patterns, representing the Birker Fell andesites of the Lower B.V.G. The highly brecciated nature of the upper parts of these bodies led to speculation whether they were lava flows or early sills intruded into soft sediments. Dr.Smith was thanked for an intriguing field day by both Societies.

COAL MEASURES OF WEST CUMBRIA

Leaders : Mr.D.Dickins, Dr.P.Guion & Mr.N.Jones

7 July 1990

20 members and friends met at the British Coal offices on Keekle Extension Opencast Site (NX 998,179), 4 km east of Whitehaven. Dr.Guion first outlined the geology of the Westphalian of West Cumbria. He explained that the lowest part of the Westphalian A contained several marine bands and was deposited in an environment analogous to a lower delta plain. In contrast the higher parts of Westphalian A and the Westphalian B successions, which contained most of the workable coal seams, were deposited in an upper delta plain environment with negligible marine influence. Mr.Jones then described the geological setting and stratigraphy of the West Cumberland coalfield, indicating that the upper part of the Westphalian sequence consisted of reddened strata (in the past this formation was known as the "Whitehaven Sandstone Series").

Mr.Dickins described the geology of the Keekle Extension Opencast Site, which was dominated by intense normal faulting of NNW-SSE trend with subordinate faults of an ENE-WSW trend. It has been suggested that the trends were concurrent but no confirmatory evidence has yet been found. Fault striation shows principally vertical movement but with occasional oblique striation; it is believed that there was a lateral component to the initial faulting which was generally obliterated by later movement. The strata of each fault block showed differing dips, with the central part of the site being occupied by an elongate dome plunging to the SSE. This dome exposes the lower part of the Lower Coal Measures (Westphalian A), consisting of sandstone units interspersed with mudstone/siltstone units and accompanied by thin coal seams and their associated seatearths. The intensity of faulting, together with old workings, created problems in both coal exploration and exploitation and it was necessary to divert the River Keekle to work the site, thereby exposing Permian and Westphalian strata.

The workings were first viewed from the periphery where steep dips on the southern and western sides of the dome and faulting in the Westphalian measures could be seen. Seven out of eight major faults exposed on the site have easterly downthrows. The Stephen Riddings Fault, seen on descending into the working coal area, bounded the western side of the cut and had a downthrow of 50 metres to the east. 200metres further to the east was the Keekle Bank Fault,with 30metres downthrow terminated the eastern side of the then current coal area.

The succession from the Sixquarter seam (the lowest being extracted on the site) to the Rattler/Bannock was observed dipping to the south-west, with the Rattler/Bannock and the Main Band cropping beneath a mantle of boulder clay. The contact between the Coal Measures and the overlying Permian Basal Breccia was examined (300,950 to 517,330); little angular discordance was present although the top of the Coal Measures had an undulating surface. The final locality visited was the river diversion where a faulted relationship between Coal Measures sandstones and the overlying Basal Breccia was inspected. This sandstone sequence consisted of 100 m reddened sandstone with thin siltstone and mudstone members interspersed with seatearths towards the base; no coal seams were present, probably having been oxidised in a post-depositional phase of weathering. These strata, at least in part, are probably of Westphalian D age.

Lunch was followed by a traverse of Westphalian C sandstones ("Whitehaven Sandstone Series") between Bransty and Parton. The first location in the Bransty cliff section (975,188) consisted of a sequence of fine- to medium-grained red sandstones with prominent cross-bedding and ripple cross-lamination, produced by the migration of sub-aqueous dunes and ripples. A 3 m thick set of tabular cross-bedding was seen half way up the cliff, with foresets representing successive avalanche faces of a fairly straight-crested barform migrating towards the southeast. These cross-bedded sandstones are interpreted as deposits of a large channel system. The same sandstone is exposed some 100 m. north in a 20 m high quarry (975,190). Here the sandbody can be divided into three units separated by erosion surfaces with associated lag conglomerates, containing intraformational claystone and siltstone clasts. The two localities show a variety of sedimentary structures which were deposited in an ancient channel system. This sandstone forms a virtually continuous exposure extending further north for 0.5 km in which units can be seen that are stacked laterally (multi-lateral bodies) as well as vertically (multi-storey bodies) and with other examples of low-angle barforms. These faces are dangerous and should be viewed from a distance.

The cliffs from Redness Point to Parton (977,199) are formed by the Countess Sandstone, of probable Westphalian C age which, according to Eastwood *et al,* (1931), is situated approximately 90 m above the Bannock Band coal. At the foot of the cliffs adjacent to the ruins of the old brickworks the sandbody is underlain by 4m of dark grey, structureless micaceous siltstone containing occasional thin sandstone streaks and ironstone nodules. It has yielded abundant, well-preserved plant material including *Calamites*, *Neuropteris*, *Asterophyllites* and *Annularia*. The presence of structureless siltstone and abundant plant material suggests that these deposits represent rapidly deposited, sediment-laden overbank flows, commonly occurring during high stage and blanketing the plants growing on the channel margins.

The Countess Sandstone is at least 8 m thick, yellow-brown in colour and is dominantly fine- to medium-grained. The base is erosional with a relief of about 1m. and with flute-like scours in the base. Above this base is a well-developed lag conglomerate of siderite and coaly masses while low angle trough cross-bedding and ripple cross-lamination form the principal sedimentary structures within the sandbody. The Countess Sandstone here is interpreted as the deposit of a large river channel which flowed towards the south-west. The coaly clasts at the base suggest that a coal seam, in the form of peat, was cut through forming a washout. The meeting closed with thanks to the leaders for an interesting excursion.

ROCKS OF THE ARMATHWAITE DISTRICT

Leader : Mr. E. Skipsey

14 July 1990 - Joint meeting with O.U.G.S.

20 members & friends of the two Societies met in the Fox and Pheasant Hotel car park, close to Armathwaite bridge (NY 356,461). Three separate localities were visited during the day, all described in the Penrith Memoir (1981). The waterfall formed by the Armathwaite dyke crossing the River Eden provided the first exposure, reached by the footpath signposted 'Longdales' past the hotel. The path branched right after about 1 km, at a stile on the boundary of the Forestry Commission estate, and descended to the river; the waterfall (503,453) was reached some 100 m to the north.

The Armathwaite dyke at this point is approximately 25 m wide and is intruded into the Penrith Sandstone. The dyke is believed to continue into Durham and North Yorkshire, where it is known as the Cleveland dyke. It is one of several tholeiitic dykes in Northern England related to the "Mull" swarm of the Hebridean Volcanic Province. Whole rock K/Ar age dating suggests an age of 60 ma. The dyke rock is a hard, dark bluish-grey basalt, finely crystalline apart from small phenocrysts of clear feldspars. Numerous small streaked amygdales, filled by a dark chloritic mineral show evidence of flow. Members examined the junctions with the host rock but found that the alteration effects were confined to the dyke margins with some bleaching of the sandstone, although weathering obscured much of the evidence.

A cliff section (505,452) in the Penrith Sandstone known as Coombe Crags, some 400 m upstream from the waterfall, was the second stop. The accessible length of the cliffs extended for some 250 m in a northwest-southeast direction with a short bluff, adjacent to the steps down to the riverside, roughly at right-angles to the main section. A river-cut platform lies alongside the footpath at the foot of the cliffs. The principal features of the sections are the vertical sequences of planar or wedge cross-bedded units. At least seven units can be recognised in the sequence, with some attaining thicknesses up to 2-3 m and extending along much of the section. Each cross-bedded unit is separated from an overlying set by a major discontinuity or bounding surface. These bounding surfaces formed planes of erosion which had removed the upper part of a lower dune before a later one advanced across the surface. Minor bounding surfaces within the cross-bedded units represent re-activation surfaces. The section was interpreted as a series of desert sand dunes migrating before south-easterly trade winds, with later dunes truncating and climbing over the remnants of earlier ones. Cockersole has described in some detail the geometry of similar dunes in the Penrith area (Cockersole, 1990, vol. 5.3).

After lunch the party travelled five kilometres downstream to Low House Woods (516,491), on the west bank of the River Eden. Here along a riverside path leading to Wetheral, a fluviatile facies of the Penrith Sandstone Formation was examined in the river bank. The Formation is much thinner in this northern part of the Eden basin, amounting to some 50 m and consists of this fluviatile facies. The section contains cross-bedded dune sands intercalated with water-laid strata, including flat-bedded and fine grained red sandstones, purple-red siltstone and mudstone, together with beds of coarse breccio-conglomerate containing angular fragments of Carboniferous limestone and sandstone. The lenticular beds of conglomerates often represent the in-fillings of old channels cut into the underlying sandstone. The mudstones are mostly laminated with many sedimentary features including load-casts, mud rip-up conglomerates and sand-filled dessication cracks.

This fluviatile facies is very similar to the well-known brockrams of the Kirkby Stephen and Appleby districts. Like them, the beds represent outwash fan deposits spread upon the desert floor by flash floods bringing debris from nearby high land.

The meeting then closed with the leader being thanked for introducing Society members to a district not previously visited by either Society.

THE GEOLOGY OF KELTONFELL TOP, KIRKLAND

Leader : Mr.M.B.Dodd

18 July 1990

16 members and friends met near the old iron ore mine (NY 087,183) where the Keltonfell Top siding had an unusual junction on the (demolished) bridge with the main line of the Rowrah and Keltonfell (R. & K.F.) mineral line (1877-1914).

Keltonfell was the largest iron ore mine in the Skiddaw Slates. Prospecting began in the 1850's but not until Bairds took over in 1868 and the R. & K.F. reached Kelton in 1877 were the thick veins, up to 5 m. and mainly ore, developed profitably. Working was by shaft, following the proving of a vein by adit, with stoping up to remove the ore. This practice was responsible for the extensive surface subsidence visible along H and J veins in particular. The main veins run north and northwest, usually fault-guided, and varying much in width, pinching out at depth. The deepest workings were about 180 m. below the surface, with drainage and subsidence being the main difficulties. Water was drained along the 25 and 50 fathom levels, this lower level about 140 m from the Croasdale-Ennerdale Bridge road still discharging large volumes to this day. The ore quality was good with 50-55% iron content but mining ceased in 1913 when the shallow ores were exhausted.

The Whitehaven Memoir (Eastwood *et al,* 1931) distinguished the Blakefell mudstones on Knock from the Loweswater flags near the Felldyke road - today all would probably be the Loweswater Flags. It suggested an overturned anticline and recognised the thermal metamorphism of the slates, which Cooper (1988) attributed to a deeply buried, elongate body stretching from near Egremont to Causey Pike. The bleaching and baking of the slates with the reported "spotting" with white micas and chlorite and the presence of tourmaline on Knock are all due to this thermal event.

The Skiddaw Slates at the first locality (087, 182) consisted of parallel laminated fine sandstones and siltstones (Bouma C & D units) with flute and sole structures, and near vertical dip and variable strike. The party followed the R & KF to inspect a large, steep-sided dry valley which Huddart (1967) identified as a sub-glacial channel. Its course bears little relation to underlying relief, with two almost right-angle bends before emerging from a small gorge at Ghyll Farm.

The Kelton ore was examined at the foot of the large tip from Pits Nos. 2 and 3 where it was seen to be less "attractive" than the limestone ore, consisting of heavy, greasy "blue" material, sometimes slickensided. An earthy incoherent ore was noticeable while kidney and specular ores were less obvious.

The walk to the third locality (080,187), where the vein is exposed, follows the line of collapse on C vein, which hades NE between 60° and 75° with a strike of 340° (uncorrected). The strike in the Skiddaw Slates is about 60° some 2 - 3 m from the vein but swings to 40° by the veinwall, suggesting fault movement to the NW. Colour banding in the parallel laminated pale siltstones and darker fine sandstone shows up very clearly. Locality 4 (077,187) may be the position of an old shaft or a level from which tipping occurred.

Locality 5 (078,190) is a curious horse-shoe shaped feature about 20-25 m across. The strike is 20°-40° with obvious cleavage in the less competent beds, with possible small faults disrupting the strike, and there is a small slump? fold. Huddart identified this as "two other glacial channels" draining west, an explanation we found difficult to accept. The excursion ended with thanks expressed to the leader.

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HONISTER CRAG and YEW CRAG SLATE QUARRIES

Leader : Mr.A.D.Cameron

16 September 1990 & 21 April 1991 - Joint meetings with Cumbria Amenity Trust

Members of the Society and the Cumbria Amenity Trust, a mining historical society, held two excursions to the slate quarries near Honister Pass. The first assembled at Honister Hause where a brief introduction was given on the history of the site. Slate extraction is thought to have started in the 1400's at points where the slate outcropped at the top of Honister Crag, a prominent feature on the road from Gatesgarth in Buttermere to Borrowdale. The site was well established at the time of the earliest written records with extensive surface and underground workings. Most of the underground workings were reached by tunnels driven in from the face of the crag, making both access and product removal difficult. Before the late 1800's the slate was transported by hand-sledging it down the gullies and screes to the road-side. In the late 1800's an inclined tramway was constructed diagonally up the crag face, linking the entrances to the underground workings. This construction involved major feats of engineering and the remains form one of the finest industrial monuments in Cumbria. By 1920 two underground inclines had been constructed to carry large slate blocks to the cutting sheds at the Hause, one serving the Honister slate band and the other the higher Kimberley band.

The party entered the underground workings at the Road End entrance on the edge of the crag and negotiated the Kimberley Bottom Level to the foot of the internal incline on the Kimberley slate band. The method of operating the incline was explained, after which the party moved back into daylight and on to the Honister Bottom Level. Some distance along this level is the foot of the Honister Internal Incline which the party climbed, passing on the way a number of tunnels that penetrate deep into the mountain. The tunnel running from the incline head is blocked by a massive rock fall but access was gained via a lower tunnel.

At this point the party was approximately half way up the crag; beyond this point the higher workings were much older and had been abandoned for over one hundred years. Much of this area has only been explored recently and the party were taken up through these extensive ancient workings, eventually returning into daylight on the crag face. The final stage of the trip was an ascent of the upper half of the external incline to the top of the crag where a number of open quarry workings were inspected.

On the second visit, the party met at the top of Honister Pass and walked along the quarry road to the disused Yew Crag workings, on the south-west slopes of Dale Head. The leader explained that the quarry was worked on eight main levels. The slate was carried down the fellside by an inclined tramway. The remains of the winding drum and brake dating from 1892 were seen. This system was later replaced by aerial haulage and occasional rusting pylons remained.

Tom Shipp described the environmental conditions of the deposition of the Borrowdale Volcanic Group and the subsequent metamorphism which led to the development of slaty cleavage in the tuffs. A variety of sedimentary structures was observed in the slates, notably cross-bedding. Small masses of vesicular and amygdaloidal lava were seen enclosed by the tuffs. Near the top of the quarry a strongly cleaved fine-grained tuff was overlain by another bed, either a lava flow or a coarse tuff. These upper bed showed little sign of cleavage and the cleavage was refracted at the junction between the two beds.

The party entered the quarry at the eighth level and descended underground to the third level before ascending to the fifth level to leave the quarry. Large slickensided bedding planes often formed the roofs of the chambers with quartz and calcite on these surfaces and in large tension gashes. The leader and his assistants were thanked for their expert guidance through the labyrinth of the workings on the two visits.

GEOLOGY OF THE AREA SOUTH OF TORVER

Leader: David Kelly

19 May 1991

Fifteen members of the Society met at Torver. The aim of the excursion was to traverse Torver Low Common from NW to SE working down dip to younger beds, examining the rock units and the ways in which differential erosion of the units had produced the landscape. Well established rock units are applied to the Windermere area further north but different units were proposed by Rose and Dunham (1977) for the Low Furness area to the south and an unpublished PhD thesis by Norman (1961) proposed a new set of stratigraphic units for the area between Torver and Gawthwaite; this last is used in the account.

Cresswell (1962) noted four stages of deglaciation in the area:
1) ice covering the whole of Torver Common, which rises to 300m. and shows roche moutonees and ice-scoured hollows.
2) ice moving down the main Coniston valley with a top surface at about 150 m, dividing south of Coniston village with the major flow taking the Coniston valley route, its floor at13 m below sea level, and part taking the Torver valley route (with a floor at 90 m A.O.D.).
3) when the ice surface fell to about 75m. above present day sea level it was unable to enter the Torver route and only occupied the Coniston valley, depositing a terminal morraine at Nibthwaite.
4) the corrie glaciation of the Old Man/Wetherlam group.

The paths of the two glaciers may have been subject to geological controls. A major N-S trending fault is believed to run along along the Coniston valley while the Torver valley is parallel to the strike of the Silurian rocks, possibly partly following the outcrop of weaker beds.

The first location was a small roadside quarry at Whins (SD 270933), probably part of the Wray Castle Formation. Turbidite siltstones and fine sandstones are interbedded with mudstones, the latter with vertical cleavage. *Monograptus colonus* has been recorded from this location. There was much discussion about the origins of Torver valley and the major escarpment from Black Combe to Coniston, of which one side of the valley forms part. The valley floor is probably underlain by the Stennerley Mudstone, a member of the Wray Castle Formation, forming an area of relatively low relief. Alternatively the valley may be fault-guided, which is supported by the apparent discordance of the valley to the strike of rocks in the Cat Bank area. The rocks lying beneath the valley floor were examined in a small quarry near Hazel Hall (270928).

The party then climbed the slopes of Birk Haw (267922). The higher relief with much exposed rock corresponds to the base of the overlying coarser beds, the Poolscar Sandstone Member of the Gawthwaite Formation. On the north side of the valley at approximately 267918, excellent examples of turbidite structures were observed. Beds up to 4m. thick of green/grey greywacke sandstones have clasts up to 3mm. diameter while the finer units show cross laminations and cleavage.

The Mere Moss depression (267915) is underlaid by the Salthouse Mudstone of the Latrigg Formation, which may be part of the Coniston Grits. The mudstones are slighltly silty and unlaminated. A sill forms a minor ridge within the depression and trends NE-SW with the strike of the rocks. The sill is 5 to 10m. thick and slightly offset in places, either because it is transgressive or because of minor faults. The pink rock is medium to fine grained with feldspar phenocrysts while quartz and biotite are also visible in the hand specimen. Higher relief on the ridge SE of Mere Moss (268914) indicates the outcrop of the Yewbank Sandstone of the Latrigg and Yewbank Formations. The rock is similar to the Poolscar Sandstone but slightly finer grained.

A microgranite dyke 10 m wide intruding the Bannisdale Formation was examined in the quarry at Brown Howe (289909) beside the A5084. The dyke trending NE-SW can be traced on the opposite side of the road and on the fellside to the SW. Its composition appears to be similar to the Mere Moss sill while the country rock is typical of the Bannisdale Formation with an easterly dip rather than to the SE as noted elsewhere on the excursion. The Bannisdale Formation was seen again in a cutting on the west side of the road (287901) where an anticline plunges NE.

A final stop on the fellside above Lake Bank (287895) provided a view of the terminal morraine complex at the foot of Coniston Water. Gresswell (1962) identified five separate recessional morraines of which three could be seen, at High Peel Near, Park Nab and Water Yat (at the foot of the present day lake).

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GLACIATION OF LOW FURNESS

THE PROBLEMS OF THE 'IRISH SEA RE-ADVANCE'

Leader : Dr.R.Clark

8 June 1991 - Joint meeting with Farnham Geological Society

The party met at Bardsea coastal car park (SD 304,744), on the A5087 4 km south of Ulverston, where the two objectives of the excursion were described - the examination of landforms and sediments characteristic of the last general (Late Devensian) glaciation in south Cumbria and to see contrasting deposits and landforms east of Barrow-in-Furness, illustrated by Figure 1.

The sea cliff at Wadhead Hill, adjacent to the meeting place, showed two units of glacial drift. The lower unit is of bedded sands and gravels, with sand dominating in the southwest but coarsening to gravels in the northeast part of the unit; palaeocurrent indicators show sediment coming from northerly directions while the upper unit is a till accessible at each end of the exposure. Both units contain clasts of

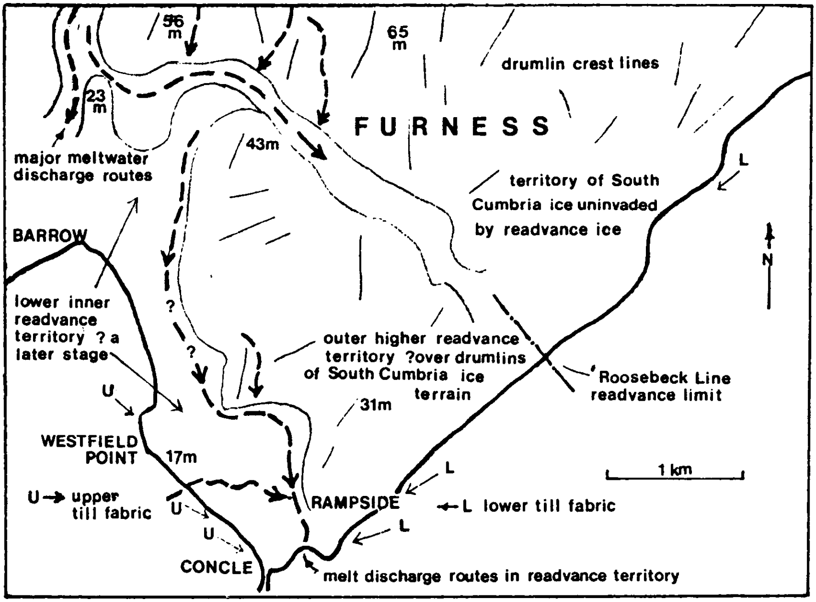

Fig.1 Sketch map showing glacial deposits and land forms in Low Furness (partly based upon Fig. 3, p. 128 in Huddart *et al,* 1977).

Borrowdale Volcanic Group rocks, Silurian grits and Carboniferous limestones. The sands and gravels may be a kame deposit or remnants of an esker complex laid down beneath relatively unerosive ice. Subsequently the ice moulded its basal sediments and debris-rich basal ice, forming the local swarm of drumlins of which Wadhead Hill is one. It has been assumed that ice flow lines from south Cumbria over Morecambe Bay were able to diverge somewhat, possibly as constraint of Irish Sea ice diminished, so that Low Furness drumlins are aligned between south and southwest.

Coastal erosion has revealed the interface between the Carboniferous Limestone (Asbian) strata and the glacial till at the second site, Sea Wood (297,737) 1 km further south along the A5087. Limestone was incorporated in the bed of the ice as angular clasts of large size range set in a grey silt, presumably formed by abrasion and crushing. Abrasion dominated on bedding planes separated by low scarps determined by joints. Trails of limestone clasts in the till show how fresh debris was carried up into the ice, possibly along shear planes. The upper weathered part of the till contains rounded, mainly small, clasts of grits and volcanic rocks.

The interior of a drumlin on a line slightly oblique to its long axis has been exposed by coastal erosion in the sea cliff at Moat Scar (275,696 - road parking at 271,694). This exposure is entirely of till apart from a small inclusion at the distal end of packed clasts with little matrix, perhaps a washed till or glacifluvial deposit; a high proportion of the clasts are of Carboniferous Limestone.

After lunch at Concle (234,660) Dr. Clark explained that the till seen at the first three sites, associated with south Cumbria ice, was largely concealed in the Barrow area by a thick sand unit with thin silt partings and rare gravel lenses. This in turn is covered by a persistent thin till unit. Clasts of west Cumbrian and Galloway granitic rocks as well as volcanic rocks and St.Bees Sandstone are found in both the till and gravels. That and till fabric directions imply ice movement from the nothwest. The sand and upper till occur west of a line from Roosebeck to the Duddon estuary, crossing the drumlin track at a high angle to the drumlin alignment and is interpreted as an eastern limit of ice readvance (Huddart *et al*, 1977).

'Readvance' sediments were examined in coastal exposures near Concle (232,661) and at Westfield Point (224,669). There is little disturbance at the almost horizontal interface of the level-bedded sands and till but locally there is some truncation of bedding in the sands and occurrence of shear structures. Near Concle there are masses of till at the same horizon with unexplained difference in matrix colours, dark grey (wet) and dark brown (wet) while the sand and till junctions are notably more irregular. A thin (ca 1 metre) sand unit lies on the upper till at Concle; it has not been established whether this is an outwash or blown sand.

Little is known of the 'readvance' deposits away from the coastal exposures and the significance of terrain differences in the 'readvance' territory is uninvestigated. This is an area that merits more study. The supposed readvance itself poses broader problems:

1. How far southwest beyond Furness had the south Cumbrian ice extended in its drumlin stage ?
2. Did the 'readvance' ice override the south Cumbrian ice or had the latter already melted ?
3. What circumstances enabled ice to move onto Low Furness after the south Cumbrian ice had thinned or melted altogether ?
4. How far did the 'readvance' ice extend south-east beyond Low Furness ?

Reference

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PERMIAN ROCKS OF THE NORTH SOLWAY BASIN

Leader : Dr.S.K.Monro

23 June 1991

20 members of the Society met at Locharbriggs Quarry (NX 994,810), 4 km north of Dumfries. The leader, Dr. Stuart Monro of B.G.S., Edinburgh, explained that he wanted the members to examine three quarries and by observation to build up a picture of the Permian environment some 280 million years ago in that area of Scotland.

There are extensive exposures of aeolian sandstones similar to the Penrith Sandstone in the Locharbriggs working quarries, providing clear evidence of the large scale cross-bedding and the preserved foresets characteristic of sand dunes. The units of foresets were separated by low angle bounding surfaces representing planes of erosion formed as the dunes migrated across the substrate under the influence of predominantly easterly winds. The closely sized and rounded sand grains and the absence of any trace of organic remains testified to the arid nature of the climate. Some very small scale cross-bedding features measured in centimetres as opposed to the large dune cross-bedding measured in tens or hundreds of metres suggested that the former could be the result of local swirling gusts and eddies within the overall easterly palaeowind.

The second visit was to Castledykes Park (976,746), by the River Nith just south of Dumfries. The park had been constructed in old Permian sandstone quarries and included a sunken garden developed on the floor of a rectangular quarry. The north face of this quarry exposed dune-bedded sandstone sharply cut by a channel, some 25 metres wide and filled with poorly stratified, ungraded and sub-angular breccias. This was interpreted as a high energy fluviatile episode, perhaps a mud flow. On the opposite wall of the quarry was a feature that looked like a metre-wide 'dyke' of the same brecciated material. After discussion it was finally considered that the 'dyke' was merely the irregular edge of the channel fill, exposed in working the quarry.

The final stop was at Kelhead working quarry (146,691), between Dumfries and Annan, although it was not possible to enter the quarry late in the day. It was evident from loose blocks at the quarry entrance that very well cemented brecciated material, composed of limestone clasts, was being extracted over a significant area in the quarry despite nearby exposures of bedded Carboniferous Limestones.

Summarising the excursion, the leader built up a picture of a sand-filled basin with dune formations in an arid climate while the surrounding elevated topography nearby provided material washed down as mudflows and breccia spreads by infrequent flash floods. Dr. Monro was thanked for providing an fascinating and unusual excursion.

THE CLEATOR MOOR COAL AND HEMATITE MINES

Leader : Mr. M. Dodd

<u>17 July 1991</u>

The party met in Moor Row village to examine some of the surface remains of the Cleator Moor coal and hematite mines. The leader explained that the area is covered by drift which thickens northwards from Cleator Moor Square where the Hensingham Grit is close to the surface. The hematite-bearing Carboniferous Limestone is overlain by the Coal Measures and the Hensingham Grits in a succession which dips gently westwards. The beds with which the hematite deposits are associated in a variety of irregular masses are displaced by two complex series of post-Carboniferous/pre-Brockram faults and post-Triassic faults.

The party left the village along the the line of the dismantled Cleator Moor South railway. Close to the outskirts of the village the old Crossfield pit remains stretch away to the south-west, with the sites of the old shafts seen in the scrub around the old branch rail lines. Most of these pits were shallow and not very productive. South of the rail line the River Keekle lies in a straight concrete channel, known as the "Black Ship", built to prevent the river flooding the Montreal and Crossfield workings below. The mound of the Montreal No.10 pit is visible across the river on the outskirts of Moor Row.

Further along the old line where a bridge crosses a footpath are the remains of the Montreal No.6 pit tips. The deeply subsided land to the north marks the location of the highly productive Montreal No.1 pit. A further 200-300m. along the track is the site of a massive collapse which in 1871 produced a hole 50 m wide and 30 m deep, leading to the development of an alternative railway line - the Cleator Moor North line. The lanscaped area below Cleator Moor Square was originally the site of one of the Crossfield pits and is a memorial to the local people who died on the Alexander Keeland accommodation platform. The wooded area of subsidence just before the main road in Cleator Moor hides the remains of seven pits of the Crowgarth (Leconfield) royalty north of the railway. The earliest mine, Crowgarth, was sunk in 1789 close to what was to become the site of the Cleator Moor goods station. Between the railway bridge and Cleator Moor Square is the site of the Montreal School, demolished after subsidence damage.

The party then headed along the Whitehaven road, passing the site of a blast furnaces behind Furnace Court and then returned to Moor Row along the route of the Cleator Moor North railway. To the north were nineteenth century coal pits, with the small tips of Bowthorn colliery on the right. By the scrapyard are the remains of the famous Montreal No.4 pit. Here the Cleator Moor Coal fault throws the Carboniferous Limestone against the Coal Measures, allowing coal to be mined to the north of the shaft and iron ore to the south. Near Moor Row Junction, just before the viaduct over the River Keekle, are the remains of the Montreal No.12 pit to the south of the track. This was the deepest shaft in the area (at -100m. below O.D.) and was the pumping point for the Montreal mine drainage.

SKIDDAW GROUP OF WATCH HILL AND SALE FELL

Leader : Dr. R. Hughes

<u>11 August 1991 - Joint meeting with Westmorland Geological Society</u>

The party met at the Pheasant Inn, Bassenthwaite, where the leader explained that the objectives of the excursion were to examine the facies, lithologies and structural relationships in part of the Skiddaw Group and to study the contact relationships of an igneous body. The Skiddaw Group is thought to be about 5km. thick and is essentially a turbidite sequence. There are two mappable coarser formations, the Watch Hill Formation and the Loweswater Formation. These two were confused in the past but are now recognised as having biostratigraphic and lithological differences.

A small quarry on Elva Hill (NY 1724, 3202) in the type area of the Watch Hill Formation was the first location visited. The formation is made up of typical Bouma A, B and C sequences (Figure 1), suggesting that these are upper fan turbidites (in contrast, the Watch Hill Formation in the Great Cockup area contains a coarse conglomerate interpreted as a channel fill deposit). At the base of the coarser greywacke units sole markings are seen, which tend to be somewhat irregular in shape and it is not easy to deduce palaeocurrent directions from them; NW-SE or SE-NW directions were tentatively suggested. The boundaries between the A and B units are generally gradational and excellent examples of graded bedding can be observed. At the top of the B units there are often abrupt boundaries with finer units.

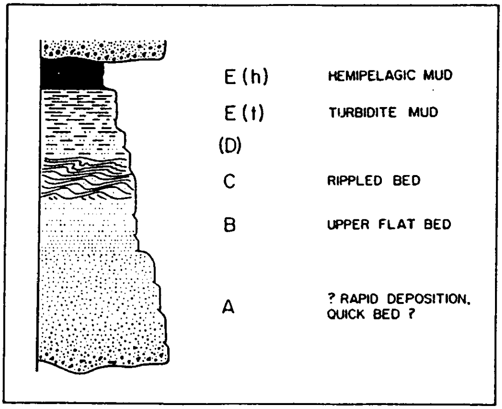

Fig. 1 Classical Bouma turbidite sequence

Another quarry just below the summit of Watch Hill (1500,3157) revealed a fine-grained, even-textured felsite, the Watch Hill Felsite. The felsite is about 12m. thick and shows columnar jointing. The basal contact is not exposed but the Watch Hill Formation is seen a few metres down the slope. Above the felsite occurs 30-40cm. of breccia, overlain by the Watch Hill Formation. Jackson (1961) interpreted the breccia as the rubbly top of a lava flow, with younger sediments filling the surface irregularities. This would indicate vulcanism in the area early in the Arenig, contemporaneous with vulcanism in North Wales. However, Dr.Hughes had interpreted the felsite as a sill, the brecciated contact with the overlying rocks being produced by the effects of the heat from the intrusion on ground water. Steam would have formed at the magma/sediment contact and the resultant explosive expansion would have disaggregated the sediments. The presence of siltstone lithoclasts in the breccia implies that the sediment was at least partly lithified when the intrusion occurred. No baked margins are visible. This interpretation has significance for the onset of vulcanism in the

Lake District; if the felsite was a sill then it may be contemporaneous with the Borrowdale Volcanic group, indicating that Lake District vulcanism did not begin until the Llandeilo-Caradoc stages.

The view from Watch Hill to the south and east illustrates the regional structure with the Kirkstile Formation outcropping on the hills partly occupied by Cockermouth Golf Course, immediately north of the A66 road. Graptolites from the *Didymograptus hirundo* zone have been found north of Embleton. The Watch Hill Formation lies in the *Tetragraptus approximatus* zone and, as both formations dip to the north, appears to overlie younger Kirkstile Formation. This anomaly can be explained by the existance of an east-west trending thrust, the Watch Hill Thrust, on the south side of Watch Hill. Similar thrusts of southerly translation occur in the Skiddaw Group in the Grassmoor area.

Later a 200 m forestry track section was examined on the slopes of Sale Fell (190,302) where the folded sediments of the Loweswater Formation show facies differences from the Watch Hill Formation. Typical Bouma B, C and D units are present, probably indicating a mid-fan turbidite environment. Coarser graded sands with sole structures are absent. Evidence of younging is provided by truncated cross-laminations in some of the C units. The same track also shows spectacular fold features with a major upright anticline trending ENE-WSW across the section, interpreted by the leader as a tectonic feature rather than a slump fold. Observation of the core of the fold shows the angle betwen the limbs is very tight. Two cleavages can be identified with the stronger feature being the near vertical, axial planar slaty cleavage. A weaker crenulation cleavage shows the same dip in both limbs indicating that this post-dates the axial planar cleavage.

The leader was thanked for his stimulating explanations to interesting locations.

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GEOLOGY OF THE LOWTHER VALLEY, SOUTH OF PENRITH

Leader: T. Shipp

8 September 1991

Sixteen members and guests met at Lowther Church gate where the leader said that the excursion would demonstrate the relationships of landforms and rocks around the Lowther Valley.

The River Lowther at Askham Bridge (519,243) has cut a gorge through the strata, which dip NE at about 10^{0}. An recent landslip had occurred, caused by water lubrication of purple shale beds sandwiched between brown medium-grained and cross-bedded sandstones. An impure limestone formed the top member of the sequence and this cyclic succession suggests a Yoredale type facies, tentatively dated as the Brigantian stage.

The party crossed open moorland north of the Helton Fell Road (497,214) to a limestone exposure with a disused limekiln and a group of shallow openpit diggings. This limestone was judged to be contiguous with exposures to be seen about 1km. to the north on Heughscar Hill, stratigraphically below the Askham Bridge succession. Good specimers of Lower Carboniferous fossils were found in scree heaps, probably from the Ashfell Limestone (Holkerian stage). A short traverse west demonstrated a clear relationship between vegetation and the underlying rock types; greensward on limestone and heather/bracken/bent on sandstone. Excavations presumably for dry stone walls were seen in the sandstone which was thought to be the Ashfell Sandstone. Swallow holes in a lower limestone horizon were seen near a prehistoric burial cairn alongside the Helton-Pooley Bridge bridlepath. Time did not permit investigation further west to find the base of the Carboniferous succession but the leader explained that the nearby Tarn Moor Tunnel (Manchester Waterworks) had been driven in rocks of Skiddaw and Borrowdale Volcanic Groups. Skiddaw mudstones here contained *Didymograptus murchisoni*; the youngest rocks of the Skiddaw Group so far found in the Lake District.

A series of small outcrops, near a walled enclosure on an otherwise open moorland at Lanty Crag (501,202) proved to be of coarse agglomerates and volcaniclastic sandstones dipping at steep angles. These were assigned to the Borrowdale Volcanic Group.

Several metres of cobble conglomerate were seen at Heltondale Beck/Setterah Syke (507,206). These were described by Capewell (1955) as of fluviatile origin, composed of rounded phenoclasts (90% Borrowdale Volcanic Group materials). This rock bears comparison with the Devonian Mell Fell Conglomerate found near Pooley Bridge and could therefore be at or below the base of the local Carboniferous succession.

Although on the itinerary, the locality at Bampton Howes/Mill Crag (510,182) was not visited due to lack of time. Volcanic agglomerate overlain by cleaved andesitic tuffs occur here. A partially quarried roche moutonnee of well-jointed basaltic andesite was seen at Frith Wood (515,158) on the journey along the waterworks road, within the hard, glacially-eroded Borrowdale Volcanics of the Haweswater-Naddle area.

No fossils were found in the steeply dipping cleaved mudstones exposed in Tailbert Gill (534,152), but a number of interesting ovoid concretions with cone-in-cone structures were seen. This locality marks the site of the Tailbert-Lanshaw Tunnel, just over 1km. in length, which was driven in Skiddaw Group mudstones containing *Didymograptus bifidus* of Lower Ordovician (Llanvirn) age. This occurrence of the Skiddaw Group rocks is known as the Bampton Inlier. The small Thornship Gill (553,135) was followed for 0.5km. SW to a number of exposures of blue-black cleaved mudstone with a reported *Didymograptus bifidus* fauna, but no fossils were found on this occasion.

Close to the bridge over the River Lowther at Keld Gill (551,142), steeply dipping exposures of sandstones with silt bands were seen - they were believed to form part of the Skiddaw Group. East of the river a small escarpment, a marked change in topography and better quality farmland enclosed by limestone walls marks the beginning of the overlying Lower Carboniferous. The east bank of the River Lowther at

Shap Abbey Bridge (548,153) is formed of angular conglomerate with gentle easterly dip resting unconformably upon an irregular eroded surface of steeply dipping purplish weathered slate. The overlying green pebble conglomerate, containing pink, angular feldspar clasts, grades up into coarsely bedded gritty marl and then into dolomitic limestone of Chadian/Courceyan Stages, reminiscent of the basal Carboniferous at Shap Wells. Time did not allow an ascent to the Upper Asbian Knipe Scar Limestone but the road at Knipe Moor (521,191) provided a good viewpoint, allowing the leader to relate landscape features to the underlying geology.

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CAPEWELL, J.G., 1955. The post-Silurian, pre-marine Carboniferous sedimentary rocks of the eastern side of the Lake District. Q.J.G.S., 111, 23-46.

Other Excursions

The following excursions were also held during 1990 and 1991.

9 May 1990: Glacial features in Rosthwaite
leader : Dr.J.F.Cockersole.

19 May 1990: Eskdale Granite - greisen & mineralisation
leader : B.Young (Joint meeting with Russell Society).

23 May 1990: Building stones of Whitehaven.
leader : Mrs.M.Fox.

8 May 1991: Caldbeck Mining Museum and the Howk.
leader : I.Gray.

15 May 1991: Submarine forest at Allonby.
leader : Dr.F.J.Cockersole.

26 May 1991: Borrowdale Volcanics & glacial features around Rosthwaite.
leaders : W.K.Bond & M.B.Dodd (joint meeting with West Sussex Geological Society).

7 July 1991: Old quarries around Caldbeck.
leaders : F.Lawton & M.Sanderson.

A GEOLOGIST AT LARGE IN THE FALKLAND ISLANDS

Presidential Lecture given by T. Shipp on 14 March 1990
at West Cumbria College, Whitehaven.

Introduction

The Falklands, remote and windswept islands scattered in a compact archipelago 650 kilometres east of the tip of S. America, were largely unknown before the 1982 British/Argentine conflict pitched them into the glare of world publicity. The Falkland Islands consist of two large and several hundred small islands located in the South Atlantic Ocean, between latitudes 51°S & 52.5°S and longitudes 57.5°W & 61.5°W. Their total land area in excess of 11,000 square kilometres is about the same size as Wales, although the settled population is under 2000. The complexity of the Falklands coast-lines ensure that nowhere in the Islands is more than about 20 km from the sea.

The richness of Falkland wildlife with its myriads of birds and seals surprises many. The intriguing landscape contains unexplained geological enigmas such as the mysterious "stone runs", silent streams of grey, lichen-coated angular boulders covering the sides of many valleys in the islands. Charles Darwin was the first to remark upon these impressive streams of boulders when he visited the Falklands in the nineteenth century but nobody has yet been able to produce a convincing reason for their presence. Despite the relatively short 200 year period of human occupation, much of the natural vegetation of the islands has been modified due to man's activities. This is because the economy of the islands has been based on wool and the intensive grazing of large flocks of sheep have had a profound impact.

The hinterlands of the islands contain craggy hills, peat bogs, lakes and rivers, and wildlife may be threatened by disturbance due to the increasing numbers of tourists.

The Expedition

With these social and environmental pressures in mind, the Brathay Exploration Group initiated in 1987 an attempt to mount an ecological expedition to the Falklands. When this project failed to materialise, Dick Clark, who had previously worked in the Falklands in the 1960s, decided to get together a small group of people interested in studying aspects of the ecology and geomorphology of the islands. We set to work to raise funds and support from local and national businesses, and from trust funds. Six of us flew out in November 1989 on the 18-hour flight by the R.A.F. from Brize Norton in Oxfordshire, via Ascension Island, to the new airport at Mount Pleasant. Figure 1 provides a map of the islands showing the localities described in the text.

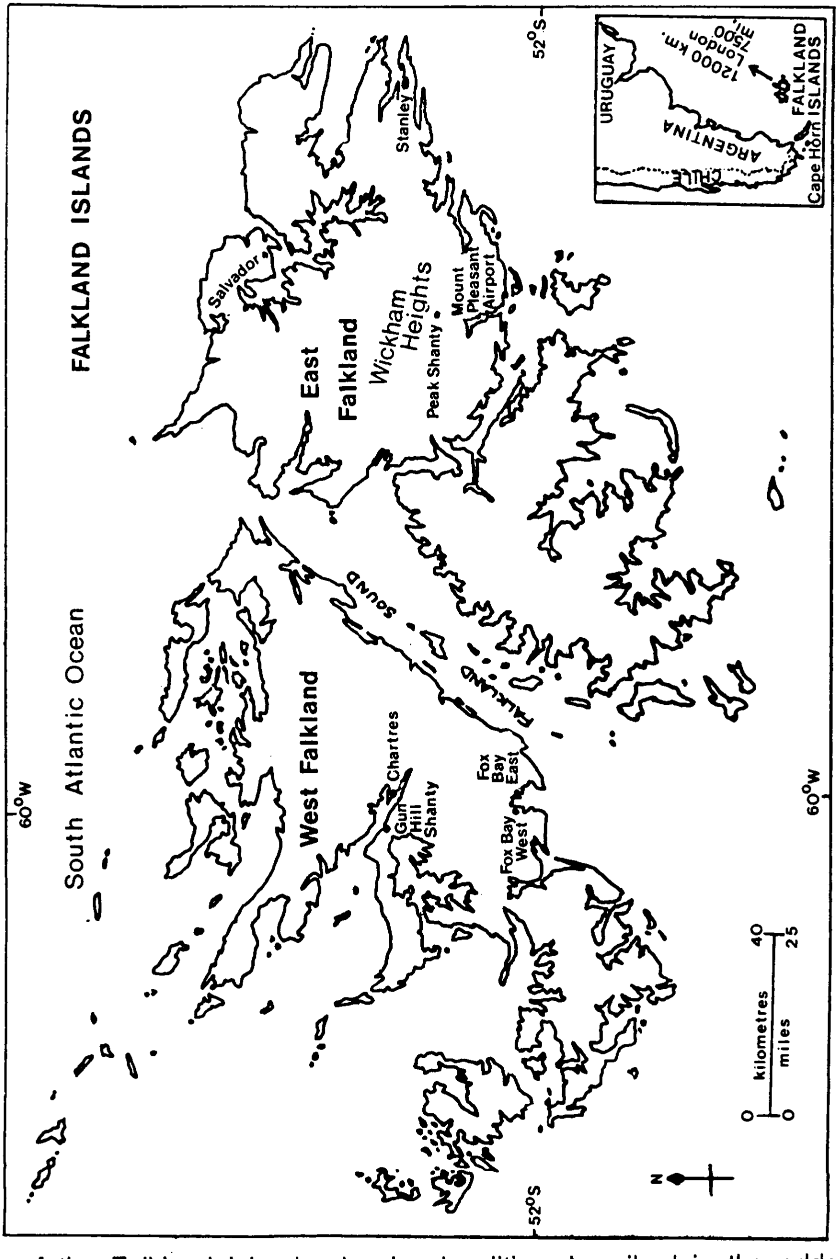
The Geological Work

The geological work was undertaken between 15 November and 15 December 1989 and four areas were investigated, two in East Falkland and two in West Falkland. The 1:50 000 Falkland Islands Series H791 topographic maps were used, published by the Directorate of Overseas Services in 1962, whilst information on minefields was supplied by the Directorate of Military Surveys at 1:25 000. The only available geological map was that at a scale of 1:250 000 compiled from aerial photographs by Dr. J.R. Adie and Miss M.R. Greenway and printed in 1972 by the D.O.S. in two sheets. The drawbacks of scale and loss of detail and accuracy introduced through this mode of compilation became apparent very shortly after setting foot on the Falkland Islands.

Lithologies, sedimentary structures and alignments of folds, faults, joints and dykes were recorded in order to :

(i) provide "foundation" data for the geomorphological and biological work of the expedition, and
(ii) update extant geological maps.

The rock types seen were mostly sandstones and orthoquartzites with subsidiary siltstones and shales. Table 1 provides an account of the stratigraphy of the geological succession.



Map of the Falkland Islands showing localities described in the address

The visit of Charles Darwin to the islands in 1846 has already been mentioned. He first described the stone runs; others who have attempted interpretations include Joyce (1950), Clark (l972, 1976) and Clapperton (1975). The first systematic geological interpretations were made by Andersson (1907) and Halle (1912). The first report on geological resources commissioned by a British government was made by Baker (1924) who reported the virtual absence of economically exploitable geological materials but who seemed determined to establish the former position of the islands within the Gondwana supercontinent, an approach furthered by Adie (1952). The report by Greenway accompanying the 1972 geological map of the islands did little more than restate work done by previous workers, although it is the most comprehensive account to date. Most of the recent work has been geomorphological, including appraisal of changes of sea level by Adie (1953) and by Clapperton & Roberts (1986). Periglacial features have been discussed by Clark (1972, 1976) and by Clapperton & Sugden (1986).

Geological investigations made around Peak Shanty, East Falkland

The isolated shepherd's hut, Peak Shanty, lies close to L'Antioja Stream which runs from north to south into Swan Inlet, incising a valley at right angles to the strike of the bedding and fold structures. Greenway (1972) interprets this valley as lying along a dip fault, but no ground evidence for this was forthcoming; boundaries and folds continued without a break on opposite sides of this valley. Peak Shanty is situated just to the south of the junction between Lafonian Tillite (C_1), the diamictite of Frakes and Crowell (1967), and the older quartzites of the Port Stanley Beds (DC) which form the high ground extending north to Mt. Wickham (633 m) and east to Pleasant Peak (250 m) overlooking Mount Pleasant Airport.

Black Rock Slates (P_1) were encountered in two localities, a small fold with marked axial planar cleavage a few hundred metres west of the defensive pillbox on L'Antioja ridge road and spectacular small scale folding revealed by road excavations leading to the water intake at L'Antioja stream crossing.

Lafonian Tillite exposed along the mid-section of L'Antioja Stream fitted well with the interpretation by Frakes and Crowell (1967) as distal submarine glacial outwash with clasts dropped from melting icebergs although the lack of marine fossils make this less than certain. The brown soil developed on this tillite is susceptible to wind erosion when the vegetation cover is broken and a number of wind-scoured basins were encountered.

Asymmetric fold structures in quartzites of the Port Stanley Beds (DC) with axes trending E-W and steeper limbs to the south, occurred far more commonly than suggested by Adie and Greenway's (1972) Map. In the 10 km between the southern edge of the quartzite near Peak Shanty and the Wickham Heights ridge six sub-parallel E-W trending folds with amplitudes of several tens of metres were observed. Segments of these folds are periclinal in form. In both East Falkland & West Falkland, the most impressive aspects of quartzite are :

(i) its massively cross-bedded nature,
(ii) the development of tor-like features on high slopes and ridges, and
(iii) the widespread development of "stone rivers".

<u>Geological investigations made around Gun Hill Shanty, West Falkland</u>

This locality lies on the south shore of Christmas Harbour, some 5 km WNW of Chartres settlement. The hilly promontory ending in Dunnose Head extends some 35 km further west, separating Christmas Harbour from Port Philomel and Whitsand Bay to the south. More hilly ground lies to the SE with Mt. Doyle (370 m), Mt. Philomel (600 m) and Mt. Sulivan (480 m). The lower boundary of the Port Stanley Beds (DC) quartzite rises from sea level at Christmas Harbour to 230 m at the southern end of the Mt.Sulivan massif. The quartzite, as elsewhere in the islands, forms a resistant capping of higher ground with a characteristic feldmark vegetation developed on its thin, sandy, acid soils. There are tor-like forms where the current-bedded structures have been etched by the weather, and stone rivers are developed in places, particularly in the NE sector of Kangaroo Valley, on Mt. Philomel and on the southern summit of Mt. Sulivan.

The lower ground is almost universally underlain by Port Philomel Beds (D_1), composed of thinly bedded sandstones with impressive scour and fill channel structures, dark micaceous sandstones with ripple drift bedding and thinly banded striped siltstones. The dark colouring

Table 1 - STRATIGRAPHY of the FALKLAND ISLANDS

System	Formation		Thickness	Description
Jurassic or Lower Cretaceous			Up to 100 m wide	Dolerite dykes
Upper Triassic to Upper Permian	Upper Lafonian Group	PT	9000 m approx.	Sandstones and shales with Triassic or Rhaetic species of *Glossopteris* flora. Clay rocks, shales and sandstones with Permian species of *Glossopteris* flora. Glacially varved shaly beds.
Lower Permian	Black Rock Slates	P1	125 m approx.	Black, cleaved mudstone with thin sandy layers near base
Upper Carbon-iferous	Lafonian Tillite (diamictite) and Bluff Cove Beds.	C1	350-850 m 0-100 m	Greenish-grey silty cleaved mudstones with numerous clasts of quartzite and igneous rocks. Intercalations of yellow sandstone. Grey mudstone with few clasts, and sandstone
		UNCONFORMITY		
Devono/ Carbon-iferous	Port Stanley Beds	DC	approx. 800 m	Pale orthoquartzite with occasional shale bands. Resists erosion, forming high ground. Highly cross-bedded
Middle Devonian	Port Philomel Beds	D1	approx 800 m	Similar to Port Stanley Beds, but found in West Falkland. Occasional obscure carbonised plant fossils.
Late Lower Devonian	Fox Bay Beds		800 m	Flaggy sandstones showing large scale scour and fill cross bedding. Silty brown sandstones and dark shales. Marine invertebrates and invertebrate trails *cf. Aulichnites* in lower parts.
Lower Devonian	Port Stephens Beds	D2	1500 m	Coarse sandstones and conglomerates.
		UNCONFORMITY		
Pre-cambrian	Cape Meredith Series		little exposed	Igneous and metamorphic rocks

with occasional carbonised plant fragments suggest that these beds may have formed in a deltaic or lacustrine environment. Close to the junction with the overlying quartzites (DC) these beds are quite tightly folded with strongly directed joint patterns and small faults. The Christmas Harbour region appears to lie on the SW limb of a series of parallel anticlines trending NW from the Chartres area. Decollement appears to have taken place, with the overlying massive quartzites (DC) sliding over and causing crumpling and small-scale faulting in the underlying thinly-bedded Port Philomel sandstones and siltstones.

To the south of the quartzite ridge forming Gun Hill the Port Philomel Beds of Whitsand Bay, open to the prevailing westerly winds, have been subjected to massive wind erosion with dunes and wind-eroded hollows, many of them filled with shallow ponds. The extent and severity of wind erosion is indicated by the existence of small "buttes" of layered sand and peat with turf topping standing some 2-3 m above the surrounding scoured terrain, also the widespread existence of polished, facetted quartzite boulders of dreikanter type, found up to altitudes of 250 m. On one occasion a sand-blow was observed from a distance, with the long plume of wind-borne dust.

A 75 m wide dyke cf medium-grained dark igneous rock was recorded south of Chartres, trending 60°, on or close to, a major NNE-SSW fault line. A previously unrecorded 3 m dyke of finer grained rock, trending 40°, was discovered to the west of Dog Hill in Whitsand Bay. This dyke in D_1 beds does not appear to penetrate into the overlying quartzite. A scatter of dark igneous boulders was seen on low ground SW of Mt. Doyle, but the SSW-trending dyke mapped there by Greenway (1972) was not seen in outcrop.

Geological investigations made around Fox Bay West, West Falkland

The two settlements at Fox Bay are founded on Fox Bay Beds (D_1) which show evidence of marine origins, some horizons containing fossils of Devonian age. Brachiopods and trilobites were found, together with some trace fossil trails, tentatively identified as *Aulichnites* (M.Romano, pers. comm.). North of the settlements is an area, underlain by slabby scour and fill channel cross-bedded sandstones and siltstones. Wind erosion has been severe, with large areas of residual gravelly subsoil and with belts of dunes encroaching on grassland. Some effort was made to locate the intersecting dykes shown NW of Fox Bay on the 1972 map but igneous outcrops were rare. The NNE-SSW "double" dyke was encountered in the Centre Camp, SE of Lake Sulivan and the main dyke appears to be 40-50 m wide, of dark, medium-grained rock. It was traced for 4 km SSW to the Arroyo Malo where it was offset 200 m. The second "parallel dyke" shown on the map was elusive in the field. A small (0.25 m) dyke trending 18° mag. was found on the seashore due north of West Head.

Geological investigations made at Salvador Settlement, East Falkland

The major inlet of Port Salvador has been mapped as an inlier of relatively softer Port Philomel Beds (D_1) surrounded by a rim of harder quartzites of Port Stanley Beds (DC). Time constraints allowed investigation of only a small part of the inner coast between Bold Point in the west and Sheila's Creek in the east. Considerable folding and zones of closely-spaced joints in the shales and sandstones of the D_1 Beds suggested that the broad folding that had produced the anticlinorium in the quartzites to the south had caused differential folding, intra-formational slippage and shatter in the less competent underlying beds. The geological boundary between DC and D_1 beds is incorrectly shown on the published map (1972) as running from Paddle Beach northwards around Salvador settlement to the inner (NW) end of Sheila's Creek. This boundary was found to run along the strike of the Port Stanley Quartzite with Port Philomel Beds occurring along the shoreline for 16 km from Bold Point to the northern side of the narrow channel to Sheila's Creek.

Along most of its length the boundary is covered by soil and vegetation and is inferred to be unconformable, but at Sheila's Creek, exposures of shattered and slickensided rocks suggest the boundary there to be a fault zone. The Rincon peninsula, SE of Salvador, has suffered massive wind erosion. It appears that soil development and conservation on the friable Port Philomel Beds depends on the maintenance of good vegetation cover; when this is broken the wind takes over.

Conclusions

The major impetus behind the 1989 Cumbria & Lancashire Falklands Expedition was the scientific investigation of aspects of the Falklands environment. However the same conflict which made the Falklands known to the world has brought in its wake all the problems associated with a relatively large influx of people and the demands of economic development. Large-scale construction schemes for airports, roads and buildings have suddenly been thrust upon a landscape where people formerly travelled by horse over dirt tracks. Accelerated development of the natural resources of the islands for tourism, agriculture and construction means that parts of the wildlife and landscape may be threatened even before we have learned much about them. The Expedition's research therefore is intended to extend knowledge about those areas of the natural history of the Islands, thought to be at particular risk, in the hope that this will aid the preservation of the wild heritage of the Falkland Islands.

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SEDIMENTATION IN CUMBRIAN LAKES

A lecture by Dr.R.A.Smith of North Cheshire College on
11 September 1990 at Lorton Road School, Cockermouth.

Cumbria contains a wide range of lake types, from major features such as Windermere to small mountain tarns, but for all their ultimate fate is to be infilled.

Two principal processes aid this infilling :

a) the gradual reduction of open water by the build-up of vegetation which traps incoming mud and sand, leading to fens and ultimately colonisation by trees into carrs.
b) the physical transport of sediment into lakes leads to the build-up of alluvial flats and deltas. There are many instances of large sedimentary areas at the heads of lakes, while deltas build from streams on their flanks.

However shorelines along most lake margins indicate that neither process is operating. Significant wave action on the larger lakes can be sufficient to erode banks composed of softer materials, e.g. boulder clay, although rocky shorelines are virtually unaffected.

What is the fate of the sediment carried into the lakes? Much of it consists of shingle-grade material, deposited immediately off-shore and in neighbouring bays, while finer material is carried further off-shore. These deposits build an off-shore shelf which may carry vegetation, developing into fens, but usually is scoured by currents or waves to maintain a barren shelf. Sediments accumulating on the lake floor are of variable thicknesses with material being moved around. Work at the F.B.A., Windermere, indicates that suspended sediments and fines are repeatedly re-activated and deposited with the greatest accumulations in the deepest parts - a process identified as "sediment focussing".
Stream sediment input can be analysed under several characteristics:

1. Hinterland characteristics
a) total amount of sediment carried
b) characteristics of sediment load
c) ratio of bed load to suspended load
d) fluctuation of stream flow
2. Lake basin characteristics
a) water depth
b) shape, size and slope of basin
c) energy regime - normally low but with wide fluctuations
d) level fluctuations

At the point of discharge there are two situations, namely:
1. Inertia-dominated mouths where streams are rushing down hillsides into a low-energy lake - the coarse bed load is dropped at the stream mouth in a delta lobe.
2. Friction-dominated mouths are found in deltas at the heads of lakes.

Here there is a high percentage of suspended load which is carried with a river plume reaching well into the lake. Shoaling due to friction slowing stream flow results in bifurcating channels with bars at their mouths and the development of bird's foot deltas.

Examples of these processes were described, providing interpretations of localities observed by members of the audience. The speaker was thanked for his commentary on familiar features.

THE LAST GLACIATION IN CUMBRIA

A lecture by Dr.R.Clark on 10 October 1990
at Lorton Road School, Cockermouth.

The number of publications demonstrate how glaciation in Cumbria continues to stimulate interest. Many deal with specific aspects of glaciation or with particular areas. Few attempt to tie together evidence from across Cumbria or to link events in Cumbria to those in adjacent areas. The speaker introduced a regional view of the Late Devensian glaciation in Cumbria, described more fully in Clark 1990.

That glaciation began about 26000 BP, reaching a climax some 8000 years later and then waning, with Cumbria becoming largely ice-free by ca.14500 BP. The principal local ice-sheds or ice-partings were the Cross Fell ridge of a north Pennine ice cap and another extending across the Lake District from the Howgills Fells by High Street to Dunmail Raise and the head of Great Langdale, thence to the hills north of Ennerdale.

An early stage of ice accumulation included major ice movement from western Scotland into the Irish Sea basin and from eastern Galloway across the Solway lowlands to the edge of the Lake District, there meeting local ice. Eastern Galloway ice also spread into the Tyne basin and up the Eden valley, over Stainmore into the Tees valley and beyond. As the Lake District ice cap grew, supplemented by ice from the west side of the north Pennine ice sheet, it so congested the upper Eden valley that Galloway ice was excluded. Eden valley ice continued to escape over Stainmore and became sufficiently thick to move across the Pennines north of Hartside, combining with Galloway ice moving east into the Tyne basin.

During the waning of the glaciation major changes in the directions of ice movement occurred, especially in the north and east of Cumbria. Such changes can be understood only in the light of:

1. great reduction in the area of ice cover which still experienced net ice accumulation, and
2. changes in the ice mass occupying the Irish Sea.

Ice loss in the Irish Sea basin was possibly stimulated by the early combined effects of rising sea level and depression of the local crust beneath its load of ice. The first and most rapid break-up of the ice mass may well have taken place in the area of the deeper trough in the western Irish Sea basin. Disruption of a partly grounded outer ice sheet margin would allow rapid calving of ice bergs, thus accelerating flow in the ice mass to this outer margin and in turn leading to a thinning of the ice mass. In time thinning of "Irish Sea ice" affected the areas feeding ice east into the Tyne basin and over Stainmore, leading them to discharge ice into the Irish Sea basin. Thus the deposits and landforms of the late ice movement were imposed on earlier ones.

Although south Cumbria presents a wide range of glacial features, its glaciation was relatively simple. From the south side of the Lake District and Howgill Fells ice moved across Morecambe Bay and the Bowland Fells, held on its southward passage by ice from western Cumbria and the west of Galloway. This southern ice became sufficiently thick to overtop the Bowland Fells and to force some ice from the Lune valley east into Craven, so strengthening the Aire valley glacier. Only when the influence of ice in the Irish Sea basin weakened was local ice able to spread westwards in the western part of Morecambe Bay.

In the early part of the waning phase, ice from the upper Eden valley still moved east across Stainmore, accompanied by meltwater which cut high-level channels as on Little Fell. However when the mass of ice in the Irish Sea basin thinned sufficiently, ice in the Eden valley turned north to the Solway lowland. In places a north-directed grain is imposed on earlier east-directed drumlins. A northward train of Shap granite erratics branches from an older train directed towards Stainmore, and there is an extensive suite of channels associated with northward meltwater flow. From the north side of the Solway also, ice was drawn to flow into the Irish Sea basin alongside ice generated on the Cumbrian side.

As the cover of ice thinned in the Lower Eden - Tyne gap area, ice flow across the Pennines north of Hartside ceased. Movement of both ice and meltwater became progressively concentrated in the centre of the Tyne gap. By the time the last meltwater to move east to the Tyne valley passed through the Gilsland col at about 140 m. O.D., local ice was stagnant. Subsequently all local meltwater moved west over the lowland south of the Solway Firth until the last ice there, mainly Scottish, ceased to be an effective barrier. These changes produced a complex succession of meltwater courses from high on the Pennine scarp down to the lower Eden gorges and the Solway plain.

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RECENT ADVANCES IN THE UNDERSTANDING OF THE SKIDDAW GROUP

A lecture by Dr.R.Hughes of B.G.S. on 12 December 1990
at Laithwaite School, Keswick.

The conclusions presented in the talk had emerged from work by a B.G.S team over the past six years. The Skiddaw Group rocks consist of marine clastic sediments, subjected to low grade metamorphism and structurally complex, of Tremadoc to Llanvirn ages (Lower-Middle Ordovician) with isotopic ages from 510 Ma to 470 Ma. The most significant advance in recent years has been the establishment of a firm lithostratigraphy, made possible by the advances in biostratigraphy achieved using graptolites and achritarts, based upon work by David Rushton and Stuart Molyneau of B.G.S. The graptolite biostratigraphy of the Skiddaw Group has a long history, originating in the work of Gertrude Ellis, at the beginning of the century. Dennis Jackson revised this scheme in the early 1960's and his work has been expanded recently resulting in a more complex picture of graptolite biostratigraphy in the Lake District. The new names are based upon Scandinavian rocks where the Arenig-Llanvirn sequence is structurally much simpler than the Skiddaw Group. Achritarts, poorly understood microscopic animal cysts, formed another very useful fossil group in the Lake District as trilobites and conondonts, elsewhere valuable, were of little use due to their rarity.

The Skiddaw Group crops in four inliers within the Lake District with the main area in the north having a maximum thickness of 5 km; other areas include Black Combe, south of the Borrowdale Volcanic Group, and the Ullswater and Bamptom inliers to the east. They are also present in the Cross Fell Inlier, in Upper Teesdale and were proved in two deep boreholes in Weardale. Their lateral correlatives are the Ingletonian Group of N.W. Yorkshire and the Manx Group of the Isle of Man. The Skiddaw Group is believed to form the continental basement beneath the Upper Palaeozoic cover throughout Northern England, except where volcanic rocks of the younger Borrowdale Volcanic Group punched through them. Two lithostratigraphies are recognised in the northern inlier, divided by the Causey Pike Fault structure.

Northern sequence The Skiddaw Group, overlaid unconformably by the Eycott Volcanic Group, consists mainly of finely laminated clays, muds, silts and fine sandstones with occasional thicker sandstones, typical turbidite sediments. Two mappable sandstone formations (the Watch Hill Formation and the later Loweswater Formation) divide the fine grained rocks into three formations which are very similar.

Southern sequence There was a similar style of deposition until late Arenig times with turbiditic sediments and then very different style because of a catastrophic event - a submarine slide which transported and re-deposited much of the earlier, already lithified, sediments and produced what is known as the Buttermere Formation, a melange of disordered sediments.

Virtually everything within the Skiddaw Group is of turbiditic origin and so a study of the theory of turbidite formation is important to understand their deposition. The turbidite model, proposed in the 1950's, revolutionised understanding of marine sedimentation. Turbidites are rocks formed by fluid-rich density currents running down continental slopes and depositing entrapped sediments on the abyssal plains. Each sequence in the beds can be identified with their own specific grain-size and sedimentological characteristics. This sequence of beds is formed by materials falling out of the density flows according to their density, although the materials carried in the turbidity currents can be very variable depending upon the grain size of the materials incorporated when the current originated. Generalised models are applicable for coarse- to fine-grained sediments with the medium-grained sequence being the classic one described in some detail by Bouma. These models are directly applicable to the Skiddaw Group and have assisted in the interpretation.

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HYDROCARBON EXPLORATION IN THE MANX BASIN

A lecture by Dr. D.E.Jackson of the University of Newcastle upon Tyne on 13 March 1991 at West Cumbria College, Whitehaven.

The Manx basin is one of a system of connected Permo-Triassic and Jurassic basins which include the Kish Bank, Celtic Sea, Cheshire and Solway Basins. The basin, measuring 80 km by 60 km, contains a vertical thickness of 16 km of Permian, Triassic and early Jurassic strata and is characterised by the occurrence of thick Permo-Triassic sediments cropping extensively on the sea floor. Structurally it is a rhomb-shaped graben containing eight smaller half grabens. The present day limits of the basin are controlled by the Lagman Fault, the Eubonia Fault and the Lake District Boundary Fault while the deeper parts of the basin are outlined by the Sigurd, Keys and Formby Point Faults. Within the basin, tectonic style is greatly influenced by the presence or absence of Permian halite which facilitates fault detachment and fault block rotation.

The abbreviated stratigraphy means that it is difficult to work out the tectonic history of the basin after early Jurassic times. Indeed the only event about which we are sure after Liassic sedimentation is the emplacement of the Fleetwood dykes of Tertiary age.

Since the initiation of the Offshore License Rounds, the Manx Basin has features in the Second, Third, Fourth, Fifth, Seventh, Ninth and Eleventh Rounds. Some measure of the oil industry's growing interest in the area is indicated by the increase in licensees from two in 1965 to nearly forty in 1991. Lower Triassic sandstones constitute the primary play in which 6 trillion cu.ft. of reserves have been discovered, mostly in the giant Morecambe Field. Due to the shallow depth of the reservoir (3200 feet), the operator, British Gas, has used slant drilling in the development programme. To date less than 100 billion cu.ft. have been produced; greater production is planned in the 1990's when supplies of Frigg gas from the North Sea begin to diminish. Other gas discoveries in the Manx Basin are also in the Triassic. These include blocks 110/7-3, 113/26-1,110/7a-4, 110/7b-6, 113/27-2, 110/3b-4 and 110/2b-9.

The Triassic Sherwood Sandstone forms an excellent reservoir with porosity in excess of 20 per cent and permeability often better than 100 millidarcies. These sandstones are fluvial in origin and basin-wide in extent. The major constraint on exploration is that the overlying saliferous Mercia Mudstone must be present to form a seal. All the gas discovered to date is almost pure methane with various amounts of nitrogen. The source of the gas is considered to be underlying Coal Measures which have been proved in several wells.

We can thank the oil industry for making possible our present understanding of this small, very complex and interesting basin, the existence of which could hardly have been predicted by extrapolation from Cumbrian coastal geology.

MINERALS OF THE CALDBECK FELLS

A lecture by Dr. M. Cooper of the Natural History Museum
on 25 September 1991 at Castlegate School, Cockermouth

Dr.Cooper explained that most of the mineralisation of the Caldbeck Fells was associated with igneous rocks, granites, gabbros and volcanics. The most important lead and copper bearing veins trended NE-SW and were crossed by a series of lesser veins trending E-W.

There was a long history of mining in the Caldbeck area where the easiest access is from the north; so it is significant that the earliest mines, developed by imported German miners in the second half of the sixteenth century, were dug on the north-facing fellsides at Roughton Gill, Red Gill (copper and lead) and Potts Gill (lead, then barite). Early records show ore being taken by pack horse to Brigham Forge at Keswick, where a smelt mill built by the Company of the Mines Royal operated until 1654. There is little written record of mining activities until the early nineteenth century, following the demise of the Mines Royal after the Civil War, but Dr.Cooper felt sure that the Lake District metalliferous mines were worked sporadically during this time. There was an upsurge of mining during the nineteenth century, accompanied by the recognition that beautiful mineral specimens were "collectable" and the accumulation of *curiosities* became a gentleman's hobby. Although several collectors' pieces from this period show evidence of faking (by glueing together diverse minerals to produce "tasteful" assemblages) many collectors took their pastime very seriously. Dr.Cooper demonstrated this by showing a page of detailed drawings and notes describing crystals of *scheelite* by Thomas Allen.

Tungsten mining proper began in the early 1900's and a photograph taken in 1912 showed the earliest workings on the Coombe Height side of Brandy Gill. The greatest diversity of minerals occurred at vein intersections, where mineralising fluids from later phases interacted with minerals formed at earlier stages. Thus at Poddy Gill a tungsten-bearing vein intersects a lead vein, producing such rarities as green *stolzite* and red *carminite*.

The speaker then described an assortment of rarer minerals found at other identifiable mining sites:

Drygill An E-W trending 2m. wide vein of quartz contains *mimetite* (lead arsenate), associated with botryoidal *plumbogummite* (lead aluminium phosphate) which also occurs as yellow epimorphs on mimetite. This mine was worked by Mr.Hugh Pattinson in the nineteenth century, who, hoping for a good quality lead ore, found mimetite which he sold for glass making.
Driggeth-Sandbed Worked from around 1700 until recently, the mine latterly produced large tonnages of high quality barite. More colourful minerals obtained included *pyromorphite* (lead phosphate), *adamite* (zinc arsenate), green *cornwallite* (copper arsenate) and *phillipsburgite*.
Roughton Gill The earliest levels were driven by the Elizabethan miners while the lowest level was of Victorian age, reflecting the long history of the mine. However the underground layout of the mine is not known since the mine plans, stored at Carlisle after closure, have disappeared. Here *pyromorphite*, in shades varying from yellow to green, is present in large amounts in a variety of crystal habits, together with blue *hemimorphite* (zinc silicate). One rarity shown was *corkite*.
Red Gill A local name, the "Old Dutch Level", shows German associations. This mine is world famous for its rare minerals, including *linarite* (blue copper sulphate), pale blue *caledonite*, colourless transparent *cerussite*, green *malachite*, white hexagonals of*leadhillite* and tiny transparent needles of *mattheddlite*.

Dr.Cooper was disappointed that there had been no "first" discoveries in the Caldbeck Hills despite the abundance of rare and beautiful mineral types. He hoped that there would soon be a *caldbeckite* and showed photographs of several recent discoveries, as yet unidentified, for which the Caldbeck Fells could be the type locality. The evening closed with a vote of thanks to Dr.Cooper given by Ken Bond.

SHAP GRANITE

A lecture given by Dr.D.W.Williams of the Open University, on 9 October 1991 at West Cumbria College, Workington

Dr. Williams introduced his talk as providing a visitor's view of this unique granite. Although the Shap granite only crops over a small area in eastern Cumbria (5.5 km^2), it appears to be a small boss emerging from a large composite batholith which underlies much of the Lake District. It is related to the Weardale granite underlying the Alston Block to the east. The intrusion and its broad metasomatic aureole occurs at the junction between rocks of the Borrowdale Volcanic Group and the Windermere Group. It has been dated at 393 $^{+}10$ Ma, the beginning of Devonian, and later than the end-Silurian deformation which folded the country rocks.

The appearance of the granite is distinctive, due to the numerous large pink phenocrysts of potassium feldspar set in a matrix of quartz, feldspar and micas. These phenocrysts even occur close to the contacts with the country rock, as seen in Blea Beck, and indicate that they had been formed before the intrusion took place. At this locality tongues and veins of the pink granite can be seen penetrating the country rock, with fragments of the latter caught up in the granite margins. However one of the most intriguing features of the granite are the dark rounded patches, 'blob-like' in appearance, enclosed within the granite. They are mainly few centimetres in cross-section but may be as wide as a metre. Most of these patches contain large phenocrysts which show evidence of partial absorption within the darker masses, varying from rather rounded crystals to phenocrysts with white reaction rims and ghost crystals where absorption is largely complete. It has been suggested that the dark enclaves consisted of masses of a slightly more basic magma carried up by convection currents, collecting the phenocrysts as they rose.

Dr Williams described late alterations caused by hot solutions ascending along joints in the granite. These produced aplite veins, zones enriched with pink feldspars, and also layers of soft, rotted kaolinized granite. A later phase of mineralising fluids led to the deposition of sulphide minerals and calcite on some joint faces.

EVOLUTION OF THE LAKE DISTRICT LANDSCAPE

A lecture by Dr.J.Boardman of Oxford University
on 13 November 1991 at Laithwaite School, Keswick

Although the Lake District is conventionally viewed as an ice-derived landscape, the evidence for glacial impact is rather poor. Dr. Boardman suggested that the effect of glaciation was not as prevalent as commonly thought. He argued that the major valleys were probably in existence before glaciation and they were only slightly modified by glacial processes. His views are developed in an article elsewhere in this edition.

NUCLEAR WASTE DISPOSAL AND ORDOVICIAN VOLCANICS

A lecture by Dr.M.G.Petterson of B.G.S., Newcastle upon Tyne,
on 11 December 1991 at the West Cumbria College, Whitehaven.

Dr.Petterson commenced by outlining the nature of the investigations which B.G.S. are conducting on behalf of NIREX in West Cumbria and then described the nature of the rocks in which it was planned to build the repository. The material to be stored will be dangerous for a long period of time (10^5-10^6 years). The aim is to isolate the hazardous materials from the biosphere for up to one million years and to prevent it coming into contact with any medium which could bring it back into the biomass.

The repository is to be excavated within rocks which are not exposed at the repository site itself. Thus it was necessary to look over a wider area in order to determine the characteristics of the host rocks. B.G.S. has been surveying the district for the past ten years and so has accumulated a large amount of information on the rocks. So the study has started from an existing data base comprising geological maps together with borehole and mine records from nearby coal, iron ore and anhydrite mining. New information has been derived from seismic lines shot over the district and a series of deep boreholes being drilled down to depths of 2 km. All the geological and geophysical data is being fed into the development of a hydrogeological model which will help to predict fluid movements, the most important element in the investigations. The Borrowdale Volcanic Group rocks, which will host the repository, are virtually impermeable but are fractured and faulted, imparting significant secondary permeability and providing possible fluid pathways.

The repository site is extensively drift covered and underlain by Permo-Triassic sediments. Rocks of the Borrowdale Volcanic Group underlie the area at depths of around 470 m and are increasingly deeply buried further to the west; depths in excess of 1500 m beneath Sellafield make the Sellafield site itself unsuitable. These detailed investigations will enable a new Gosforth/Bootle geological map to be published soon.

The Borrowdale Volcanic Group are the main subject of the investigations. They were erupted sub-aerially over a relatively short period of 1 -10 million years. Rare acritarchs found at Holehouse Gill have proved a Caradocian (Upper Ordovician) age with a radiometric age dating of 454 Ma, confirming this age.

While the Group can be up to 6 km in thickness, it is only 3 km thick at the repository site. The Borrowdale Volcanic Group can be divided into two sub-groups:

Lower Unit - dominated by effusive volcanism with many lava flows and the intrusion of high level sills. The great bulk of the unit consists of andesite sheets with an important exception being a massive pyroclastic ignimbrite in the Wasdale-Sellafield area.

Upper Unit - dominated by caldera-forming rhyo-dacitic ignimbrites which represented a highly explosive stage in the evolution of the Borrowdale volcanoes. These features are usual in caldera-forming volcanic provinces, which tend to form on continental crust situated above active destructive plate margins (e.g. Japan, western USA, Phillipines and Indonesia).

The area of the Lower Borrowdale Volcanic Group rocks northwards from Wasdale into Ennerdale has been the subject of Dr. Petterson's mapping. Much of the district is composed of andesite sheets, 10 to 200 m thick, formed as a plateau andesite field and showing typical trap topography. The most common lithology is of brecciated andesites with highly clastic margins, often with intervening stratified deposits of airfall tuffs and reworked volcanic detritus. The brecciation of the andesite flows was caused by the surfaces solidifying, then being over-ridden by the still molten interiors of the flows. Another notable feature are the occurrence of high level peperitic sills which show many of the characteristics of flow breccias. They form by magma being intruded into wet unconsolidated sediments at shallow depths; the magma reacts explosively with water, brecciating the magma and the adjacent sediments.

Certain members in the lower unit can be mapped over considerable distance thus providing means of correlating horizons. The Eagle Crag Tuffs in Ennerdale form one such horizon in the lower part of the unit. Higher up the sequence is the Seatallan dacite which is the most acid rock in the region and provides a useful marker because of its characteristic chemistry and field appearance. It marks the start of the Craghouse Tuff event. The Craghouse Tuff is a welded ignimbrite: ignimbrites are the product of highly explosive pyroclastic flow eruptions which erupt huge volumes of magma (30-3000km^3) over a very short period of time. The rapid evacuation of crustal magma chambers induces caldera collapse, with the thickest intra-caldera ignimbrites situated within the caldera itself. Mapping has revealed that the Craghouse Tuff thickens from 30m. east of Burnmoor Tarn, to 250m. around Scoat Tarn, 800m. at Crag House and 1100m. west of Gosforth. One caldera fault extends N-S and NE-SW from the western edges of the screes to Dorehead. The proposed repository is to be excavated within the centre of the Craghouse Tuff, and hence within the interior of an Ordovician caldera.

RIGS in Cumbria

A talk given by E.Skipsey after the 1992 A.G.M.

Britain for its size has some of the most varied geology in the world. Unfortunately opportunities to study it are disappearing before our eyes because of the pressures on earth science sites - infilling quarries, sand and gravel extraction, coastal defences and afforestation, for example.

What can be done to protect these sites ?
While the SSSI network (Sites of Special Scientific Interest) provides protection for some earth science sites of international or national research importance, there are many other geological locations of great interest and value for which there is no protection. Schemes to conserve comparable wildlife sites have been operating for many years; for instance, the Cumbria Wildlife Trust, one of forty eight county Trusts operating under the umbrella of the Royal Society of Nature Conservation, manages over forty nature reserves in the county.

Hitherto, little has been done to protect non-SSSI earth science sites but now English Nature is promoting a scheme to form county groups that will safeguard geological sites in similar manner to the wildlife trusts. These sites, known as **RIGS** (regionally important geological/ geomorphological sites) are ones worth protecting for educational, historical or research importance. They are best conserved by local groups of interested people, RIGS groups, based on local geological societies, wildlife trusts and museums working together with landowners and planners.

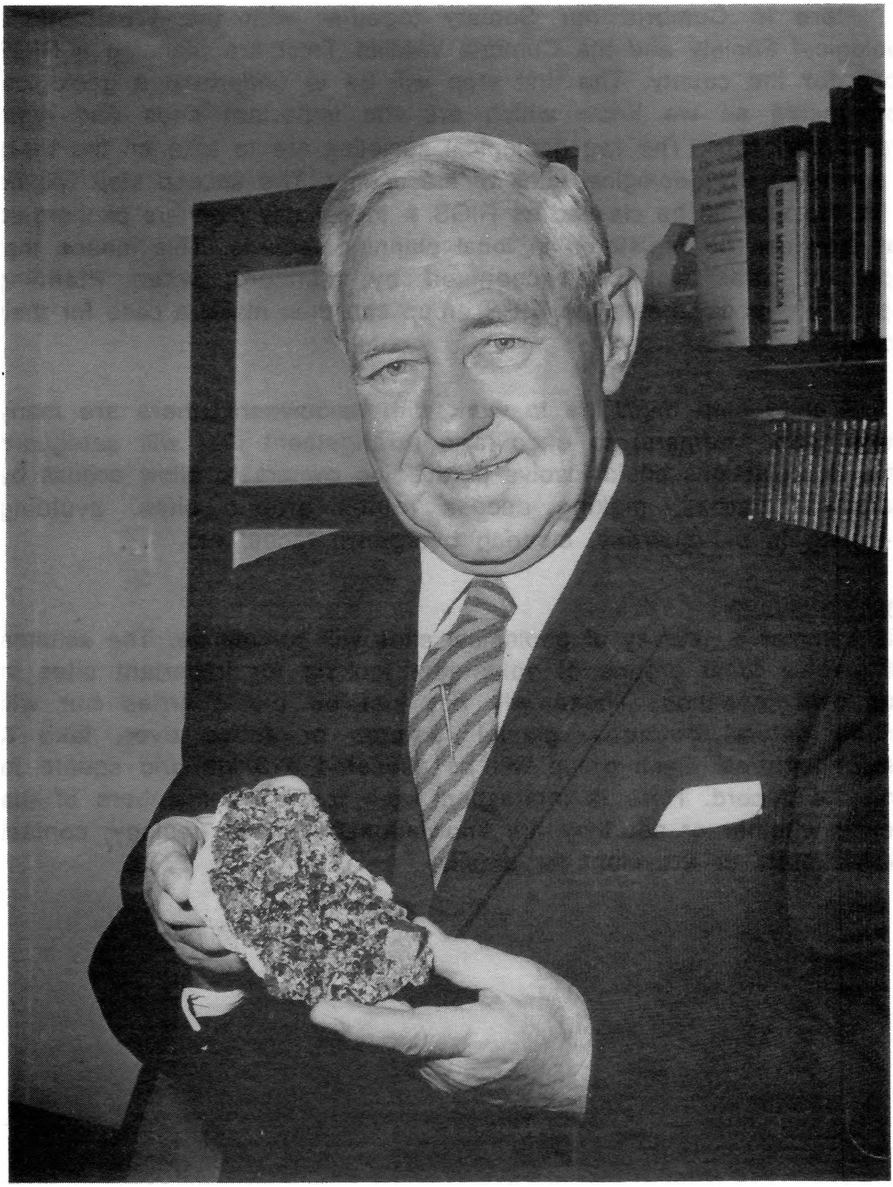
The main purposes of a RIGS group is to identify important sites and seek their protection by alerting owners & planners to the important local sites (they are often unaware of their significance), by encouraging better site management through liaision with owners to protect the best features and by promoting local interest and involvement in conservation through publicity and encouraging good practice by site visitors.

Here in Cumbria our Society together with the Westmorland Geological Society and the Cumbria Wildlife Trust are planning a RIGS group for the county. The first step will be to undertake a geological stock-taking so we know which are the important sites and what threats they face. The two geological societies are to take on the tasks of surveying the geological sites of the county. The second step will be to list the sites to be classed as RIGS & then notify planners of them so that they can be registered in local planning records. This means that important sites will be recognised by planners; when Planning Applications pose threats the RIGS group can then make a case for their protection.

A third step might be to work with landowners (there are many others than farmers) to encourage arrangement that will safeguard sites. Such actions could involve persuading owners to allow access by geological parties, making access routes around sites, avoiding fly-tipping in old quarries, clearing overgrown faces, etc.

<u>What we can do</u> !

This summer a survey of geological sites will commence. The scheme will involve local groups of volunteers looking for important sites in their own localities. These will not just be old quarries but will include natural outcrops, glacial features or active river, lake & coastal features. Each group will be allocated a10 km grid square to survey & record. Here is interesting work for many members of the Society whether or not they are knowledgeable about geology; contact the Secretary or President for details.



EDGAR SHACKLETON 1903 - 1991

OBITUARIES

Edgar Howard Shackleton, F.G.S.

An appreciation by Tom Shipp

Edgar Howard Shackleton, the Society's Honorary Life President, died in Whitehaven on 14th March1991 after a long and active life. It is fitting that Edgar's association with geology, in particular with the Cumberland Geological Society, should be commemorated. Accordingly the Proceedings Volume 5 Part 3 provide both a grateful acknowledgement and a record of his commitments and contributions towards the promotion of geological interests in North West England.

He was born in 1903 at Great Harwood in Lancashire and could never have been mistaken for other than a Lancastrian. His long interest in geology was kindled at the age of seven when his father took him down the Cock Pit coal mine. He left school at the age of twelve during the 1914-18 War to start work in a Lancashire cotton mill. He commenced a textile engineering apprenticeship at the age of fourteen, attending evening classes at Blackburn Technical College. Geology and botany were his favourite subjects. He reached Inter-B.Sc. standard but due to local difficulties he was unable to matriculate and so he was denied an external degree. In the early 1920's his tutor at Blackburn, John Ranson, introduced him to the art of lecturing and planning geological fieldwork. He was able to assist the Geological Survey which was working in East Lancashire about this time. This encouraged him to form, and become secretary of, the first regional group (East Lancs.) of the Geologists Association.

During the mid-1920's Edgar married Doris Pilkington and they moved to Bowness-on-Windermere where he earned a modest living as a lecturer and rock-climbing guide. One of his pupils of those days was Lord Hailsham. In 1934 he joined Hoover Ltd. as a local representative and was soon promoted to area supervisor covering north Cumberland.

In the 1939-45 War he was drafted into ordnance work, manufacturing explosives at Drigg. After the war, Edgar and his wife remained in West Cumberland and he joined the United Steel Company at Workington. Although appointed as an instrument engineer he advised on many geological problems, including faulting and drainage in iron ore mines, assessment of clays and refractory sandstones and the mineralogy of imported ore supplies, from which he collected and documented numerous manganese minerals, some not previously recorded. It was about this time he met the late Charles Edmonds, a local miner's union organiser with unrivalled knowledge of the Carboniferous Limestone stratigraphy in West Cumberland. Together they instituted Workers Education Association classes in geology, enthusing a group of people to form a West Cumberland Geological Group. In 1961 this formally became the Cumberland Geological Society, with Charles Edmonds as its first President. Bob Pearson became Secretary whilst Edgar Shackleton was vice-President, chairing most meetings.

For the following two decades, Edgar led the Society as its President, contributing lectures, articles and field excursions. He was a prominent lecturer on the programmes for Lake District visitors organised by Newcastle University Department of Adult Education. He served on the Regional Committee of the British Association for the Advancement of Science and also gave valuable service to the Lake District Naturalist's Trust, his particular concern being the conservation of geological sites. Three of his publications, The Limestone Series of West Cumberland (1962), Lakeland Geology (1966) and Geological Excursions in Lakeland (1975), have been reprinted several times and reflect his enthusiasm for geological matters. In 1973 he was awarded the Charles Edmonds Prize and in 1980 the Society awarded him Honorary Membership.

Due to failing health in 1981 he relinquished active Presidency and the Society conferred upon him the title of Honorary Life President in recognition of his unique involvement in its development. He was further honoured by the Geological Society of London in 1981 with the award of the R.H.Worth Prize, in recognition of his many contributions to the science of geology.

In concluding this short appreciation, the aspect of his geological work that stands out was his enthusiasm to put the subject across in ways that could be understood by all.

Some of his memorable quotes include:

"We need people who can talk sound geology in a language that ordinary people can understand, people who bring to life what ordinary folk regard as dry-as-dust themes".

and more pithily

"Geology is sinking beneath a vast pile of words" with the result that *"geology and geologists go perennially unhonoured and unsung outside the circles of those intimately connected with the science."*

One of his Presidential Addresses commenced with:

"This is not intended as a learned dissertation. I intend to avoid technical language as far as possible but in doing so I am conscious of a difficulty. What was technical and abstruse several years ago may well have become commonplace today. I have to strike a balance - - that some shall not be irritated with others left floundering."

He recognised that:

"One of the many advantages of being an amateur is that one can sometime say things that would daunt the professional."

He has given inspiration and guidance to countless students, amateur geologists and interested visitors to the Lake District. In remembering Edgar, the concluding sentence from his "Geological Excursions in Lakeland" is a fitting memorial to this largely self-taught geologist whose interest in geology spanned much of the twentieth century:-

" If my humble efforts at guidance can bring pleasure and enjoyment as well as a little understanding of a great field of human endeavour on a none too simple subject, I shall be well content".

<u>The Edgar Shackleton Collection</u>

A note by Mervyn Dodd.

Edgar Shackleton commenced collecting geological specimens in an organised manner after moving to Cumbria in the 1930's and, despite bouts of ill-health, continued to do so until the late 1970's. Most of his material is from Cumbria but he collected specimens from elsewhere, especially when attending British Association meetings. Several specimens from more distant locations were given by or exchanged with other amateur collectors. All his specimens were meticulously labelled in his clear script and identified, to species level in the case of fossils, with localities noted and where appropriate stratigraphic horizons were given.

Edgar was generous in his gifts of specimens to friends, museums and educational organisations. The collection he gave in the 1970's to the Lake District National Park Centre at Brockhole is the largest and best preserved of several. His son, Howard, has the splendid, almost showy, mineral collection which adorned the family home in Hensington while Whitehaven Museum has a small teaching collection which he donated.

It has not been the policy at Brockhole in recent years to have large permanent displays of relatively small artifacts. Concern over the safekeeping of the collection led Tim Haley, the Manager at the Brockhole Visitor Centre, and Bruce Bennison, the Cumbria County Museum Officer, to commission in 1990 a survey and assessment of the collection by Rosemary Roden, a peripatetic geological curator. Her main conclusions were that access was difficult and the storage of the specimens, housed in 77 plastic trays, was not ideal. She reported that the collection was a good reference one for the geology of the Lake District and of scientific value with unused educational potential. I quote her comment that "The strength . . . . . lies in its wide stratigraphic range from the PreCambrian to the Pleistocene, ... demonstrating the stratigraphy of the Lake District and the region's relation in the geological history of other parts of the British Isles." The fossils are the "Jewel in the Crown" of the collection, particularly the Lower Carboniferous specimens from the edges of the Lake District with corals being well represented.

The Lake District National Park Centre has agreed to transfer the collection to the Museum of the West Cumbria Mines Research Group at Florence Mine, Egremont. It is hoped that the Museum will be opened by April 1992; access to the collection will be by arrangement with the Secretary of the West Cumbria Mines Research Group (Dave Banks), at 31,The Crescent, Thornhill, Egremont; phone 0946-823812.

The following list records Mr. Shackleton's publications:

Publications

The Limestone Series of West Cumberland, 1962.

Lakeland Geology, 1966. Dalesman Publications, Clapham, N.Yorks.

The Story of Lakeland Geology, 1973. Proc.Westmorland Geol.Soc.1.1.

Geological Excursions in the Lake District, 1975. Dalesman

Presidential Addresses published in the Proceedings

Granites and granitisation	15 February 1962
The age of the Earth	14 February 1962
Mountains - their nature and origins	9 November 1963
Making geology known	10 February 1964
Mn minerals and the unstable crust	9 February 1965
Time measurement and the fossil record.	8 February 1966
Minerals and mineralisation.	7 March 1967

Articles published in the Proceedings

Jonathan Otley: father of Lakeland Geology	1963; 2. p.5-8.
Charles Edmonds: first C.G.S. President	1964; 1. p.3-4.
Rev. J. Clifton Ward	1964; 1. p.5-7.
Robert Harkness	1962; 2.1. p.19-22
Henry Alleyne Nicholson	1969; 2.3. p.105-7
Erosion at work; recent Lake District changes	1969; 3.3. p.115-116
Adam Sedgwick	1970-1; 3.1. p.33-6
J.F.N. Green	1973-4; 3.1. p.147-9

Excursions

Glacial meltwater system; Uldale & Egremont.	23 June 1961
L. Carboniferous stratigraphy; Yeathouse & Frizington	14 April 1962
L. Silurian stratigraphy; Ambleside & Coniston.	14-16 Sept 1962
Mines and minerals of Carrock Fell	27-28 July 1963
Ore stocking ground; Workington Iron & Steel Co.	30 Nov 1963
Skiddaw group at Skiddaw Dodds.	18 April 1964
Coniston Limestone; Appletreeworth Beck.	7 July 1968
New Red Sandstone; Bigrigg.	16 August 1969
Criffel area, Kirkcudbrightshire.	21-3 Aug 1970
Borrowdale Volcanic & Coniston Limestone; Millom	27 Sept 1970
Brathay Quarries, Ambleside.	6 May 1972
Embleton granodiorite, Cockermouth.	26 August 1972
Carboniferous Limestone around Caldbeck & Uldale	14 May 1977
Drilling for haematite, Egremont.	6 July 1977
Carboniferous Limestone outlier at Wilton, Egremont	10 May 1978

OTHER OBITUARIES

Boyce Dereck Allen

The Society also records the death of Dereck Allen on 12 January 1991. He was one of the Society's staunchest supporters and is missed by his many friends. Dereck's interest in geology started from a gift of Coal Measure fossils when a boy at Hanley High School. His interest in the subject was re-kindles when his sister-in-law joined the Sorby Society in Sheffield and the family investigated geological localities in Derbyshire. This geological interest assisted Dereck in his post of Chief Public Health Inspector in Coventry, an area of mining, pollution and subsidence problems.

Dereck joined the Society in1977 shortly after he and his family moved to Cumbria on his retirement. He became the first Membership Secretary in 1978, 'inventing' this office to relieve the then new Treasurer of some of his heavy work load. He continued in this office until 1990 when he stood down to bring new blood on to the Council. He died while out walking with his family on Watch Hill and, geologist to the end, his last shouted instruction just before he collapsed was to look at the rocks in the quarry ahead.

He will be remembered as a well informed excursion leader and as a lively contributor to discussions at lectures and on field excursions.
F.T.B.L.

James Hobbs

The death of a founder member of the Society in 1991 is recorded with the passing of James Hobbs. He took a B.A. degree in geography and history at Manchester University before joining the teaching profession. He taught at Heversham Grammar School until his retirement in 1968 and he was a knowledgeable amateur geologist very familiar with the geology of the countryside around Kendal.

He was a life member of the Geologists Association and a long-time member of the Cumberland Geological Society, although his activities with our Society diminished with his increasing age and the advent of the Westmorland Geological Society, of which he was a Vice-President.
W.A.

ANNUAL DINNERS - 1990 and 1991

The 1990 Annual Dinner was held on 21 April at the Chase Hotel, Whitehaven, when the guest of honour was Brian Young, of the British Geological Survey, Newcastle.
This event marked the many occasions when Mr. Young has assisted the Society with articles, talks and excursions. It also marked his term as President of the Yorkshire Geological Society.

The 1991 Annual Dinner was held on13 April at the Trout Hotel, Cockermouth when Dr. and Mrs. Cockersole were the guests of honour. The Charles Edmonds Prize was awarded to Jim Cockersole in appreciation of many tasks he has undertaken on behalf of the Society.

ANNUAL GENERAL MEETINGS

THE 30TH ANNUAL GENERAL MEETING of the Society was held at Workington College on 27 February 1991 with the President, Mr. I. Gray, in the chair. The General Secretary reported on a year full of activity and told members of the Society's two publication during the year. The biennual Proceedings (Vol.5, Part2) was distributed in May and later in the year the Bibliography of the Geology and Geomorphology of Cumbria, Part 2 (1974-1990) was published. The accounts for the year ended 31 December 1990 were presented and accepted.

THE 31st ANNUAL GENERAL MEETING of the Society was held at Workington College on 26 February 1992 with the President, Mr. I. Gray, in the chair. The General Secretary reported on the year's activities. The Treasurer presented the accounts for the year ended 31 December 1990 which were accepted.

OFFICERS and COUNCIL

Officers and Council elected for 1991 and 1992 are given below.

OFFICERS ELECTED FOR:	1991	1992
President	I. Gray	K.W. Bond
Senior Vice-President	T. Shipp	I. Gray
Junior Vice-President	K.W. Bond	E. Lawrence
General Secretary	K.W. Bond	Dr. R.A. Smith
Excursion Secretary	D. Kelly	D. Kelly
Treasurer	F.T.B. Lawton	F.T.B. Lawton
Membership Secretary	Mrs. M. Fox	Mrs. M. Fox
Editor	E. Skipsey	E. Skipsey
Publications Secretary	T. Loftus	T. Loftus
Librarian	M.F. Burton	M.F. Burton
Chairman, Guide Sub-committee	M.B. Dodd	M.B. Dodd
Council Members	Dr. R. Clark	Dr. R. Clark
	E. Curzon	D. Dickens
	Dr. T. Dias	Mrs. A. Marchant
	D. Dickens	
Honorary Auditor	F. Yearsley	F. Yearsley

In addition, Dr. F.J. Cockersole and Mr. T. Shipp, Past-Presidents, are ex-officio members of Council

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