THE CUMBERLAND GEOLOGICAL SOCIETY

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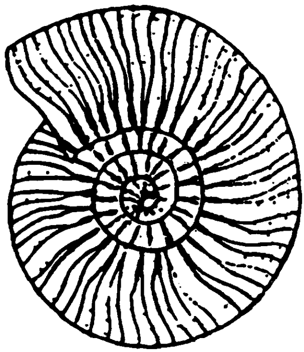

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EDITOR'S NOTES

I would like to thank all those who have contributed articles, provided lecture and excursion notes and assisted in the preparation of the Proceedings.

The Proceedings is a biennial publication that caters for contributions on all aspects of geology and geomorphology of northern England. Contributions are welcome and should be submitted to the Editor.

Chris Thompson, Editor.

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General Secretary: Dr R. A. Smith,
[redacted]

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ORIGINAL ARTICLES

A FIELD GUIDE TO THE PENRITH SANDSTONE IN THE NORTHERN PART OF THE VALE OF EDEN

E. Skipsey

Introduction

The Vale of Eden in the east of Cumbria lies between the north Pennines and the eastern margins of the Lake District uplands. The outcrop pattern of the broad tract of Permo-Triassic rocks is illustrated in Figure 1. The lithologies of these rocks show features diagnostic of arid environments. This study is principally concerned with the rocks of Permian age in the northern district of the Vale of Eden, which here consist of aeolian and fluvial sandstones together with basin-margin continental conglomerates and breccias.

The axis of the Eden basin runs NNW-SSE with its eastern margins controlled by the Pennine Faults, which downthrow to the west. It is thought to have been an isolated depositional basin in Permian times lying in the rain-shadow of high land to the east, similar in many ways to Death Valley in eastern California today.

Regional Setting

Since the boundaries between the various Permo-Triassic sequences are diachronous, it is helpful to recognise the three lithostratigraphic units defined in Figure 2, using the new classification adopted by B.G.S. (Chadwick et al 1995). The oldest rocks are those of the Permian Appleby Group, comprising aeolian and fluvial sandstones of the Penrith Sandstone Formation and associated basin-margin continental breccias. The Appleby Group is succeeded by the Cumbrian Coast Group, which includes the Eden Shales Formation, up to 200m thick in the Vale of Eden, and the partly equivalent St Bees Shales. The Eden Shales Formation was formed as salt-flat deposits (sabkhas) of thinly bedded shales and siltstone with important evaporite deposits. The shales in turn are followed by the mainly fluvial Sherwood Sandstone Group of Triassic age, locally represented by the St Bees Sandstone.

The Permo-Triassic red-bed rocks of the Vale of Eden and the adjacent Carlisle Basin overlie a locally complex sub-crop of Carboniferous rocks but seismic reflection data indicates that the two basins were unlikely to have been connected during Permian times (Chadwick, ibid.).

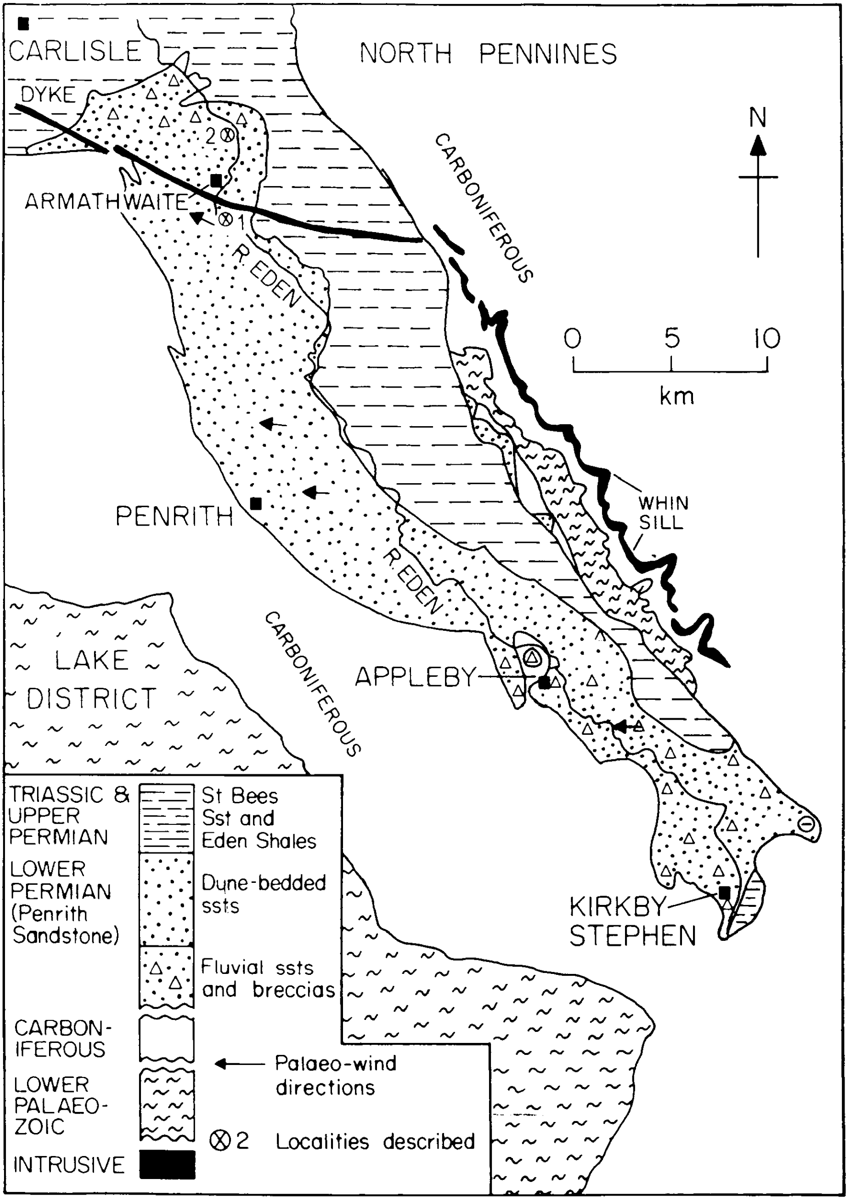

Fig. 1 Eden Valley Geological map, showing the outcrops of Permian & Triassic rocks and the locations described in the article. Arrows indicate the Permian wind directions, derived from field measurements taken at outcrops.

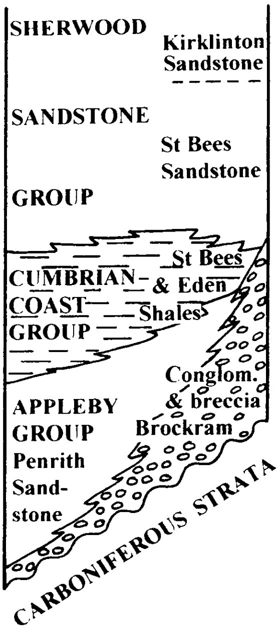

Fig. 2 Summary of the Permian and Triassic stratigraphy in the Vale of Eden, based upon the new classification adopted by the British Geological Survey.

The Penrith Sandstone Formation dips gently to the east at 2-5 degrees along the western limb of the basin for some 50km from Armathwaite in the north to Kirkby Stephen in the south.

It is believed to attain a thickness of over 400m near Penrith but it is much thinner towards the northern margins. The former extent of Permian cover is uncertain although geophysical surveys (Bott 1974, Lee 1984) have defined the area of the main basin. While the eastern boundaries are formed by faults, the original extent of Permian deposits to the west is unknown although the Lake District massif was probably upstanding in Permian times (Kimber and Johnson 1986).

Extensive studies of the Permian and Triassic rocks of the Vale of Eden have been undertaken by the British Geological survey in recent years with the resurvey of Sheets 24 (Penrith), and also 31 (Brough-under-Stainmore) to the south. The Memoir for Sheet 24 by Arthurton and Wadge, published in 1981, covers the southern part of the district under discussion while the Memoir for Sheet 18 by Trotter and Hollingworth, published in 1932, deals with the northern part of the area. Important contributions were also made by Waugh and Macchi, who published a guide to the Permo-Triassic rocks of Cumbria (1984). Skipsey (1989) published a field guide for the Eden Valley and

Cockersole (1990) reviewed the depositional environment of the Penrith Sandstone. Chadwick et al (1995) used seismic reflection profile data to review the tectonic and sedimentary history of the Solway Basin and adjacent areas, which provided information about the structure of the Vale of Eden.

Aeolian And Fluvial Deposits

The sandstones and breccias of the Vale of Eden can be divided into a number of litho-facies on the basis of textural and structural characteristics which reflect different aeolian and fluvial depositional environments. The sediments show many similarities to those described by Brookfield (1979) in his studies of Permian basins in SW Scotland.

The most striking features of the aeolian sandstones are the steeply dipping cross-bedding, the internal layers within a stratum which are visible in many of the outcrops, and the remarkable roundness of sand grains, both characteristic of wind-blown sediments. The large-scale cross-bedding of the sandstones, notable for dips up to 30 degrees, consistently lie in the north-west quadrant. The sandstones are believed to have originated as ancient sand dunes, a characteristic landform of deserts. They were formed by wind-blown sand accumulating as foreset beds on the steep lee slopes of dunes advancing in a north-westerly direction, with the sand carried by prevailing winds blowing from a south-easterly quarter.

Towards the basin margins, particularly in the south and west where the relief was greatest, the wind-blown sand deposits pass laterally into planar-bedded sandstones deposited by flowing water and then into coarser pebble beds, known locally as 'brockrams'. The extreme climate (intense heat by day, freezing at night) created a loose rocky surface in the mountains. Rare but violent rainstorms washed this rock debris down steep gorges, to form large fans of coarse pebble deposits along the edges of the uplands where the gorges opened onto the desert plain. The poorly sorted sediments show a rapid decrease in particle size downstream. On the flood-plain these processes resulted in flat-bedded, water-laid sandstones and siltstones with occasional playa (temporary) lake deposits, inter-fingering with the dune sandstones.

Most attention over the years has been given to the southern part of the Vale of Eden where a wide variety of exposures allow detailed studies of these sediments. The strata are less well exposed in the northern part of the Vale where they are largely of the aeolian facies although a minor fluvial phase can be recognised at outcrop and in boreholes north of Armathwaite. The evidence in the northern area is now reviewed and examples of aeolian and fluvial facies are studied.

Aeolian and fluvial deposits in the north

Some of the best exposures of the aeolian sandstones are found along the banks of the River Eden north of Kirkoswald, where the river runs through a succession of broad gorges excavated by vast quantities of water released by melting ice during the final stages of the last Ice Age. Exposures in the long line of cliffs at Coombe Clints (NY 505 452), on the east bank of the River Eden 1km south of Armathwaite bridge, are discussed below in detail. Further exposures can be found at the Nunnery Walks, Staffield (NY 537 429), further upstream between Armathwaite and Kirkoswald, which provide extensive cliff outcrops set in pleasant woodland walks. Cliff sections also occur in the gorge of the River Ive at Highhead Castle where prior permission for entry is required from the owner.

The only extensive exposures of Permian fluvial deposits in this area are 5km downstream from Armathwaite on the west bank of the River Eden and are described later. Four boreholes of the six in the district also proved the fluvial strata but it is difficult to establish the positions of the fluvial components within the sandstones as the wells rarely penetrated the full sequence. Figure 3 records the outcrop and borehole evidence in the Armathwaite district.

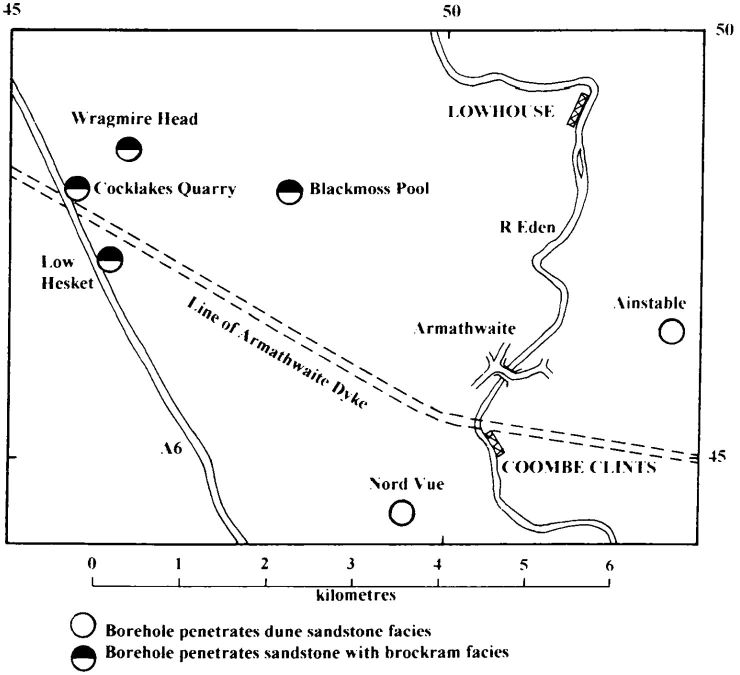

Fig. 3 Outcrops and borehole locations in the Armathwaite district. The line of the Armathwaite dyke is shown crossing the River Eden a short distance to the north of the Coombe Clints cliff section

Aeolian cross stratification

The long exposure in the cliffs at Coombe Clints provides opportunities to examine the pattern of cross-bedding over an extended section. The cliffs are best reached from the north along a footpath past the Fox and Pheasant Inn, Armathwaite bridge, turning right at a stile after 0.5km and walking down through the woods to the riverside. The accessible length of cliffs extends NW-SE for some 150m as illustrated in Figure 4a. Some 20m height is generally exposed although the southern end is partly masked by trees and talus. A bluff (Fig. 4b), adjacent to the steps down to the riverside, is roughly at right angles to the main section.

The principal features of the cliff sections (Figs. 4a & b) are the vertical sequence of planar cross-bedded units, separated by erosional breaks in sedimentation known as 'bounding surfaces' (Brookfield 1979). At least seven cross-bedded units can be recognised with some units extending over 50m and attaining thicknesses of 2 to 4m. Sets of horizontal-bedded laminations occur immediately above the bounding surfaces. These are usually a few centimetres thick but occasionally approach a metre in thickness. When traced laterally to the right (south-east) in Figure 4a they thicken and assume progressively steeper angles of dip, up to 30 degrees, which are directed towards the north-west quadrant. Examples of dip angle and direction values for both dune foresets and bounding surfaces are given in Figure 4a. Where exposures are adequate, it can be seen that the bounding surfaces separate sets of steeply dipping arid truncated foreset beds below from the flat-bedded laminations above. The bluff (Fig. 4b) beside the path shows a series of gently concave-upwards units. Here, as in Figure 4a, two orders of bounding surfaces can be recognised - important, low-angled planar surfaces (m) extending along most of the section and a lower order of impersistent planes of discordance within the cross-bedded sets and cut off by the major ones.

Interpretation of Coombe Clints section

The sandstones shows many features characteristic of aeolian deposits, including

(a) well-defined cross and planar bedding. The cross-bedding represents successive layers of wind-blown sediment deposited as foreset beds down the lee slope of an advancing dune while the planar bedding probably represent aprons of sand lying in front of the advancing dune face;

(b) characteristic laminations within the dune structures which show grainfall laminations, formed by windblown sand being deposited down the lee slope, and sandflow or avalanche laminations, caused by the collapse of the sand layers on the lee slope due to oversteepening, in which adjacent laminations commonly show sharp grain-size differences (Collinson 1985);

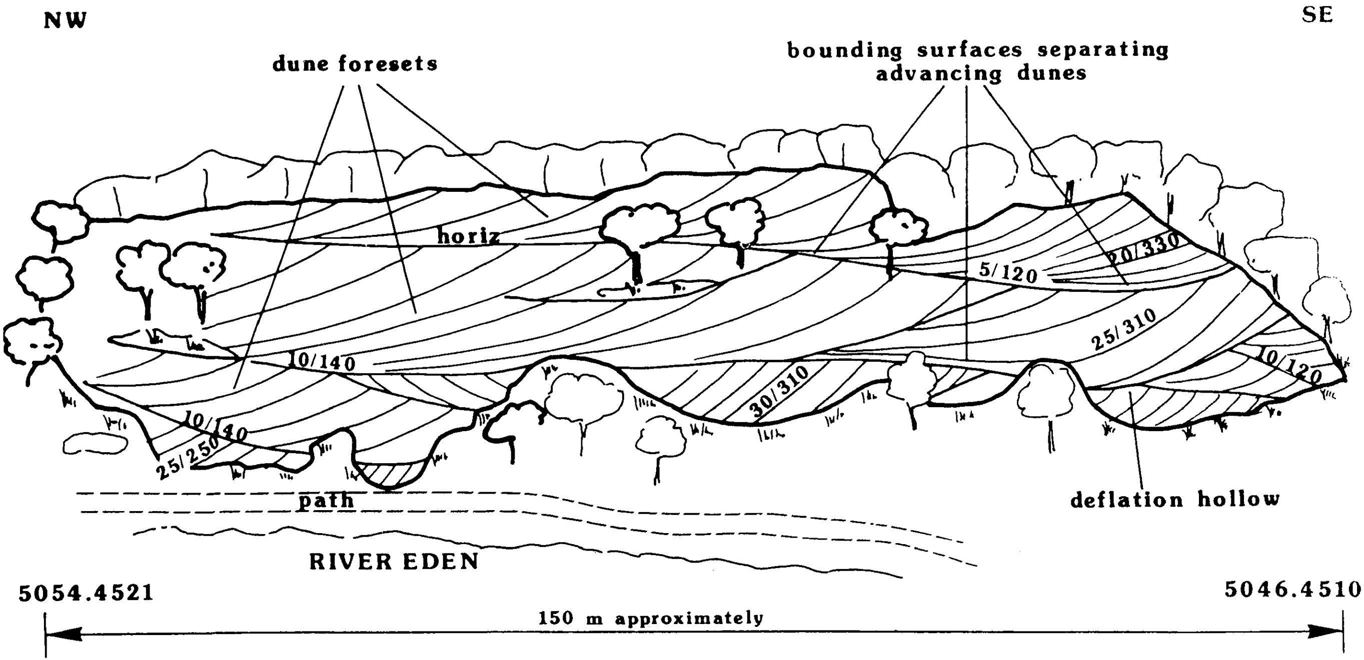

Fig. 4a Diagrammatic section of Coombe Clints cliff section illustrating the pattern of aeolian cross-bedding along an extended section. Bounding surfaces separate sets of steeply dipping and truncated remnants of older dunes from younger dunes advancing across the erosion surfaces. Examples of dip angle and direction values for both dune foresets and bounding surfaces are given

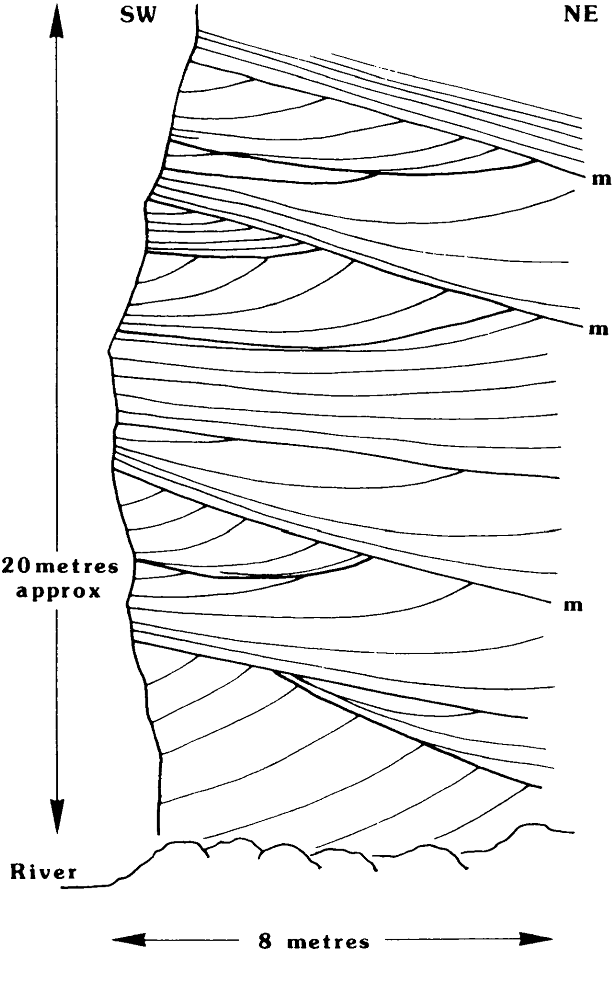

Fig. 4b Diagrammatic section of the bluff at Coombe Clints, showing a series of gently concave-upwards units with two orders of bounding surface. The important low-angle surfaces (m) extend along most of the section.

(c) many erosional breaks in sedimentation, described here as bounding surfaces, above which the laminations are usually horizontal but show an upward increase in inclination before being terminated by the next low-angle truncation.

Although individual cross-bedded units at Coombe Clints range up to three or four metres in thickness, they are believed to be merely the basal remnants of dunes of originally much greater height. The major bounding surfaces separated the remnant of an older eroded dune from a newer accumulation in a dune that advanced downwind to cover it. The section, Figure 4a, is aligned in a NW - SE direction and lay roughly parallel to the prevailing Permian palaeowind direction (Waugh ibid., Arthurton and Wadge ibid.) while the bluff section, Figure 4b, exposes a section partly at right angles to the wind direction. The sections can be interpreted as a sequence of dunes migrating towards the north-west, with later dunes truncating and climbing over the remnants of earlier ones. The major bounding surfaces at the base of each unit represent erosional deflation surfaces, often forming deflation hollows with gravelly residues where sand has been removed by the wind at the lowest level of a dune.

Fluvial Facies

Fluvial deposits occur on the west bank of the River Eden at Lowhouse Woods, 5km north of Armathwaite, and are approached along the riverside path to Wetheral. This sequence of water-laid sandstones, mudstones and pebble beds is defined as the Lowhouse Member and is believed to lie some 100m below the top of the Penrith Sandstone Formation. Riverside cliffs from GR. NY 515 491 to 516 492 provide 200m of exposures up to 10m in height (Fig. 5). The sequence consists of cross- and planar-bedded sandstones, purple-red siltstones and chocolate coloured mudstones together with coarse pebble beds (brockrams) which contain clasts up to 200mm in diameter. A conglomeratic horizon also forms the river bed along this section and, when the river is low, can be traced upstream for 600m as far as NY 515 485. The clasts in the conglomerates are sub-angular to rounded and consist predominately of medium-pale-grey limestone. Infrequent sandstone and siltstone clasts heavily impregnated with iron are also present.

Interpretation of the Lowhouse section

Alluvial fan sediments become finer with increasing distance from the fan apex, merging with those of the floodplain beyond the edges of the fan. The exposures in the Lowhouse section are formed by shallow water flows in the distal areas of a fan, either as downstream elements beyond braided stream deposits or in overbank flooding of channels on the fan. They consist dominantly of thinly laminated and relatively well-sorted fine pebble, gravel and coarse sand units up to 1m thick, overlaid by thin, planar laminated silty sands

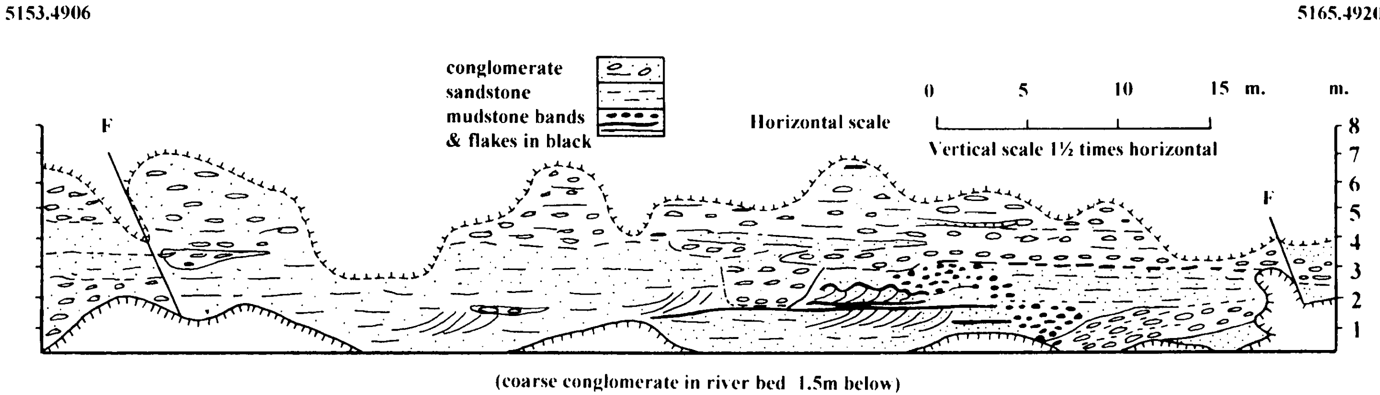

Fig. 5 Diagram illustrating the Lowhouse cliff section along the west bank of the River Eden 5km north of Armathwaite, adapted from Figure 16, Trotter and Hollingworth, 1932. The sequence consists of cross-bedded and fluvial sandstones, siltstones and mudstones with coarse pebble-beds (brockrams).

deposited during the waning stage of floods. Such deposits commonly show small-scale basal channelling but contacts are often non-erosive. Although much of the sandstone is structureless or planar-bedded, high angle cross-bedding can be seen in some layers, which with the well-sorted and well-rounded appearance of quartz grains in the bands, suggest that they may represent temporary encroachment by aeolian dunes and locate the deposits as lying on the margins of a dunefield.

The mudstones are laminated with features including dessication or sun cracks and mud curls. These result from muds deposited in small ponds on the flood plain drying out and producing polygonal patterns; these may be preserved due to infilling by wind-blown sand. Subsequent floods have ripped up these areas of mud curls and formed accumulations of mudstone fragments, known as mud rip-up conglomerates.

The sources of the fluvial sediments are difficult to determine since the exposures only reveal the finer, distal components of possible alluvial fans. The presence of a fluvial horizon in some nearby boreholes gives some indication of its areal extent but does not narrow down the location of its source. Table 1 summarises information from the boreholes shown in Figure 3.

The clasts were derived from rocks of Lower Carboniferous age, probably the thick limestones of the Alston Group, and did not originate from the Lower Palaeozoic rocks of the Lake District massif, confirming observations by Trotter and Hollingworth (1932). Lower Carboniferous rocks today crop both to the west in the Caldbeck district and to the east along the Pennine escarpment. Either province could have sourced the deposits, with fans originating on distant high ground and their margins reaching into the northern area of the Vale of Eden basin.

Borehole	Grid Ref.	Details from borehole logs
Ainstable	NY 5257 4645	97m sandstone
Nord Vue	NY 4939 4426	58m sandstone. bottom 15m bleached
Wragmire Head	NY 4633 4863	73m sandstone with mudstone & conglom. bands in bottom 35m
Blackpool Moss	NY 4824 4816	37m sandstone with alternations of mudstone, sandstone & congloms. at 19m & 31 m depths
Low Hesket	NY 4607 4739	68m sandstone, 'brockram at 47m, 117m Coal Measures beneath,
Cocklakes Quarry	NY 4563 5093	14m Eden Shales, 80m sandstone, brockram & sandstone in bottom 17m. - Finished in C.M.s.

Table 3 Summary borehole data - see Figure 3

Post - depositional changes

Two features of post-depositional changes are illustrated in the Penrith Sandstone Formation rocks of the Armathwaite district, one of which may be confined to the sandstones at Coombe Clints.

Dolomitisation of limestone clasts

Limestone clasts in the Lowhouse deposits appear to have been recrystallised after deposition with limestone clasts being extensively dolomitised. Many show internal zonation and contain cavities or geodes lined with calcite. Similar features have been identified at localities in the south of the Eden basin, such as Thistley Quarry, Appleby, and Belah Scar, Brough Sowerby. In contrast the proximal areas of alluvial fans, seen south of Kirkby Stephen and in Hoff Quarry west of Appleby, contain fresh, unaltered limestone clasts. Waugh (1970) suggested that the mineralising fluids were derived from dolomitic and gypsiferous horizons within the overlying Eden Shales. The extent of the original cover by the Eden Shales probably provided the control, with the coarser proximal areas of the fans standing above the cover of Eden Shales and thus escaping dolomitisation,

Bleaching of the Penrith Sandstone at Coombe Clints

The Penrith Sandstone is known throughout the Eden Valley for Its characteristic red-brown colouration. In marked contrast, the sandstones in the Coombe Clints section are a pale biscuit colour. This feature is particularly noteworthy at the northern end of the section for to the south the colouration becomes stronger, firstly an orange shade before assuming its characteristic red-brown colour.

It is believed that the red colouration of Permian sediments is a reflection of 'in situ' reddening within a hot, arid desert with the formation of a porous pellicle or skin of hematite and illite around each sand grain (Arthurton and Wadge 1981). It would appear therefore that the original red-brown colouration of the sandstone at the northern end of the Coombe Clints section has been bleached by some process that reduced the ferric oxide pellicle around the quartz grains to ferrous oxides. The most likely cause of such a reduction would be a passage of methane through the porous sandstone and a possible source of methane can be recognised in this locality.

A Tertiary WNW-trending basic dyke, the Armathwaite Dyke, crosses the district and is exposed in the River Eden at Armathwaite Mill where it is 27m wide. Figure 3 shows the location of the dyke and indicates that it is only 100m from the northern end of the Coombe Clints section. While metamorphic alterations along the contacts with the Penrith Sandstone are confined to bleaching of a marginal zone of a few centimetres, a more likely source of methane may lie in Carboniferous strata at depth.

Chadwick et al (1995), in their review of the Late Dinantian-Silesian post-extensional phase of basin development, suggest that thick developments of Coal Measures concealed in the Solway Syncline between the Cumbrian and Canonbie coalfields continue round the northern margin of the Lake District into the Vale of Eden. However the Coal Measures rocks are commonly reddened and coals removed to a depth of more than 100m beneath the sub-Permo-Triassic erosion surface in the Solway-Cumbria district, resulting from post-Carboniferous weathering. Deep oxidation occurred when the climate was arid, the water table lay well below the surface and oxidation set in. There was much erosion before Permian deposition commenced and deeper stratigraphical levels were reddened as the land surface was lowered (Mitchell et al, 1978).

So it will depend upon the thickness of Coal Measures strata beneath the Permian unconformity or the presence of carbonaceous beds within the Carboniferous as to whether any coal seams remain within the Eden Valley basin from which methane could be generated. However in their discussions of coal-bed methane resources*, Chadwick et al, (p.51) suggested that the Coal Measures in the Vale of Eden with those beneath the Solway Firth may represent a considerable, as yet unproved, coal-bed methane resource*.

(*Coal-bed methane is adsorbed methane which can be extracted directly from coal seams, rather than free methane produced from porosity in conventional reservoir rocks - an energy resource not yet exploited in UK)

It is well known from work in the North-East coalfields and the Alston Block (Ridd et al, 1970, Creaney, 1980) that coal seams close to igneous intrusions will suffer thermal metamorphism. Examples of dykes cutting coal seams resulting in the carbonisation of the coal have been known for many years (Skipsey, 1960) and so it can be postulated that the Armathwaite Dyke may cut Coal Measures or Lower Carboniferous strata at depth, resulting in the generation of methane. It is further postulated that this methane has migrated upwards, perhaps along fractures resulting from the intrusion, and that the bleaching of the sandstones at Coombe Clints is evidence of this event.

Conclusions

This article has reviewed the evidence from the northern part of the Vale of Eden which confirms a desert environment in Permian times. The rocks of the Appleby Group consist principally of aeolian sandstones with associated fluvial sandstones and basin-margin continental breccias. The most striking feature of the aeolian Penrith Sandstone is the steeply dipping cross-bedding which is interpreted as a sequence of dunes, with later dunes truncating and climbing over the remnants of earlier ones. A fluvial sequence, the Lowhouse

Member, within the aeolian sandstone sequence consists of cross-bedded sandstones, water-laid siltstones and mudstones together with coarse pebble beds which are believed to be distal alluvial fan deposits although the sources of the sediments are difficult to determine.

The radical differences in Permian climate and environment to those of the present day UK can be explained by changes in the locations of the continental landmasses around the surface of the Earth and global climate patterns. By Permian times, 260 million years ago, the continents that had existed throughout the Palaeozoic had collided and fused into one single super-continent, known as Pangaea. Palaeomagnetic and palaeowind data indicate that the land that was to become Britain lay within this large continental mass, located at about 10 degrees north of the Permian equator, and with dominant winds from the east. Like the Sahara and Arabian Deserts today, this latitude was marked by a major desert belt and so Britain lay in a region of hot deserts.

During Permian times the Eden basin occupied a low lying depression in the rain shadow of ranges of rocky hills lying to the east with others to the south and west. These upland areas were occupied by stony desert landscapes which contributed the debris that formed the marginal alluvial fans while the depression was filled with shifting sand seas, mobilised by prevailing easterly palaeowinds. Around the margins of the basin there is evidence of some interfingering of the contrasting facies.

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DID THE WEST CUMBRIAN HEMATITE DEPOSITS FORM DURING THE BREAK UP OF THE PANGEAN SUPERCONTINENT?

John Rowe

Introduction

The west Cumbrian hematite deposits (Figure 1) are large ore bodies hosted within the Dinantian Limestones around Egremont which have long held a fascination for geologists. A series of models have been proposed to explain the genesis of these deposits (e.g. Goodchild 1889-90; Kendall 1875; 1882; Trotter 1945; Rose & Dunham 1977; Dunham 1983), however, their origin remains unresolved. This article briefly describes the results of recent palaeomagnetic and geochemical analyses (Rowe, 1994, Rowe *et al.*, 1998 and Rowe & Burley, *in press*) which closely define the age of ore genesis and nature of the fluid from which the hematite precipitated and thus constrains which model most fully explains the observed mineralization.

Geological setting and occurrence of the hematite deposits

The geological setting of the deposits is described in detail by Rose & Dunham (1977). In the locality of the study area (Florence Mine, to the south of Egremont) rocks of the Lower Palaeozoic Ordovician Skiddaw Group are overlain by the Borrowdale Volcanic Group (BVG). The hematite deposits are generally hosted within Dinantian Limestones which unconformably overlay the BVG and which, in turn, are overstepped unconformably by Permo-Triassic cover. Up to 60m of Quaternary boulder clay is present at the surface in the Egremont area (Rose & Dunham, 1977).

The west Cumbrian hematite deposits are spatially associated with the north-south trending Lake District Boundary Fault which partly defines the eastern margin of the East Irish Sea Basin (EISB, Figure 1). This basin-bounding fault juxtaposes the offshore Permo-Triassic EISB sequence against the Dinantian Limestones and Lower Palaeozoic strata of west Cumbria.

Models of ore genesis

Two conflicting schools of thought emerged during the nineteenth century to explain the origin of the west Cumbrian hematites and have strongly influenced all subsequent ideas of ore genesis. Kendall (1882) advocated the ascent of iron-bearing fluids associated with igneous activity that precipitated hematite upon cooling. In contrast, Goodchild (1889-90) proposed that surface water percolated down through the Permo-Triassic red beds, dissolved iron and re-precipitated it as hematite within the limestone.

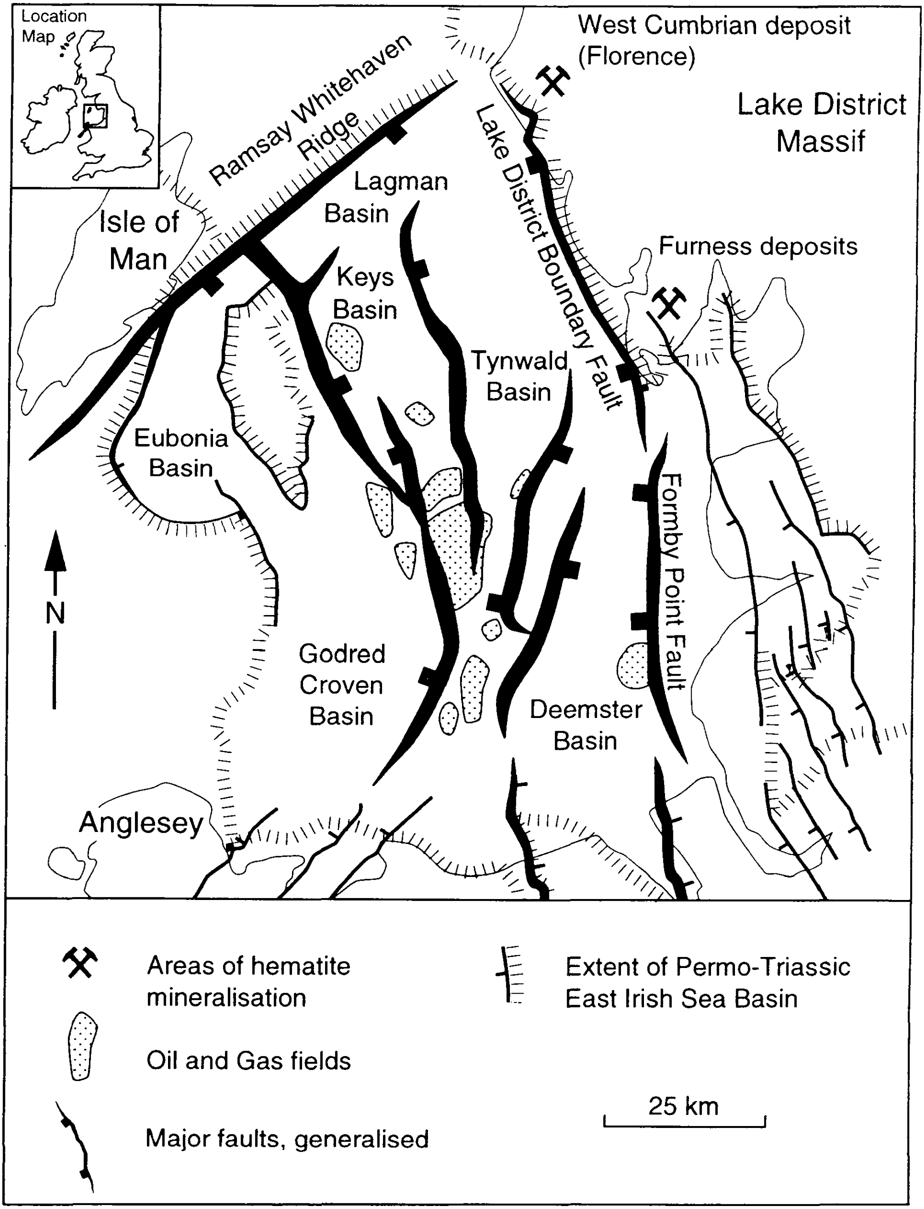

Figure 1. General geological sketch map pf the EISB showing the regional setting of the West Cumbrian hematite deposits. Taken from Rowe *et al* 1998.

Rose & Dunham (1977) put forward the model of ore genesis which has received most recent acceptance and which the present study was designed to test. In common with Goodchild (1889-90), Rose & Dunham (1977) suggested that geological evidence (such as the dip of the orebodies) indicated a descending rather than ascending fluid, noted the spatial relationship of the south Cumbrian hematite deposits with the large EISB and postulated that the mineralizing fluid was a basinal brine expelled from the EISB during burial or uplift. Dunham (1983, 1984) subsequently used the same hypothesis to explain the formation of the west Cumbrian hematite deposits. The mineralizing fluids were envisaged by Dunham (1983) to have leached large amounts of iron from the offshore Permo-Triassic red bed sedimentary rocks of the Sherwood Sandstone Group (SSG). This iron re-precipitated as hematite at the basin margins where the sandstones were in direct contact with the limestones (either overlying or fault juxtaposed). According to this model it is implied that the hematite deposits post-dated both:

i) deposition of the SSG (believed to be Scythian in age; Warrington et al. 1980) and,

ii) burial of the offshore SSG to depths of greater than 2.5 km; the estimate of which was based on microthermometry of fluid inclusions entrapped within gangue minerals associated with the hematite reported in Shepherd (1973). A burial history curve in Stuart & Cowan (1991) indicates that the EISB attained a depth of 2.5 km during the Early Jurassic.

Palaeomagnetic analysis and age of the mineralisation

To test the model of Rose & Dunham (1977) thermal demagnetization of 21 orientated specimens collected from Florence Mine was carried out using the methodology of Collinson et al. (1967). Details of the methodology and results of these analyses are detailed in Rowe et al. (1998). However, the mean magnetic direction, after thermal demagnetization, has a south-western declination of 203° and a shallow negative inclination of -13°. A single, thermally stable, primary magnetic component is present in all specimens studied and this is interpreted as chemical remanent magnetism (CRM) which formed as the hematite precipitated from solution at temperatures below the Curie Point of hematite (690°C). The presence of CRM with no major secondary overprint records the polarity and direction of the Earth's Magnetic Field during ore precipitation. The pole position for the Florence Mine specimens derived from the mean direction is 38.6°S, 333.5°E. Figure 2 shows the apparent polar wander path (APWP) for northern England, south of the Iapetus Suture based on the work of Trench & Torsvik (1991). To allow the age of the hematite to be assessed, the pole position calculated from this study and a number of reference published pole positions of Carboniferous and Permian age are superimposed on the APWP (Figure 2).

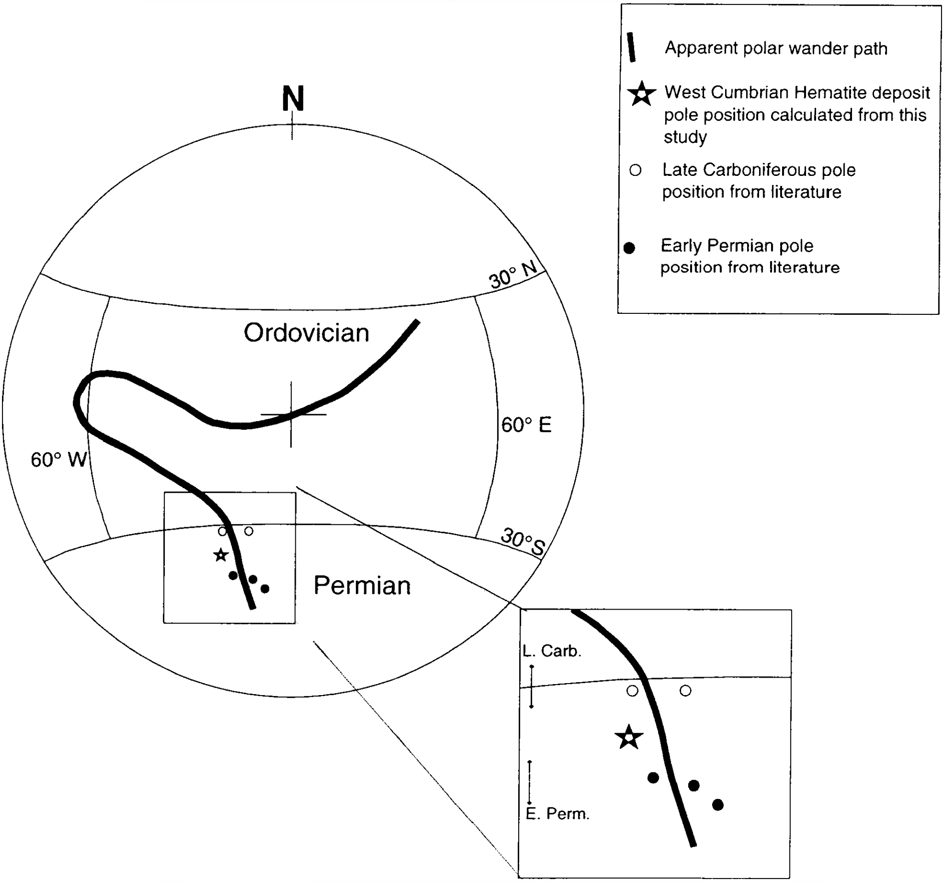

Figure 2. Ordovician-Permian apparent polar wander path (APWP) for Northern Britain south of the Iapetus Suture (based on Trench and Torsvik 1991) with an expansion of the Late Carboniferous to Early Permian portion. Superimposed upon the APWP is the pole position for the Florence deposits calculated in this study and published Carboniferous and Permian pole positions. Figure modified from Rowe *et al.* 1998.

In Figure 2, two Late Carboniferous poles plot north of, and are older than, the Florence Mine pole position and three Late Carboniferous-Early Permian poles plot south of, and are younger than, the Florence Mine pole position. Thus the hematite deposits formed at some time between the Late Carboniferous and the Early Permian and ***cannot*** have precipitated from fluids expelled from a Permo-Triassic basin which would not develop for another c.40 Ma.

Constraints upon the nature of the mineralising fluids

Gangue minerals associated with the hematite have been investigated by microthermometry of fluid inclusions and stable isotopic analysis in an attempt to constrain the source and nature of the mineralising fluids. These data are detailed in Rowe (1994) and Rowe & Burley (in press). Microthermometry of brine-filled fluid inclusions entrapped within authigenic quartz, fluorite, dolomite and calcite which co-precipitated with the hematite yield homogenisation temperatures in the region of 120°C. These homogenisation temperatures are typically taken as an approximate fluid temperature at the time of formation where no pressure correction is possible. The inclusions contain extremely saline fluids (up to 25 % NaCl wt. eq. or about 6 times the salinity of seawater). Stable isotopic analysis of authigenic barite, dolomite and calcite strongly indicate precipitation took place during the Permian and suggest that the mineralising fluid had evolved from Permian seawater.

Potential fluid sources and conclusions

As shown above, the hematite deposits precipitated from a hot, extremely saline fluid which had evolved from a Late Carboniferous/Early Permian seawater. Without the constraints from geochemistry described here, three potential fluid sources are suggested in Rowe et al. (1998):

i) The hematite ore bodies precipitated from a brine expelled from another older sedimentary basin (possibly the Stainmore or Bowland basins)

ii) The hematite ores precipitated from a fluid associated with igneous activity.

iii) The hematite ore deposits are related to the ingress of surface-derived fluids.

However only the second fluid source can readily produce a suitably hot and saline fluid. There is a growing body of evidence that at the time the hematite deposits were forming the EISB area was a site of Permian rifting and associated igneous activity during the break-up of Pangea (Penn et al. 1983; Hardman 1992; Quirk & Kimbell, 1998; Shelton, 1998). This igneous activity provided a potentially large, local source of heat, solutes and metals during the Early Permian. It seems entirely possible that circulation of seawater (possibly supplied during early seawater transgression) around the rift zone could produce a suitable mineralising fluid. Modern day analogues for these mineralising brines, known as geothermal fluids, have been studied from the Red Sea and are characterised by high temperatures, salinities and dense concentration of metals in solution.

Acknowledgements.

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THOMAS HAY, LAKE DISTRICT PHYSIOGRAPHER

Dr R Clark

Introduction

Thomas Hay (1873 - 1957) was one of the more important writers on Lake District landscapes and landforms, publishing twelve papers from 1926 to 1951. His work spanned the time from Marr to Hollingworth, Mitchell, Raistrick and their colleagues. Unlike these latter, he virtually confined his interest to the fell country. Physiography (Hay kept to the older term) changed during this period from a largely descriptive, deductive activity towards a more experimental, numerate science and he contributed to that change in respect of this area. Though he read his papers at London meetings and published in national journals he was not latterly well-known beyond family and the circle of geologists operating in northwest England. He has been described as of rather reserved though genial disposition. In 1938 he received the Back Award of the Royal Geographical Society for promoting understanding of Lake District landscapes and for demonstrating analysis of glaciated landscapes to members of inter-war Arctic expeditions. Alongside his physical landscape papers there are twelve in the Transactions of the Cumberland and Westmorland Antiquarian and Archaeological Society. Now there are very few left who knew him and the circumstances of his rather unusual life have not previously been recorded.

A life of 'two halves'

Hay was born in 1873 of a Scottish Border family settled on Tyneside. He attended Newcastle Royal Grammar School, 1887 - 92, becoming captain of rugby XV and cricket XI. He read mathematics with distinction at St John's Cambridge, graduated in 1895 and became a schoolmaster. Two years later he took a London external B.Sc. After teaching in London and then in Stone, Staffordshire, he moved in 1899 to King Edward VI School, Chelmsford. By 1903 he was Headmaster at Midhurst, Sussex and in 1909 returned as Headmaster to Chelmsford. Following family holidays at the Dun Bull in Mardale he bought Moss Crag, the house in Glenridding which became the base for the exploration of lake shore, dale and fell in which he had been encouraged by Professor Marr and H.R. Mill.

In 1928, the year of his second landform paper, Hay retired from schoolmastering, unusually early for those days and with the reluctant permission from the Governors - though probably prompted by an independent-minded wife tiring of her role at the school. Twenty-five of thirty-three years in teaching had been in headship. The prospect of mostly lone excursions among the hills proved more attractive than some ten more years of school with little or nothing more to prove there. He left Glenridding in the close of the Second World War with great sadness and, again, probably at the behest of his wife whose family home in Nailsworth became available on the deaths of older sisters. Hay then wrote on the history and construction of Bannuttree House and on Cotswold landslips. His last Lake District note appeared in 1951 when he was 78. He died in November, 1957.

'Second half': in the Lake District

David and Michael Hay told how their father 'read a tremendous amount - history, art, literature - he read and aquired a working knowledge of most things. As occasion demanded he taught French and Science - European literature too. Mathematics taught him orderly thinking but above all he was a keen observer'. 'He saw at once that a particular piece of ground, or the position of a boulder, was not quite right - something had happened'.

Observation went in harness with systematic knowledge. Citations show his reading included works in German and French, on the Alps, France, North America and the Arctic as well as a range of Lake District papers from Clifton Ward (1873) on fissures in bedrock to McConnell (1939) on planation surfaces. He also examined alpine landscapes in the company of Swiss geologists as well as joining excursions of British geological societies. Evidently he was a committed and well-prepared student.

His work was described as 'revealing delight in close argument and compact results - a sense of dynamic landscapes, processes at work - all landscape features to be read, to contribute to the story.' Nevertheless an accompanying lightness in style was not much evident in early papers except as flashes of special curiosity. In later papers he pushed for understanding, speculating as an amateur may where caution might otherwise counsel the professional.

His interests took in contemporary landscape processes, notably high magnitude-low frequency events such as major floods: he examined links between rainfall, discharge and their morphological consequences - what, when and where. But he persistently pursued certain major themes, especially the work of glacier ice, the effects of freeze and thaw of ground water, the formation and development of the high-level areas of rather subdued relief.

Rarely, after the early papers, was an article devoted to just one of these themes. There was the habit of returning to topics with new observations, insights, and connections. Though his papers deal with many of the important aspects of Lake District landscape development there is no evidence he was drawn to the popular contemporary planation-level approach to landscape history of which Hollingworth was a prominent local exponent.

Along lake shores

Early studies, started in school holidays, concentrated on comprehensive description and classification of lakeside landforms. He was encouraged in this by Marr and by H.R. Mill of the Lake District Bathymetric Survey. He was advised, too, by Phillip Lake (1865 - 1949), fellow Northumbrian and St John's scholar, Reader in the new Cambridge geography department and remembered by older generations for his 'Physical Geography', for long the standard text.

The ensuing papers (1926, 1928, 1930) remain the most comprehensive accounts of lakeshore forms. Interest in process is exemplified by attempts to explain the sometimes complex and apparently perverse planforms of lakeshore deltas. Among the sorts of feature that puzzled him were masses of waterlaid sands and gravels, their level tops some metres above present mean lake levels, 6m at the head of Ennerdale Water. Possible relations with old higher lake levels were mooted but in general there is little evidence for persistent higher levels. Impounding effects of residual ice masses were also considered. The Ennerdale features, as others, remain to be explained: they need not be linked to levels of the present lake but perhaps to events during loss of glacier ice.

The more interesting features he encountered along the shores owed more to the work of ice, frost, and rivers than to shoreline processes. Hay turned from the constraints of the lakes to broader prospects for his curiosity and to the themes and problems he then pursued to the end of his time in the Lake District.

Fells and dales

The first of the 'new' papers (1934) dealt with glacial landforms in the Ullswater area concluding, in complement to Marr (1916) and Clifton Ward (1875), that erosive ice crossed ridges up to c. 680 m O.D. and that the whole area had been ice covered. He thought that at the end of the last major glaciation dwinding valley glaciers became separated from upland ice masses that sustained a 'Highland Glaciation'. His evidence for the latter and for the intervening ice-free ground is not convincing but no substantial alternative account exists of the end of the latest glaciation in the upland.

He considered there was evidence for two glaciations on the basis of variation in till character and the local presence between tills of water-sorted sands and gravels. At that time such widely-known tripartite sequences were usually taken to demonstrate loss of ice before a second ice advance. The till-gravel-till exposure at Rattlebeck, Glenridding, important in Hay's argument, may have only local significance but, nevertheless, is a fine example of such a succession.

The presence of esker-like features among the drumlins of the lower Ullswater area was seen as indication of stagnation in previously active ice. The Ullswater drumlin tract, with the neighbouring Matterdale tract, adjacent to the field of drumlins from southern Vale of Eden round to the coast between Silloth and St Bees, shows that the ice-sheet conditions which led so widely to drumlin formation extended well into the hill country. Hay recorded that moulding of bedrock by moving ice extended to the scale of whole hills but he did not comment on the repetitive parallel grain of drift drumlins and the moulded rock-hills that stood above the drift or overlooked the drumlin zone from its flanks. Their directional conformity raises questions of contemporary formation, thickness of moving ice and, importantly, relative rates of rock erosion and drift deformation during episodes of drumlin formation.

In the heart of the fells, in the neighbourhood of uppermost valley-head moraines, Hay acutely recorded 'fascinating high-level marginal lines which reveal the old locations of the edge of a stream of ice - seen in certain lights or when the ground is covered in snow'. These trimlines can consist of the most subtle change in slope angle or debris coarseness, easier to see across a valley than underfoot. Though he mapped some associated valley head moraines and knew the 'marginal lines' matched old glacier limits he did not use them to plot the successive limits of valley-head glaciers Almost fifty years were to pass before Sissons (1980) mapped the maximum extents of the many Lake District valley glaciers he ascribed to the short severe Loch Lomond Stadial that concluded the Pleistocene.

Hay recognised the similarity of hummocky moraines in the Scottish Highlands, Torridon for example, and in Lake District dale heads but never overtly associated them with a discrete late episode of glacier formation. Nevertheless, he did record that the apparent chaos of hummocks could be caused by gullies 'breaking up the orderly array of ridges into a disorderly patchwork of more or less isolated mounds, plateaux and ridges.' The 'orderly array of ridges' marks out, as do marginal lines,successive ice margins. Hay, like Manley (1959), was content with general indications of glacier sites rather than plotting the successive margins of individual glaciers. That has been a task for this decade (e.g. Bennett 1990, Bennett and Boulton 1993).

In the 1934 paper Hay distinguished between ordinary 'real scree' and what he termed 'great taluses', the localised collection of huge angular boulders he associated with joint patterns that 'help the slow forces - in loosening and discharging' the massive blocks and with sites 'where local cliff ice or a combe [corrie] glacier - brought down local short-distance erratics'. On a visit to the Dolomites he discriminated between an inner hillfoot 'real scree' on Sasso Beacie and an outer zone of angular, unabraded, unstriated large local boulders which, arranged in a mass of arcuate ridges and furrows, he took to be the moraines of a hillside or 'wall' glacier (1935). He applied this interpretation to Lake District great taluses as at Auterstone near Ullswater, though his Dolomite example was more probably a rock glacier site below a massive rockfall. At that time dynamics of rock glaciers and rockfall were little known. The Auterstone and many other Lake District great taluses were probably from rockfalls, some within the limits of and thus post-dating the last glaciers.

In the 1930s work by Carl Troll and other continental geologists on periglacial processes was penetrating Britain: Hollingworth and Raistrick as well as Hay became interested. Patterned ground resulting from orderly segregation of finer and coarse particles into nets, circles and stripes attracted attention. Hay (1936) proposed an explanation of sorted stripes. The essential problem was not the maintenance but initiation of sorting. Hay said stripes, lateral separations of coarse and fine particles, became fixed only where a subsurface set of downslope corrugations had become stable and that this happened where vegetation had recently been disrupted and eroded. He cut trenches which showed coarser debris occupied the furrows and fines covered the intervening ridges, though whether coarser stripes facilitated run-off and the furrows formed beneath them or the furrows came first was not determined.

Sorting remains problematic even though the general dependence on heave by ice-crystal growth in moisture-retentive fine material is accepted. Werner and Hallet (1993) produced patterns by computer simulation of sorting in a notionally unsorted mixture of variously sized particles. They assumed the ice-crystal process and some random local variation in coarse-fine proportions in the original mix. Hay (1937) had said 'assemblages of small particles may become the focus of collection [sorting] and its operation a 'self-reinforcing process'. Werner and Hallet wrote of self-organisation from local feedback - over fifty years, and computers, later.

The 1937 paper also recorded the first British examples of sliding (gliding) blocks, longer known in continental Europe. These are the surface boulders which slide down hillsides - as some still do in hard winters - with bow waves of turf and soil and furrows behind showing distances most recently moved. That paper dealt especially with the 'continued struggle' especially over c.730m O.D. 'between - downslope movement of materials, and especially frost effects and solifluction - tending to destroy the vegetation ' and the plants 'continually trying to repair the damage and to regain ground from which' as Hay assumed 'it had been temporarily ousted'. Hay noted the incorporation of peat in some frost-generated landforms, the present circumstance having replaced one of greater soil and vegetation stability though he did not discuss how and when that change may have come about.

In 1942 Hay considered several types of upland landform, just four of them noted here. More evidence was presented on high altitude movement of glacial erratics on the western fells near the ice shed. He emphasised the influence of lithology on development of high altitude blockfields and the particular susceptibility of Ennerdale granophyre, and noted presence of glacial erratics in blockfields. He thought, with Marr (1916), that blockfields might survive having been under an ice-sheet and thus 'cannot be used as evidence of the amount of sub-aerial weathering since' though he was quite clear that blockfields resulted from 'vigorous frost-working on massive rocks with well-marked joints'. Distribution and development of blockfields and the possible survival of included erratics from earlier glaciations have been, and are, used in argument over extent and effect of ice cover in North America, Scandinavia, Scotland and elsewhere. As far as is known, the potential of clay mineralogy to shed some light on type, humid temperate or periglacial, and occasion of weathering has not been applied to Lake District summit blockfields*.

In a first British record of stone flats, Hay described how frost-riven blocks at suitable sites tend to 'level themselves out in a flat spread'. Stone flats, level layers of surface stones usually underlain by finer material, are formed in places that have experienced freeze-thaw cycles. High altitude Lake District sites include shallow seasonal pools. Site characteristics vary, and so might the formative processes. At Hartside (756 m O.D.) north of Helvellyn the surface stones were 'wonderfully consistent in size - only one layer of these bigger stones on top - below them a layer of small fragments, and below this fine black soil.' Incorporation of organic material in the sorting and spreading implies Holocene formation of that stone flat.

As he assumed, perhaps from present bareness and mobility, that scree is still significantly accumulating, so he thought that adjacent to the Hartside stone flat the 'little stream of surface stones working their way down the live rock edge, moved by solifluction' meant that in time the 'remaining live rock will disappear.' But the movement of debris, if demonstrable, does not itself show that frost-riving of outcrops remains vigorous. Similar processes were described from near Helvellyn Man (925 m O.D.) and at that height evidence for some present-day frost action is stronger. The combination of frost-riving and solifluction tends to produce 'greater uniformity in outline and so to increase the appearance of subdued relief'. Here he was outlining the progression of what Peltier (1950) later termed the periglacial cycle of landscape development - and he was also implying the continuing Lake District problem: what are the relative contributions to subdued summit-level relief in the fell country of pre-Quaternary temperate processes, prolonged Pleistocene periglacial episodes (cf. Boardman, 1992), erosion by ice and, perhaps, Holocene environments.

(*Footnote - Since the time of writing the author has learned of work in the Great Gable - Sca Fell area that includes study of clay minerals in superficial covers)

Plate 1. Helvellyn seen from Nethermost Pike: photograph by Thomas Hay. The subdued upland relief is of the sort described by Hay as having developed before the Quaternary. Upper parts of corrie walls are seen to the right. The middleground and foreground blockfields with residual crags (right skyline) and upright blocks are examples of features associated with periglacial processes including cryoplanation. How rock waste was moved laterally across slopes is not wholly understood.

'Several narrow but deep fissures occur across the top' of Helm Crag, Grasmere 'not quite parallel to the run of the mountain edge' with gaping fissures and great holes one like a 'huge rough cauldron'. Clifton Ward (1873) had thought earthquake shocks a more probable cause of fissure opening than recent faulting or rock failure on steep slopes. Hay looked at the 'great cracks in the flat ground' at the top of a high, near vertical face in a Threlkeld micro-granite quarry and concluded they had developed due to removal of the buttressing rock: by that token 'oversteepening of the east side of Helm Crag led to its subsequent instability.' The interplay of master joint or fault alignments, slope steepening by ice erosion, isostatic response to rapid loss of ice cover and continuing tectonic adjustments makes singular cause difficult to isolate but it is worth noting that among historically recorded local earthquakes (Melville 1986) are those associated with rockfalls.

Not all reaches of major ice-outlet valleys have been oversteepened. Hay noted valley sides where 'slope of the live rock is nearly in the same straight line as the slope of scree lying at its foot - here is one continuous slope in profile.' He saw attainment of uniform rock slopes at about scree angle as a first stage of that 'long process [by] which the mountain acquires a more subdued form.' Any projecting crags would be 'gradually reduced until a continuous [uniform] slope covers a wide area.' This was an early British recognition of an important stage in development of slopes where scree did not accumulate thickly above slope foot. Well after Hay's time in the Lake District it was described as a 'remarkable new geomorphological law' and the straight rock-cut, scree angle, hillsides were termed Richter slopes after an early continental geomorphologist. Such slopes are widespread in the Lake District.

Quite straight valley sides occur in both narrow V and broad-bottomed valleys. Some of the Richter slopes carry evidence of glacial erosion but if their general straightness was achieved in periglacial environments it may well have survived the most recent general glaciation rather little modified. Not all the abraded and plucked rock surfaces were subsequently removed in the brief but severe Loch Lomond Stadial. Clearly there is more to learn of how the dales acquired the detail of their shapes.

Of the three topics in the 1943 paper, freeze-thaw processes and sorted stone stripes, how asymmetric forms may be produced by moving ice, and the value of U and V valley cross-sections in discriminating between fluvial and glacial influences, the last is not touched on elsewhere. Hay noted the difficulties experienced on the north Pennines, certainly glaciated, in determining that fact from the shapes of local valleys, and also that certain Lake District dales have both wide open 'U-shaped' and constricted 'V-shaped' reaches though, patently, the whole valleys had discharged ice. Henri Onde (a continental geologist) had asserted that both valley forms could result from ice erosion reflecting difference in valley long profile steepness and thus the likely rates of ice movement. Hay resolved to test the relationship by measurement and concluded from his Lake District sample 'the fact that the V-shaped valley - where inclination is steep - has sufficed - owing to the swifter flow of ice - for the passage of ice which on a more gentle slope needed a U-shaped bed for its transit implies that a valley cannot be classified as non-glaciated simply because it is V-shaped,'

There was a last brief note in 1951 but two 1944 papers were the last substantial Lake District contributions. The first (a) returned to several old topics, high altitude ice transport, the Rattlebeck exposure, but particularly to valley moraines. Hay had commented in 1942 that moraines 'do not occur in our main valleys with anything like the frequency expected'. That led to the view that where 'morainic matter was deposited it must often have been exposed to very destructive influences'. He assumed, reasonably, that declining valley glaciers, immobile or still active, would leave spreads or ridges of moraine. The arcuate moraines at Rosthwaite, Borrowdale, had long been known. Hay ascribed this rare case of survival, as he saw it, to The How, one of two ice-abraded rock bosses projecting through the drift - presumably part of a more extensive rock bar separating valley basins with lower rockhead. There, 'braided streams could wander' eroding moraines: 'if there had been no How there might have been no moraines', that is, no protection from erosion.

No systematic search by Hay or subsequently for other moraines of the main glaciation is known. Sporadic observation suggests the few other moraine ridge sites down-dale from the valley heads are protected by rock bosses, spurs, or lie out of reach of rivers. Where valley-floor rockhead is low, some moraine could have been buried under younger deposits. Enough evidence remains to suggest that some Loch Lomond Stadial glaciers extended significantly beyond the limits mapped by Sissons (1980) or that some valley glaciers were active quite late in the decline of the preceding general ice cover, conceivably both.

The 1944 (b) paper is a wide-ranging discussion of the shapes of the Lake District mountains. Hay was about seventy then and retained his compact yet discursive style, implying, pointing rather than explicitly unravelling all his argument, expecting the reader to take both point and significance. He noted that in the Southern Uplands 'the rounded forms of the mountain tops are - ascribed to ice action by Scottish geologists' while the 'small parts of Lakeland with rounded summit land' were thought by Marr to be 'a remnant of the preglacial surface practically unaltered by ice action.' How can two such divergent interpretations be true of the two areas situated so close together - that they experienced practically the same later history?'

He recognised contrasts in intensity of ice erosion in and adjacent to the Lake District fells. While erosive ice had sufficient power to reshape hills marginal to the main fells there were areas within the central fells that seemed little affected by ice erosion. He outlined the decline in intensity of modification northwards from the ice-shed area along the Helvellyn ridge to beyond Raise, the northermost place 'where ice action has had much influence on the summit land'. Presaging by thirty years Clayton's (1974) classification of glacial landscape by degree of alteration Hay identified:

- 'foothills where the rounded form is very noticeable - they have been subjected to heavy ice attack,
- great valleys show the effects of ice action in their U-shape - truncated spurs - and hanging valleys,
- rugged land between the valleys - up to the summit areas - the whole the result of the plucking action of the ice,
- summit land - mainly rugged and irregular - the direct result of plucking and removal of blocks,
- parts of the summit areas have a gently sloping surface - like elevated downs - Marr interpreted [them] as relics of the preglacial surface,
- combes or corries and cliff walls - most face some point between north and east'.

By now his views on the summit surfaces were somewhat complex. He knew evidence pointed to ice-erosion having occurred close to the ice-shed, the top of Great Gable for example, but also to survival of summit block fields through glaciation. The inhibiting notion that thinner ice over high crests would everywhere and always be cold-based and thus erosively ineffective, field evidence to the contrary, was to come later.

Retrospect

Hay's Lake District physiography was but one part of his 'second half': there was Hay, local historian. It is to be considered in the context of its time. The discursive, essay-style was not displaced by the formal almost stereotyped structure of scientific papers until well after the Second War. Possibly professional papers of his time were more often controlled in construction than some of Hay's but comparisons with those by his contemporaries and immediate successors on similar topics might show choices of word and phrase to be the more obvious differences.

The essential quality, noticeable even in the earliest papers, was curiosity - the recognition that there was something needing to be understood and thus, as teacher, to be explained. His papers sustain much of their value and are still cited, as by Ballantyne and Harris (1994), Gurney (1995) and in Boardman (1997). They are a record of things seen, questions posed, answers proposed. It is still appropriate to read Hay, as Marr, for a perspective on what has been said and thought about local landscapes and, importantly, for what there may be still to do.

Nonetheless, two important regrets persist. Had Hay been encouraged to seek locational relationships among landforms and their likely associated processes, and to explore their order in time his conclusions might well have been much more significant. As it was, forty or fifty years were to pass before some of his topics were taken significantly further: some have not been.

The second regret is that in the years just after the Second War, when his work was fresh and known, more was not made of the opportunities it revealed. In the next twenty or so years only some eight Lake District landscape papers appeared, on such diverse topics as scree (Andrews 1961, Caine 1963), sorted stripes (Caine 1963), glacial troughs (Linton 1957), district glaciation (Gresswell 1952, 1962, Walker 1966), planation surfaces (Parry 1960) and Late Glacial moraines (Manley 1959). Younger students seem to have been given confining topics, established scholars didn't take understanding very much further. There were no integrating studies on broad scales and none that pulled together a range of landform types, distributions and processes. There are parts of the fell country Hay didn't mention and to all intents and purposes they remain unstudied, notwithstanding the more recent resurgence in glacial and periglacial studies. Much remains to be done.

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ORIGIN AND SIGNIFICANCE OF A LATE DEVENSIAN MELTWATER CHANNEL SYSTEM NEAR AUGHERTREE FELL, NORTHERN CUMBRIA.

Darrel A. Swift

Introduction

This study examines the origin and significance of a Late Devensian meltwater channel system near Aughertree Fell, northern Cumbria (Figure 1). Aughertree Fell, with its principal summit of Green How, forms part of a larger upland area of gently-dipping Carboniferous Limestone to the south of the Sandale-Faulds Brow ridge (Shipp, 1992). Ice flow directions were believed to have been predominantly E-W in the vicinity of the Sandale-Faulds Brow ridge at the Late Devensian maximum (Hollingworth, 1931: Plate XXVII; Eastwood et al., 1968: Fig. 23, p223). However, a more detailed pattern of ice flow to the south of this ridge is revealed by drumlins in the Ellen and Eller Beck valleys and by a small streamlined feature on Aughertree Fell (Elfa Hill, Figure 2). These trend ESE-WNW to SE-NW and appear to represent ice flow partly constrained by the underlying topography. An impressive c.4km-long rock-cut channel, dry in its upper reaches, exhibits a similar trend where it crosses a shallow col between the high ground of Aughertree Fell and the Sandale-Faulds Brow ridge and thus breaches a major E-W drainage divide (Figure 2, channel A; Figure 3, A).

The deglaciation of northern and eastern Cumbria was first considered in detail by Trotter (1929) and Hollingworth (1931) who accommodated glacial landforms and deposits into a model of frontal ice-sheet retreat in which englacial and subglacial processes were largely ignored (Huddart et al., 1977; Pennington, 1978). Trotter and Hollingworth mapped numerous meltwater channels in the course of this work but these were believed to have formed solely along ice-sheet margins or from the overflows of ice-dammed lakes. As a result, contrived and unrealistic ice margins were often proposed and many ice-dammed lakes were suggested on relatively little evidence (Huddart et al., 1977). Hollingworth (1931) interpreted the Aughertree Fell channel as having originated at the retreating margin of an active (i.e. still forward flowing) ice-sheet after ice occupying the Eller Beck valley became separated from that on the Solway Plain to the north. A clockwise 'splitting-off' of valley glaciers around the northern Cumbrian Mountains from the main ice-sheet had been suggested for other localities in northern Cumbria (Eastwood et al., 1968) and Hollingworth presented evidence for such an event from both the Ellen and Eller Beck valleys (Figure 1). In the former, two gravel deltas at c.150m OD were believed to indicate the former presence of a lake dammed by the main ice-sheet as the Ellen valley glacier 'split off' and retreated to its source in the Uldale Fells (cf. Figure 5, A and B). Hollingworth suggested that further retreat caused the separation of ice between the Ellen and Eller Beck valleys and the formation of a second lake in the Eller Beck valley. Dammed by an easterly-

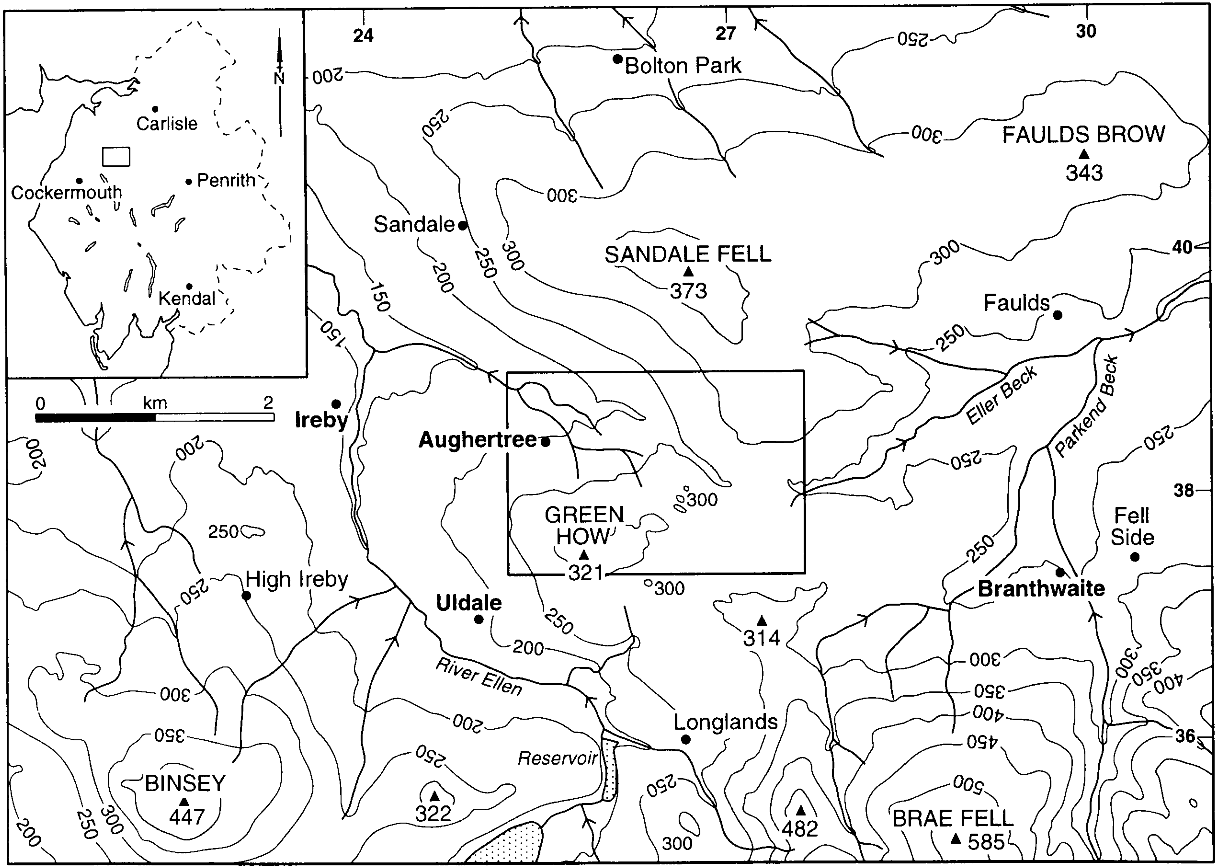

Figure 1. Aughertree and the surrounding area. Box shows location of Figure 2. All heights are in metres

retreating ice front, this lake was believed to have overflowed via the Aughertree Fell channel and into the drainage of the River Ellen.

The glacial landforms and deposits of the Aughertree Fell area have also been documented by Eastwood et al. (1968) who simply confirmed those facts already given by Hollingworth (1931). More recently, much evidence throughout northern Cumbria has been re-interpreted in support of a model of ice-sheet downwasting whereby the outer margins of the ice-sheet stagnated and decayed in situ (e.g. Huddart, 1970, 1991, 1994). However, the likelihood of ice-sheet stagnation is increasingly being questioned by glaciologists (Bennett and Glasser, 1996) and in Cumbria it has been argued that very little is known in detail about former ice flow directions or the nature of the last ice-sheet during deglaciation (Mitchell and Clark, 1994; Boardman, 1996). Mitchell and Clark (1994) have further suggested that many studies still remain largely based upon the early work of the Geological Survey and have criticised them as being superficial and outdated, having incorporated evidence tainted by obsolete theories and the archaic assumption that all evidence was formed penecontemporaneously. Thus, in the light of a greater understanding of both ice-sheet dynamics and glacier hydrology, a re-investigation of the Aughertree Fell channel system was conducted in order to ascertain more rigorously both former ice flow directions and the nature of the Late Devensian ice-sheet during deglaciation.

The Aughertree Fell channel system

Geomorphological mapping of the Aughertree Fell area was performed from stereoscopic aerial photographs at a scale of 1:7,000 (Figure 2). In addition to the main channel identified by Hollingworth (channel A), this revealed evidence of smaller channels located across topographic highs and on the lee-side (i.e. down-glacier side) of both Aughertree Fell and part of the Sandale-Faulds Brow ridge (channels B to M). Those channels crossing the pre-glacial drainage divide were then investigated in the field in order to establish the nature of their long-profiles (Figure 3, A to G). For channels B to G, channel floor gradient was measured at 14m intervals by abney-traverse from an arbitrary starting point below the drainage divide but close to the channel entrance. The profile of channel A, however, was measured at similar intervals for a distance of 1.8km from its point of inception. Features on the Sandale-Faulds Brow ridge were not investigated on the ground due to restricted accessibility. The glacial deposits of the field area (Figure 2) are characterised by a thin covering of till and the absence of sediments of glaciofluvial origin, while post-glacial sediments, comprising alluvial fans at the confluence of ephemeral tributaries and occasional debris flows, are strictly confined to channel A.

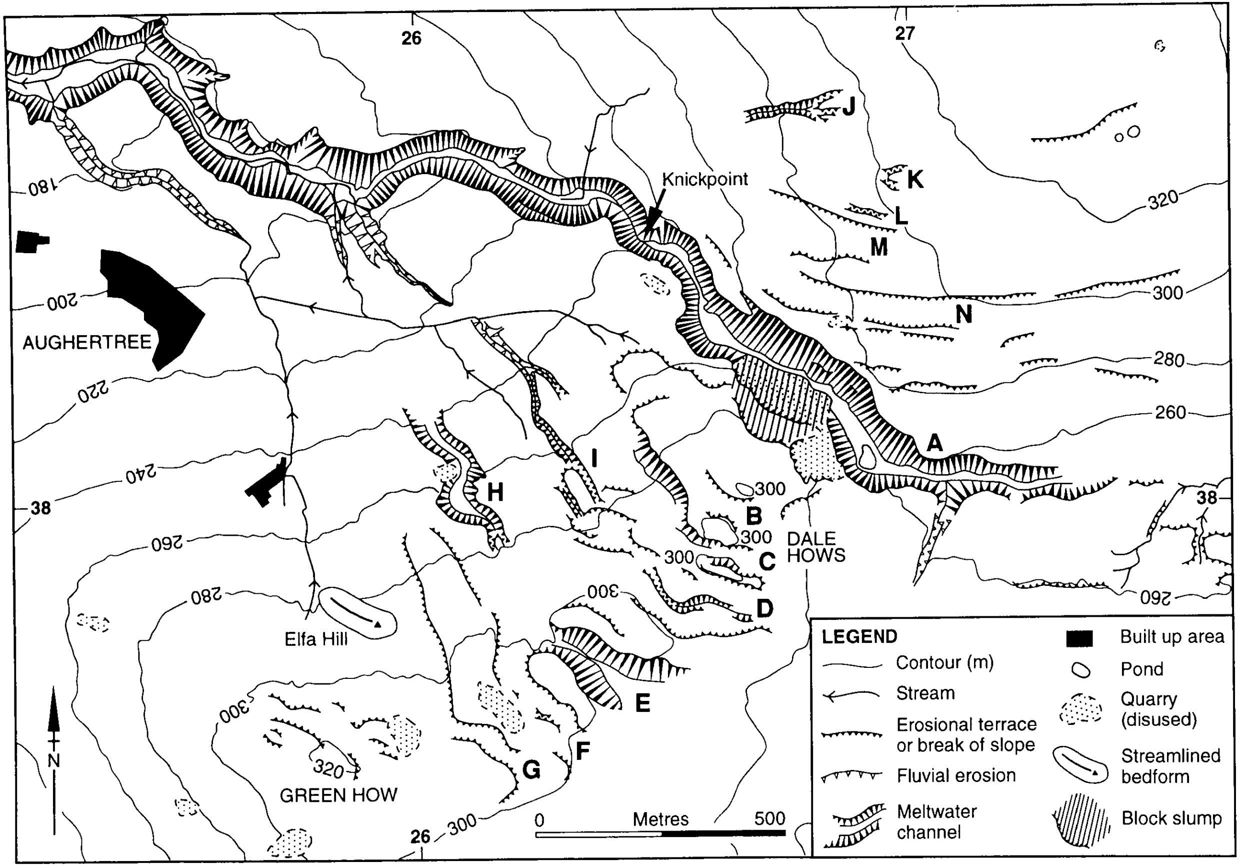

Figure 2: Geomorphology of Aughertree Fell and part of the Sandale-Faulds Brow ridge. All heights are in metres

Figures 2 and 3 reveal a morphology and distribution consistent with that of other channel systems observed throughout Great Britain (e.g. Price, 1960, 1963; Sissons, 1960, 1961a, b, 1963; Clapperton, 1968; Russell, 1995; Menzies, 1996). The channels in the Aughertree Fell system may be considered in four groups:

CHANNEL A: This is a sinuous c.4 km-long rock-cut channel (Figure 2), the upper 1.75 km of which sustains streamflow only after exceptional rainfall. Breaching the E-W drainage divide, the channel descends vertically over 100m from its point of inception at c.250m OD in the Eller Beck valley to its indistinct termination at c.140m OD in the adjacent Ellen valley. Up to 20m deep and 100m wide, the steep-sided and flat-floored channel is most well-developed along a c.500m section where it crosses the drainage divide. Here the channel is less sinuous, trending SE-NW, and appears to have possessed a uniform cross-profile which has since undergone block slumping and subsequent quarrying along the west wall. The channel floor is also distinctive, lacking any significant reverse gradients but exhibiting a complex long-profile which includes a definite knickpoint at approximately 230m OD (Figure 3, A).

CHANNELS B TO G: These dry channels are cut into bedrock across the ridge of Aughertree Fell at 300m OD and breach the E-W drainage divide (Figure 2). They are short (c.100-250m) and often poorly developed features of no great depth (up to 3m), though some are comparable in width to channel A. They are orientated ESE-WNW to SE-NW and exhibit humped long-profiles which are virtually coincident with the pre-glacial drainage divide (Figure 3, B to G).

CHANNELS H TO K: These channels are located on the lee-side of Aughertree Fell and the Sandale-Faulds Brow ridge between 240 and 300m OD (Figure 2). Extending only a short distance down the fell side, they are shallow (up to 2m deep), rock-cut features of variable width which are commonly associated with a number of feeder channels. Those on Aughertree Fell trend SE-NW while those on the Sandale-Faulds Brow ridge are orientated E-W. None possess humped profiles and all are dry, with the exception of channel I whose lower portions are occupied by a minor streamlet. Those on Aughertree Fell appear closely associated with channels B to G.

CHANNELS L, M, N AND TERRACES NORTH OF CHANNEL A: Channels L, M, and N are ill defined but exhibit some continuity of form and orientation (Figure 2). Despite their differences in length and width, each exhibits a similar orientation and occupies a position on the lee-side of the Sandale-Faulds Brow ridge. Together with channels J and K, it is possible that they form part of a continuum of channel forms extending down the ridge and into the col. With the probable exception of channel N, which is the only feature to occupy a position across the drainage divide, these channels are unlikely to possess humped profiles. Short, indistinct erosional terraces are also evident

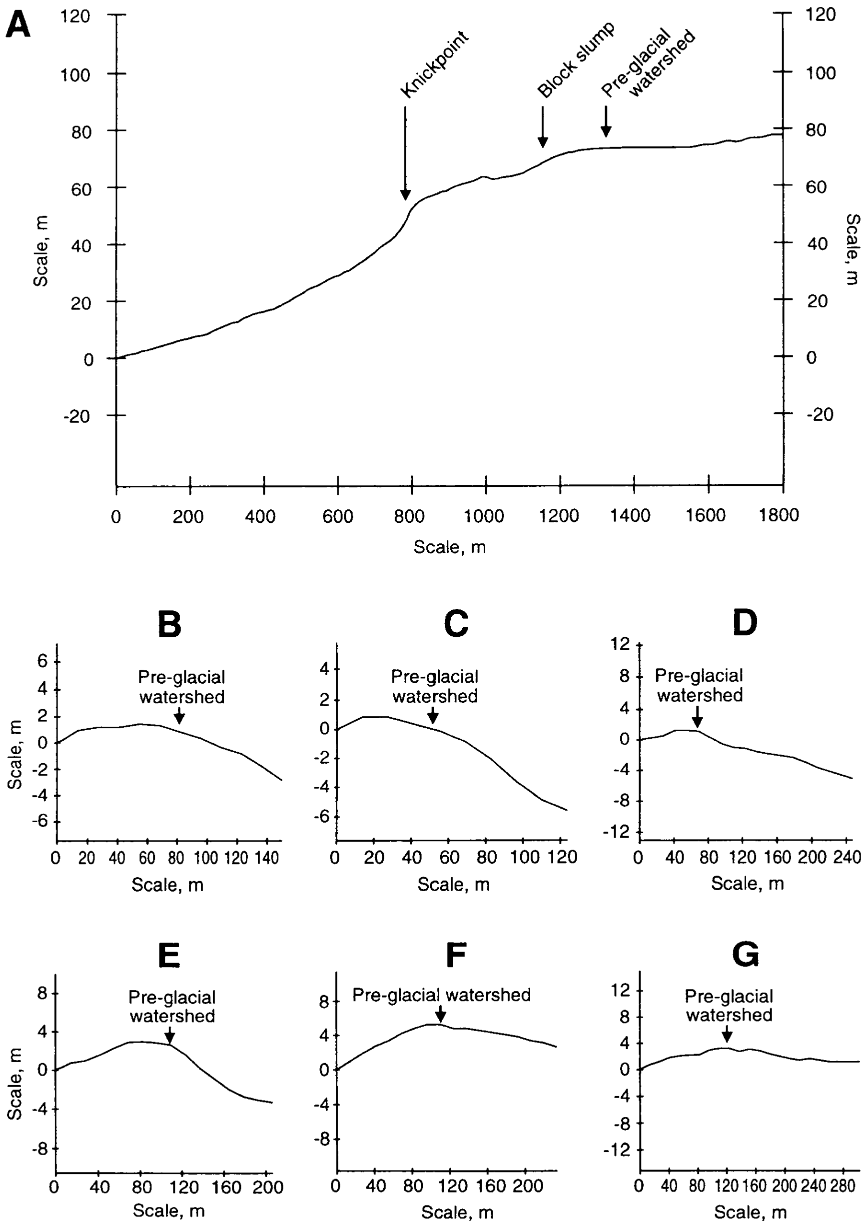

Figure 3: Long-profiles of channels A to G and the assumed location of the pre-glacial drainage divide. Meltwater flow was from right to left. Vertical exaggeration is 10x. Datum for each profile is arbitrary.

on the Sandale-Faulds Brow ridge, one of which appears to form an extension of the northern wall of channel N.

Interpretation

Glacial meltwater channels have been widely documented throughout Cumbria (e.g. Dixon, 1922; Kendall, 1924; Raistrick, 1925; B. Smith, 1932; R. A. Smith, 1967, 1977; Boardman, 1979). Following Kendall's (1902) investigation of meltwater phenomena in the Cleveland Hills, an ice-dammed lake overflow hypothesis of meltwater channel formation became the model for most British studies thereafter (Sissons, 1960; Price, 1963). Having identified many features indicative of ice-damming, Kendall greatly influenced later workers such as Trotter (1929) in eastern Cumbria (Shotton, 1981). However, the latter half of the twentieth century saw the ice-dammed lake hypothesis fall into disfavour. Objections were initially raised by Peel (1949) who noted the presence of 'humped' channel profiles which could not be formed by meltwater flowing under atmospheric (subaerial) conditions. Peel also doubted the ability of Kendall's stagnant, downwasting ice to act as an impenetrable dam capable of upholding large volumes of meltwater. These criticisms were later discussed by Sissons (1958, 1960, 1961a) who succeeded in demonstrating that many humped channels must have formed under pressurised meltwater flow beneath the ice (subglacially). It was further suggested that channels might originate from the superimposition of meltwater conduits located within the ice (englacially) during ice-sheet downwasting (Sissons 1960; Price 1960, 1963; Clapperton 1968).

Theoretical work has since demonstrated that meltwater can flow under hydrostatic pressure both englacially and subglacially (Röthlisberger, 1972; Shreve, 1972; Röthlisberger and Lang, 1987). Shreve (1972) showed that meltwater flow in a full or 'closed' englacial conduit is driven by gravity acting directly on both the water itself and on the overlying ice. Assuming meltwater is at a pressure approximately equal to the weight of the overlying ice, flow occurs normal to surfaces of equal hydraulic potential (equipotential surfaces) calculated from variations in the local pressure potential, Φ, given by

$$\Phi = \Phi_O + p + \rho_w g z \quad (1)$$

where, Φ_O is an arbitrary constant, p is the water pressure within the conduit, ρ_w is the density of water, g is acceleration due to gravity, and z is the elevation of the point considered. The second term on the right hand side of equation (1) refers to the pressure in the water due to the overlying ice and the third to the direct influence of gravity acting upon the water. From equation (1) it can be shown that equipotential surfaces dip up-glacier with a slope of around 11 times the ice surface gradient and water in englacial conduits descends steeply downwards and in the direction of the ice surface slope. For meltwater flowing in subglacial conduits at the bed of the glacier, the direction of meltwater flow is again determined by the water pressure gradient but occurs normal to equipotential contours formed by the intersection of equipotential surfaces with the underlying topography. The water pressure gradient also enables subglacial conduits to ascend major topographical rises provided that their up-slope gradient does not exceed 1/11th that of the ice sheet surface (Shreve, 1985). Consequently, the direction of subglacial meltwater flow is primarily determined by the ice-surface slope and secondarily by the underlying topography. The effect is such that subglacial meltwater follows the same route ordinary rivers would take if the landscape was tipped down-glacier at 11 times the ice-surface slope (Shreve, 1985). Hence, subglacial conduits trend in the general direction of ice flow but tend to deviate to follow valleys and cross drainage divides at the lowest cols (Clapperton and Sugden, 1977; Shreve, 1985).

The direction of subglacial meltwater flow beneath former ice-sheets can be determined by reconstructing contours of equal water pressure at the glacier bed. The technique, demonstrated by Shreve (1985), has been performed for the Aughertree Fell area and clearly demonstrates how the equipotential surfaces are distorted around topographic highs due to the influence of the underlying topography (Figure 4). Subglacial meltwater under closed-conduit conditions flows at right angles to the equipotential contours as this represents the steepest route of descent in terms of the pressure gradient. The technique has been successfully applied to meltwater channels in Antarctica by Sugden et al. (1991) but for accurate reconstructions it requires a knowledge of both the direction and gradient of the ice-sheet surface slope. However, Sugden et al. (1991) have shown that for simple reconstructions concerned only with former directions of subglacial meltwater flow the gradient of the ice-sheet surface is arbitrary and only the direction of the slope is required. Since the direction of the surface slope is coincident with the general direction of ice flow, this is assumed to have been approximately SE-NW for the Aughertree Fell area. (Reconstructing equipotential contours for an ice-sheet flowing E-W produced little variation upon the main subglacial flow directions predicted from Figure 4).

The analysis for closed conduits cannot be applied to meltwater flowing in conduits which are only partially-filled or 'open'. Here the water pressure is atmospheric and irrespective of the weight of the overlying ice (Lliboutry, 1983; Hooke, 1984), though channel alignment remains largely ice-directed due to the influence of ice deformation. Such conduits are potentially highly mobile since the rate of melting often exceeds the rate of closure due to deformation, even for small discharges (Hooke, 1984). Nevertheless, open conditions appear to be less common than previously anticipated (Hooke, 1990) and, since discharge through subglacial conduits can be highly variable, either pressure-state can exist and conditions may alternate rapidly between the two (Shreve, 1985; Hooke, 1989). Consequently, many channels originally interpreted as ice-marginal in origin have since been re-interpreted as subglacial. In some instances, an absence of features believed to be indicative of ice-damming by Kendall (1902) or Charlesworth (1957) have also been used

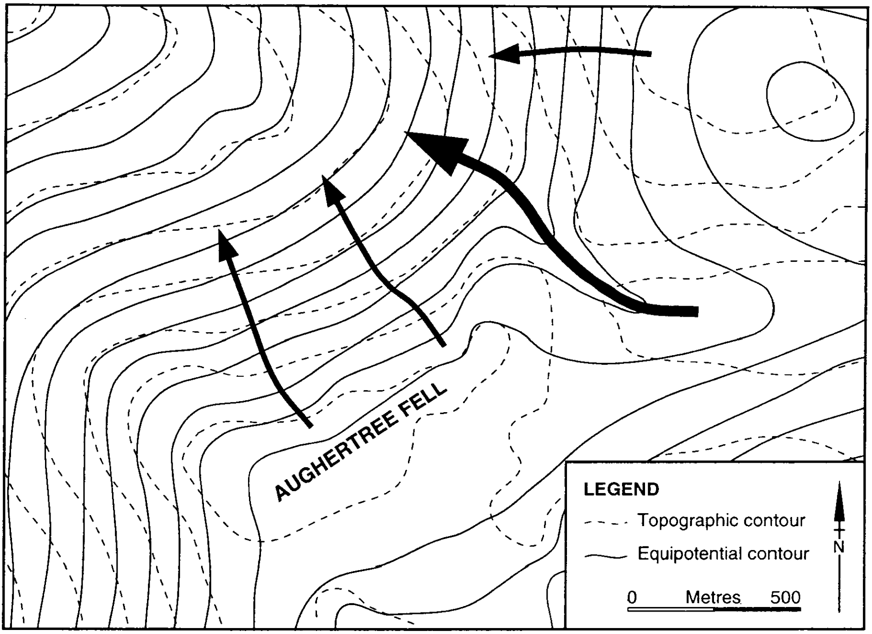

Figure 4: Equipotential contour map of the Aughertree Fell area for an ice-sheet flowing SE-NW. The equipotential contours are akin to the topographic contours which would result from tipping the land surface in the direction of ice flow. (The contours have no value in this reconstruction because the former ice-surface gradient is not known - see text for explanation.) Subglacial meltwater under closed-conduit conditions would be expected to flow normal to contours of equal water pressure. The thinner arrows demonstrate the orientation closed-conduits would assume if superimposed onto or formed on the lee-side of Aughertree Fell or the Sandale-Faulds Brow ridge. The thicker arrow indicates a low-pressure 'valley' in the equipotential contours located over the col now occupied by channel A (Figure 2). The col thus forms the preferred location for conduits crossing the drainage divide since it provides the quickest route of descent along the subglacial water pressure gradient. Cols such as this are also able to attract and capture conduits superimposed onto neighbouring topographic highs. Note the similarity between predicted directions of former subglacial meltwater flow and the orientation of channels in Figure 2.

as evidence against subaerial hypotheses (Sparkes and West, 1972). It is possible, however, that this re-interpretation has been applied somewhat overzealously. The problem of identifying the true origin of meltwater channels is complicated by many having performed numerous functions and having developed in various positions in relation to the ice margin (Sissons, 1963; Embleton and King, 1968), with the implication that many channels possess a complex history and may easily be misinterpreted.

The results of this study indicate that channels in the Aughertree Fell system are of three distinct types. Type 1 are channels B to G and L to N which are located across topographic highs and away from the major col. Their location thus implies that they are unlikely to have originated subaerially or subglacially and would instead suggest an origin of englacial superimposition. Their simple channel pattern, possessing no major tributaries, is consistent with the superimposition of established conduits from within the ice-sheet and is further supported by them exhibiting an orientation compliant with the general direction of former ice flow and coincident with that predicted from maps of equipotential contours (cf. Figure 4). The slight variation in channel orientation, from approximately SE-NW (channels B to G) to E-W (channels L to N), appears to be the result of the incipient conduits having become aligned with the local subglacial water pressure gradient. Finally, the humped long-profiles of channels B to G confirm that closed conduit conditions prevailed during at least part of their formation, though conditions may have alternated rapidly producing sudden changes in erosional capacity (Alley et al., 1997).

Type 2 are channels H to K located on the lee-side of both Aughertree Fell and the Sandale-Faulds Brow ridge. The channels run normal to topographic contours and terminate before reaching the valley floor. They are therefore unlikely to be a consequence of subaerial meltwater flow, where ice-marginal channels would be expected to run roughly parallel with topographic contours, or post-glacial fluvial erosion. Neither are they consistent with an origin of englacial superimposition due to their complex channel pattern and lee-side location. Only a subglacial origin remains but this too appears unlikely since the channels are not located in significant cols. However, they closely correspond with reconstructed patterns of subglacial meltwater flow shown in Figure 4 and appear to exhibit a close association with channels of type 1. Channels H and I, for example, appear interlinked with channels B to G whilst it has been shown that channels J and K may be closely related to channels L to N. Consequently, a subglacial origin is proposed whereby lee-side conduits occurring on the down glacier side of Aughertree Fell and the Sandale-Faulds Brow ridge collected meltwater from contemporaneous conduits superimposed on the fell-top. The resultant lee-side channels extend only a short distance down the fell-side whereupon their meltwaters may have become englacial once again.

Type 3 is channel A, the size and extent of which far exceeds those of types 1 and 2. The morphology of this channel is consistent with a subaerial origin, becoming increasingly sinuous away from the drainage divide and eventually grading into the present drainage network. The presence of a knickpoint is also suggestive of subaerial erosion since meltwater channels formed subglacially are rarely subject to the changes in base level which can occur under a subaerial regime. However, postglacial fluvial erosion is unlikely because the channel lacks any significant drainage basin and remains mostly dry, and hence a glaciofluvial origin must be preferred instead. Indeed, the location of the channel in a col across the former drainage divide and its alignment with the former subglacial water pressure gradient (Figure 4) would be consistent with a subglacial genesis, either as the result of direct englacial superimposition, the migration of previously superimposed conduits from neighbouring topographic highs or the headward development of an incipient subglacial conduit. However, it is equally possible that meltwater originated directly from the ice-sheet margin or from the overflow of an ice-dammed lake much later during deglaciation, as envisaged by Hollingworth (1931). There is no morphological evidence to suggest which interpretation is the most likely and instead the origin of this channel is considered more fully below.

Discussion

The above interpretation indicates that the earliest channels in the Aughertree Fell system are probably those of type 1. Channels of this type located on both Aughertree Fell and the Sandale-Faulds Brow ridge suggest the superimposition and subsequent migration of two or more englacial conduits. Their alignment is consistent with local patterns of ice flow, which contradict those at the Late Devensian maximum predicted by Hollingworth (1931) and Eastwood et al. (1968), and indicates that they were probably superimposed following the onset of deglaciation. Where the conduits came into contact with the underlying topography they became subglacial and, in response to the subglacial water pressure gradient and continued surface-lowering of the ice-sheet, are likely to have migrated laterally into the col now occupied by channel A. The continuum of channel forms on the Sandale-Faulds Brow ridge supports this interpretation, where more distinct channel forms higher up the ridge culminate in a series of small, indistinct terraces at the base. This suite of features is believed to represent the migration of at least one conduit superimposed onto the ridge. It is difficult to suggest how such migration is likely to have been achieved since the evolution of subglacial drainage systems under present day glaciers and ice-sheets is still poorly understood (Hubbard and Nienow, 1997). Indeed, the existence of discrete channel forms could equally result from periodic stand-stills during the migration of highly mobile conduits or the step-by-step migration of relatively static conduits as new drainage routes are initiated closer to the main col. The possibility also remains that many of these features, particularly the terraces and channels L to N, were at least partially eroded by subaerial meltwater flowing along the ice margin later in deglaciation.

The superimposition of englacial conduits was accompanied by the formation of lee-side conduits which eroded channels of type 2 into the lee-side of Aughertree Fell and the Sandale-Faulds Brow ridge Their limited extent is not unusual and probably resulted from the meltwaters of each superimposed conduit continuing their englacial course beyond the topographic obstacle. The lee-side channels would have been progressively abandoned as the superimposed conduits on the fell-top ceased to operate or migrated into the col. Whether a conduit already occupied this col or not, the migration of the englacially superimposed conduits is likely to have at least contributed to the formation of channel A (type 3). The resultant subglacial conduit would have possessed the potential to occupy this position for a prolonged period during deglaciation. Although this could easily account for the greater dimensions of channel A, the channel itself may not have extended more than 300m on either side of the pre-glacial drainage divide at this time (i.e. as far as it appears most 'well-developed' today).

Given that there is a possibility that channel A did originate subglacially, the evidence supporting subaerial modification can only be reconciled if meltwater flow within this channel changed from ice-directed and subglacial to subaerial in nature. It is at least possible that some modification occurred under open-conduit or ice-walled conditions very close to the ice-sheet margin. However, such conditions are unlikely to have prevailed for any considerable time due to the location of the channel system in a relatively shallow col between the high ground of Aughertree Fell and the Sandale-Faulds Brow ridge. These areas were liable to have emerged as nunataks far from the actual ice-sheet margin during deglaciation (Hollingworth, 1931; Eastwood et al., 1968), resulting in the separation of ice in the upper Eller Beck valley from that on the Solway Plain and a sudden change from subglacial to subaerial conditions within the channel system. Local ice-surface gradients also imply that throughout deglaciation ice occupying the Ellen valley would have been at a lower altitude than that in the Eller Beck valley. It is therefore envisaged that the change from subglacial to subaerial conditions occurred virtually simultaneously throughout the whole of channel A. Following this event it is doubtful that subaerial meltwater originated directly from the ice in the Eller Beck valley since this would have required the ice margin to have maintained a very stable position at the channel entrance. It is more likely that an ice-dammed lake formed at the channel entrance as continued retreat resulted in the withdrawal of the ice margin beyond (and thus below) the point of channel inception (cf. Figure 5, A).

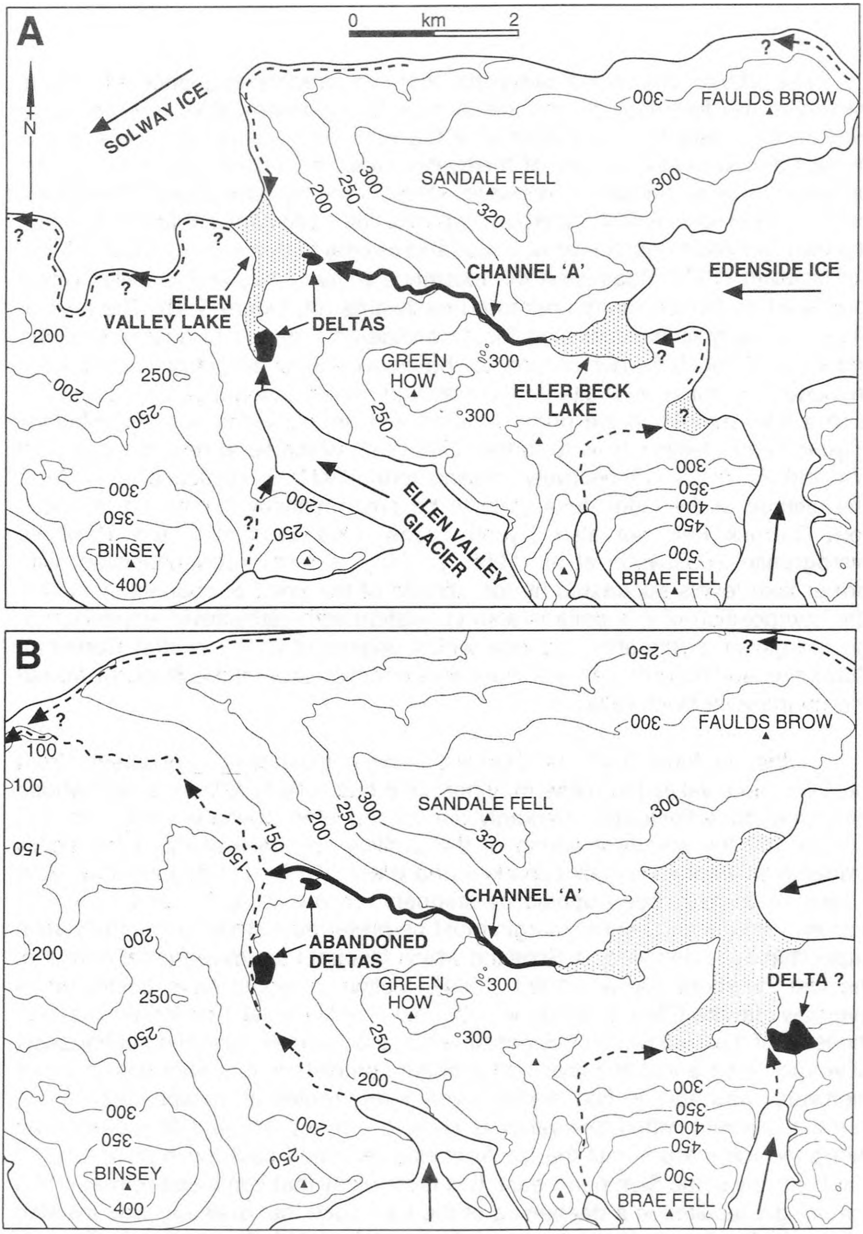

Figure 5: Possible sequence of events during the deglaciation of Aughertree Fell and the surrounding area. **A**: Hypothetical ice-sheet margins associated with the formation of ice-dammed lakes in the Eller Beck and Ellen valleys. **B**: Hypothetical ice-sheet margins following the drainage of the Ellen valley lake. Solid arrow indicates channel A. Dashed arrows indicate other probable routes of meltwater flow

The above discussion suggests that the precise sequence of events leading to the formation of channel A may be indeterminable. It is therefore relevant to consider the authenticity of the Eller Beck valley lake since this is the last demonstrable source of meltwater capable of contributing to channel formation. Indeed, proglacial meltwater streams are typically characterised by a much greater unsatisfied transport capacity than ordinary subaerial streams and may generate impressive or unusual erosional features (Alley et al., 1997). Hollingworth (1931) suggested the existence of two lakes in this valley which coalesced as the ice margin retreated eastwards (cf. Figure 5, B). The lake or lakes are likely to have existed for a considerable period of time due to the presence of much higher ground to the north and south which would have precluded the initiation of alternative drainage routes. Independent evidence for such a lake may lie in the origin of sand and gravel deltas near Branthwaite (Figure 1) and Nether Row (a further 2km east) which lie at heights of around 274 and 259m OD respectively (Hollingworth, 1931; Eastwood et al., 1968). The altitude of the latter delta, said to be predominantly composed of 'rocks from Carrock Fell' but also 'Eycott Lavas, Skiddaw Slates and Threlkeld microgranite' (Eastwood et al., 1968: p. 230), is remarkably consistent with former lake levels suggested by the altitude of the point of channel inception. The composition of this delta is also consistent with glaciofluvial deposition at the margin of a retreating ice-lobe which originated in the central Cumbrian Mountains and flowed in an anti-clockwise direction around the Skiddaw Massif and up the Eller Beck valley.

Other features such as shorelines and outflow-deltas are absent from the Eller Beck valley but these may not have had time to form in a lake whose level may have fluctuated markedly due to repeated drainage under the ice-margin and the steady lowering of the outflow col, particularly in the easily erodable limestone bedrock (Sparkes and West, 1972). It is doubtful that such a lake could have been upheld by stagnant, downwasting ice and hence an actively retreating ice-sheet margin must be preferred instead, an interpretation supported by recent work in Scotland which favours the active frontal retreat of the last ice-sheet (Brown, 1993, 1994). Meltwater would have continued to overflow into the Ellen drainage via channel A until the lake no longer reached the level of the outflow col. It is possible that the channel operated continuously until such a time that the lake had drained completely. It is also possible that meltwater was able to find progressively lower routes of escape, but the ice surface gradient within this valley is liable to have precluded flow eastwards along the ice margin until the ice front had retreated past the high ground of Faulds Brow some 5km north-east. It is more likely that continued retreat of the ice margin resulted in a deepening of the lake such that drainage was initiated into or under the ice-sheet margin before reaching the level of the outflow col (cf. Rothlisberger, 1972; Fisher, 1973; Knight and Russell, 1992). This situation would have persisted until an alternative drainage route could be established to the west along the ice margin.

Hollingworth (1931) and Eastwood et al. (1968) believed a similar lake had existed in the Ellen valley on the evidence of two deltas at c.150m OD which are mainly composed of 'pebbles of lava, tuff, vein-quartz and Carboniferous Limestone' (Eastwood et al., 1968: p. 227). The smaller delta is situated close to the outlet of channel A and Hollingworth (1931) describes it as having been deposited by meltwater from this channel on entering the lake (cf. Figure 5, A). The consistency between delta heights and the location of the smaller delta some 10m above the present valley floor suggests it may indeed be contemporary with both channel A and the ice-dammed lake, but it remains disproportionately small when compared with the dimensions of the channel itself. The discrepancy in delta size could be accounted for if much of the material excavated from the upper section of the channel was carried farther afield by a subglacial conduit. However, it is also possible that the lake drained or fell to a lower level soon after deposition of the delta began, during which time the delta may also have been partially eroded. The knickpoint in channel A is suggestive of channel rejuvenation (Figures 2 and 3, A) and the absence of further deltas of lower elevation in the Ellen valley, in addition to the lack of a distinct channel terminus, indicates that the lake may have drained completely (cf. Figure 5, B). That such rejuvenation could have worked back some 2 km along the channel profile is not in doubt due to the considerable erosional potential of proglacial streams (Alley et al., 1997). However, the possibility remains that the knickpoint simply reflects bedrock irregularities or the transition to subaerial conditions associated with the deglaciation of the channel system. While it is plausible to assume the presence of a lake in the Ellen valley, the evidence is sparse and, like that of the Eller Beck lake, proof of its existence may lie in the future consideration of landforms and deposits outside the immediate area of this study.

Summary and conclusions

Investigation of the origin of the Aughertree Fell channel system has suggested a number of characteristics of the deglaciation of the Late Devensian ice sheet in this area (c.18,000 - 14,000 years BP) which are tentatively outlined below.

(1) Local ice flow directions in the vicinity of Aughertree Fell, indicated by the orientation of channels of type 1 and drumlins in the Ellen and Eller Beck valleys, were SE-NW prior to or during deglaciation. These appear to have resulted from the increasing influence of the underlying topography and contrast with ice flow directions at the Late Devensian maximum which were believed to have been predominantly E-W in this area (Hollingworth, 1931; Eastwood et al., 1968).

(2) The superimposition of englacial conduits onto topographic highs, probably during deglaciation, followed the change in ice flow directions. Channels of type 1 are evidence of superimposed englacial drainage across the major drainage divide between the Eller Beck valley, which forms part of the Eden catchment,

and the Ellen valley. This particular route was not considered by Huddart et al. (1977) which, due to its elevation (in excess of 200m OD), may have functioned at a similar time as their proposed drainage from Edenside into the Tyne and South Tyne systems.

(3) Continued ice-surface lowering resulted in the emergence of topographic highs as nunataks and the separation of ice in the Eller Beck valley from that in the Ellen valley and on the Solway Plain. In the Eller Beck valley this resulted in an easterly-retreating ice-sheet margin and the formation of an ice-dammed lake which overflowed via channel A (Figure 5, A). A similar lake at c.150m OD in the Ellen valley is likely to have formed as ice in the Ellen valley also became separated from the main ice-sheet. The presence of ice-dammed lakes at this time suggests that the ice-sheet was active and had not stagnated.

(4) Retreat of the Solway ice resulted in the drainage of lakes in the Ellen and Eller Beck valleys. The Ellen valley lake appears to have drained first, possibly resulting in the rejuvenation of channel A as the Eller Beck lake continued to utilise the channel as an overflow into the Ellen drainage (Figure 5, B). This suggests that the drainage of ice-dammed lakes upheld by the main ice-sheet in northern Cumbria may also have occurred in a clockwise direction similar to the 'splitting-off' of the valley glaciers suggested by Hollingworth (1931) and Eastwood et al. (1968). Ice in the Eller Beck valley continued to retreat eastwards, with channel A eventually being abandoned as the lake here drained or fell to lower levels.

These characteristics are consistent with many of the conclusions reached by Hollingworth (1931) and Eastwood et al. (1968) regarding the deglaciation of the Aughertree Fell area. Indeed, little evidence has been found to suggest that deglaciation occurred by a process of marginal stagnation and decay in situ. The presence of ice-dammed lakes would instead indicate that the ice-sheet remained active during deglaciation. The study has also served to emphasise the important role of meltwater as a geomorphological agent during deglaciation and has highlighted the existence of erosional and depositional features outside the immediate area of this study which still await detailed investigation. Future research must focus on the origin and significance of these features before a coherent synthesis of events during the deglaciation of the last ice-sheet in northern Cumbria can be established.

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THE RECENT INVESTIGATIONS INTO THE QUATERNARY GEOLOGY OF WEST CUMBRIA.

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Summary

The paper reviews and summarises the recent comprehensive UK Nirex Ltd. and British Geological Survey Quaternary investigations in West Cumbria. Offshore, six seismically distinctive sedimentary sequences were recognised. The lower of two unconformities within the sequences marks the combined effects of two post-Dimlingtom ice readvances (Gosforth Oscillation and the Scottish Readvance). Onshore, a sequence of glacigenic material and landforms was described. The extent of the two late ice readvances were established with the help of criteria for recognising deformation of glacial sediments. A refined model for the Quaternary history of West Cumbria is proposed. The implications and significance of these studies are outlined with reference to the study area and adjacent parts of Cumbria.

The geological investigations instigated by UK Nirex Ltd. around Sellafield in West Cumbria, to assess the suitability of the area for an underground radioactive waste depository, rank as some of the largest ever carried out in Britain. As well as the deep drilling programmes to investigate the site for a deep rock laboratory and storage facility, much attention was focussed on the surface Quaternary deposits which mantle the coastal plain with thicknesses of up to 85m and extend offshore as even thicker sequences on the bed of the Irish Sea.

Nirex have recently published four very lengthy and detailed technical reports of their Quaternary investigation programmes (Heathcote et al 1997, Thorne et al 1997, Wingfield et al 1997 and Knight et al 1997). Following the Nirex work, in July 1997, a major Field Meeting to West Cumbria was mounted by the Environment Group of the Geological Society of London, and brought together a large group of experts including staff from the British Geological Survey, private geological consultants, UK Nirex staff and academics. The Handbook for the meeting (Browne et al. 1997) provides a useful survey of current views on the area, stemming from recent BGS work, the Nirex programmes plus inputs from other specialists. Most recently, the stream of data from the Nirex investigations has been integrated into the new Memoir 'Geology of the West Cumbria District' published by the British Geological Survey in November 1997 - section eight of which summarises in limited detail some of the current thinking on the Quaternary history of the district (Akhurst et al 1997). Recent work by Clayton (1996), quantifying Quaternary glacial erosion in the British Isles, also has bearing on the area.

The purpose of this paper is to review this wealth of new data, summarise the main findings, relay the observations of the present authors on the Field Meeting and assess the implications and significance of all this for our understanding of the Quaternary geology of Cumbria.

The Nirex Sellafield investigations which were the initial spur to much of the recent activity, are of more than local significance. The location provided a potential to record not only events in the high heart of the Lakeland uplands, notably in the Ennerdale and Wasdale valleys, but also those involving ice moving southwards between the high fells and St Bees Head, as well as those where ice moved inland across the present coastline from the Irish Sea Basin. Prior to this work, contradictory histories of the last major glaciation of West Cumbria were being debated and a number of issues regarding deglaciation, ice re-advances, variable sea level positions and landform/sedimentation relationships were awaiting solution. Within the Sellafield data lay the possibility of extending our understanding of the Irish Sea Basin and enhancing the wider picture of the British Quaternary

There was a consistency of view that the major regional ice sheets of the Dimlington Stadial (26-13ka BP) produced streamlined ice moulded drumlinoid forms as they swept westwards and southwards across the Solway and West Cumbria Lowlands. Controversy emerges however after what might be termed this 'drumlin stage'. That lowland Cumbria experienced a later incursion of ice from the north and west was first proposed by Trotter (1922, 1929) and Trotter et al (1937) on the basis of thin widespread reddish 'upper till' and locally, as near Gosforth, parallel melt discharge channels along ice margins. Two principal readvance limits were recognised - the Gosforth Oscillation (GOS) and the later Scottish Readvance (SR). Huddart (1970, 1971a, 1971b) re-examined the whole area in detail and simplified the interpretation to one event - the Scottish Readvance. Since then much of the material and many landforms of 'readvance territory' have been ascribed to sedimentation from land-side glaciers into a high standing sea lapping onto the coast as part of a 'glacimarine re-interpretation' of glacial history in the Irish Sea Basin (Eyles and McCabe 1989). The terrestrial interpretation was reasserted against the glacimarine in subsequent work by Huddart (1991) and Huddart and Clark (1994).

The objectives of the Nirex Characterisation Programme carried out between 1991 and 1996 were threefold:

- To reconstruct the geological history of the Quaternary in the Sellafield area, partly with a view that this may give some insight into the future behaviour of the surface deposits.

- To provide background information for modelling the near surface hydrogeological regime; especially to determine the quantity of water present and how it moves.

- To describe the deformation structures which are so much a part of the onshore deposits and interpret them for evidence of causative mechanisms and ascertain the nature of past disturbances and seismic activity.

The scale and scope of the Nirex investigations moved research on the area into a new dimension. The area of detailed investigation extended up to 25km from Sellafield both onshore and offshore. Onshore work included new walkover surveys by the BGS consultants as well as detailed surface mapping, sampling and logging 49 trial pits, a series of new boreholes to c. 65 m depth, remote sensing investigations, including an interpretation of airborne radiometric data, air photo interpretation and Landsat imagery and an extensive ground geophysics programme (ground penetrating radar, seismic refraction, ground conductivity and vertical electrical soundings). Offshore the techniques applied necessarily differed, but included seismic reflection profiles aquired using a boomer with sub-bottom penetration limited to c. 60 m, locally supported by vibracores and boreholes. In all this constituted a very expensive and intense programme.

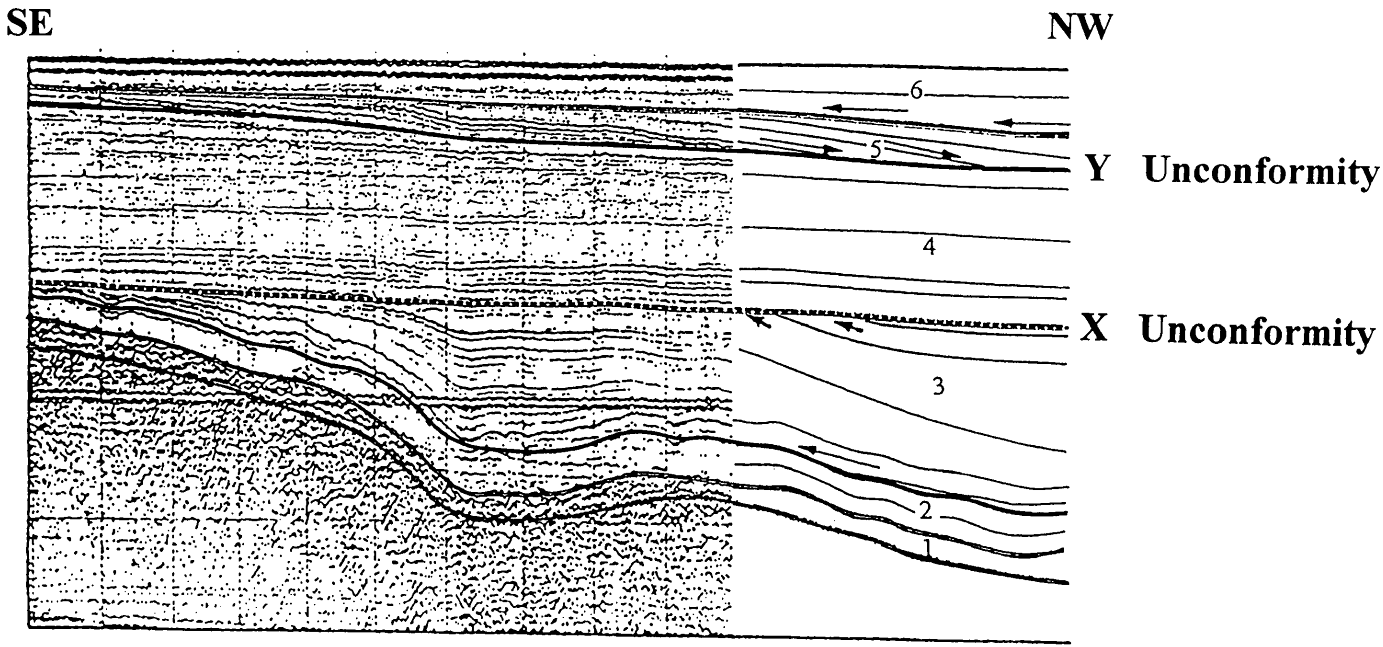
Offshore Deposits

These generally form a much thicker (up to 200m) and more complete and continuous succession than do the onshore deposits. Post glacial sequences are well represented, whereas onshore they have a patchy distribution and are laterally discontinuous.

The offshore seismo-stratigraphy was established using seismically distinctive sequences that are bounded top and bottom by unconformities which mark significant periods of erosion and non-deposition during the Late-Devensian deglaciation and the Holocene. Six major seismically distinct sedimentary sequences (1-6) have been recognised, with sequences (1-3) being overconsolidated (presumably by the overlying ice) and sequences (4-6) normally consolidated. (Figure 1 and Table 1).

It is believed the X unconformity represents the combined effects of two ice readvances - the Gosforth Oscillation and the Scottish Readvance, with no preserved sedimentary record of the period between the two. This is thus supporting the early views of Trotter and the original Geological Survey work of the inter war years. The Y unconformity represents subaerial and inter-tidal erosion during a period of low sea level in the early Holocene. The offshore deposits were predominantly deposited in a marine environment, even those laid down during the Late Devensian glaciation. These deposits are dominantly proglacial, that is, they were deposited immediately in front of, or just beyond, the outer limit of a glacier or ice sheet

Figure 1 Seismostratigraphical Architecture of the Offshore Deposits (Redrawn from Browne 1997, Figure 1.9.1)



ONSHORE	INTERPRETATION	OFFSHORE SEISMIC STRATIGRAPHY	INTERPRETATION
Post glacial - alluvium, peats Submerged forests and peats	Terrestrial and marine	Sequence 6 Silt with bands of shells Sequence 5 6m thick, fine silty sand	Marine muds and sands Sands, offshore bar. Y Unconformity
Sands (in basins) Scottish Readvance (SR) & Gosforth Oscillation (GOS) tills	Proglacial Glaciproximal (SR) Proglacial Glaciproximal (GOS)	Sequence 4 Very fine grained silts & clays, with pebbles and shells. Variable thickness, 5-25m Sequence 3A Tongue of till, seismically chaotic in character.	distal glaciomarine glaciproximal X Unconformity
Upper St Bees sequence, till, sand & gravel	Proglacial	Sequence 3 Dominantly clays,silts & muds. 30m thick, locally absent over topographic highs. Sequence 2 Thin (1-5m) seismically transparent sequence deposited in a low energy environment as rain out from floating ice.	distal glaciomarine proglacial
Main Phase Late Devensian Tills	Glaciproximal : Main Phase ice	Sequence 1 Tills, with subordinate sands & gravels Generally less than 10m thick, up to 30m thick where filling topographic lows and near the coast.	glaciproximal
Mid to Early Devensian Drigg Silts (in boreholes)	Pre-Late Devensian Environments	Pre-Sequence 1	

Table 1. A possible correlation of onshore and offshore Quaternary deposits

Onshore Deposits

Three major units exist (in descending stratigraphical order) ;

3. Post Glacial Deposits - all are younger than 15,000 years and include those of the Windermere Interstadial, Loch Lomond Interstadial and the Holocene. They comprise mainly coastal, alluvial and organic deposits and although their distribution is patchy and discontinuous the stratigraphical and palynological record is secure enough to present no significant problems.

2. Late Devensian Glacial Deposits - these represent the bulk of the materials and present considerable interpretation problems. Most are associated with the Dimlington Stadial, but no absolute dates exist to confirm this. The deposits are mostly coarse grained and comprise one or more tills. Some proglacial outwash and lake deposits also occur. The materials are generally overconsolidated and laterally variable and are commonly glacitectonised.

1. Pre-Late Devensian Deposits - only three sites of deposits of this age are recorded, two only seen in boreholes. A diamicton of possible Wolstonian age is recorded in the Calder valley. The material from the cores is believed to be of marine origin and a silt from one of them at Drigg has yielded amino acid ratios consistent with an age of about 60,000 years. As with other areas of Cumbria the paucity of pre-Devensian materials is assumed to be the result of Devensian erosion.

There are many problems of trying to correlate on-shore and off-shore sequences. There is less lithological control offshore and there seems to be important facies changes in the vicinity of the present coastline. The substantial effects of coastal processes during the Holocene have included re-working material in the coastal zone so destroying the continuity between the two areas. The inherent differences in the nature and effects of the depositional and erosional processes that have operated in the two areas, and the contrast between the onshore areas that show considerable local relief and the offshore area with a generally even-bottomed seabed, have also contributed to the uncertainties of correlating between the two zones. A possible correlation suggested by the Nirex work is shown in Table 1.

A summary of the Quaternary History of West Cumbria.

Figure 2 a-d attempts to summarise the interpretation of the main events of the Devensian in West Cumbria and is derived from figure 1.11.1 in Browne (1997) and the modified version of this in Figure 40 in Akhurst et al (1997). Figure 3 presents a schematic NW-SE transect across West Cumbria and a conceptual model of ice distribution. The salient events of the Devensian as interpreted in the Nirex reports are summarised below:

1. Early and Middle Devensian. (pre 50,000 BP)
   Powerful erosion by valley glaciers in Cumbrian mountains - local deposition of tills in lower Wasdale. Sea level probably below 20 m below OD.
   c 60,000 BP retreat of early Devensian glaciers. Deposition of Carleton Silt Formation in proglacial lake in Lower Wasdale. (Evidence from borehole record).
   c50,000 BP Middle Devensian marine inundation - deposition of Glannnoventia Formation in Lower Wasdale. (Evidence from borehole record).

2. Build up of Main Late Devensian Ice Sheet. (26,000 BP) (Figure 2a)
   Growth of valley glaciers in the Cumbrian mountains. From the north, ice gradually flowed SE across the Irish Sea from the Southern Uplands of Scotland and eventually this Scottish ice impinged on the Cumbrian coast. Ice reaching the coast between St Bees Head and Whitehaven caused the Ennerdale glacier to be deflected south westwards into the St Bees-Whitehaven channel. Proglacial areas affected by permafrost.
   Relative sea level possibly more than 50 m below OD.
   Strong glacier erosion by valley glaciers - significant sub-glacial deposition of lodgement till towards their termini, together with proglacial outwash.

3. Main Phase of Late Devensian Glaciation. (c 19,000 BP)
   Entire region covered with ice - up to 1000m thick over West Cumbrian plain.
   Southern Uplands ice hemmed in and deflected Lake District ice southwards in the Irish Sea basin and eastwards into the Tyne and Tees areas. Drumlin forms created on lowland by moving ice.
   Sea level at its minimum - 100m or more below OD.

4. Retreat of the Main Phase Late Devensian Glaciation. (after 19,000 BP) (Figure 2b)
   Retreat of the Irish Sea ice stream brought about iceberg calving either into sea or large pro-glacial lakes in Ehen and Lower Wasdale valleys.
   Deposition of coarsening upwards sequences of meltwater deposits (sandurs and deltas in main valleys) - now largely concealed.
   Deposition of glaciolacustrine or possibly glaciomarine clays silts and fine sands in Lower Wasdale and distal reaches of other valleys.

Carving of ice marginal meltwater channels at retreating margin of Irish Sea ice stream. Accumulation of fan gravels from meltwater draining SW from Whitehaven-St Bees channel.
Continued glacial erosion in Lake District valleys and periglaciation of upland summits.
Sea level probably about +15 m OD.

5. Gosforth Oscillation - readvance of Irish Sea ice. (c.16,000 BP) (Figure 2c)
Tangential readvance of Irish Sea ice stream from an unknown position offshore on to coastal lowlands to a line extending from east of Whitehaven, south to Gosforth and Muncaster Fell.
Distinct glacially over-ridden terrain produced by this readvance of ice - distinguished by glacially streamlined landforms, including kames and 'hill-hole pairs' in which sediment infilling hollows was excavated by the ice and redeposited in ice push ridges. Sands and gravels subglacially modified, exhibiting extensional normal faults and localised shearing. Fine grained deposits plastically deformed.
Local advances of Lake District ice westwards in major valleys.
High level drainage channels cut across Muncaster Fell.

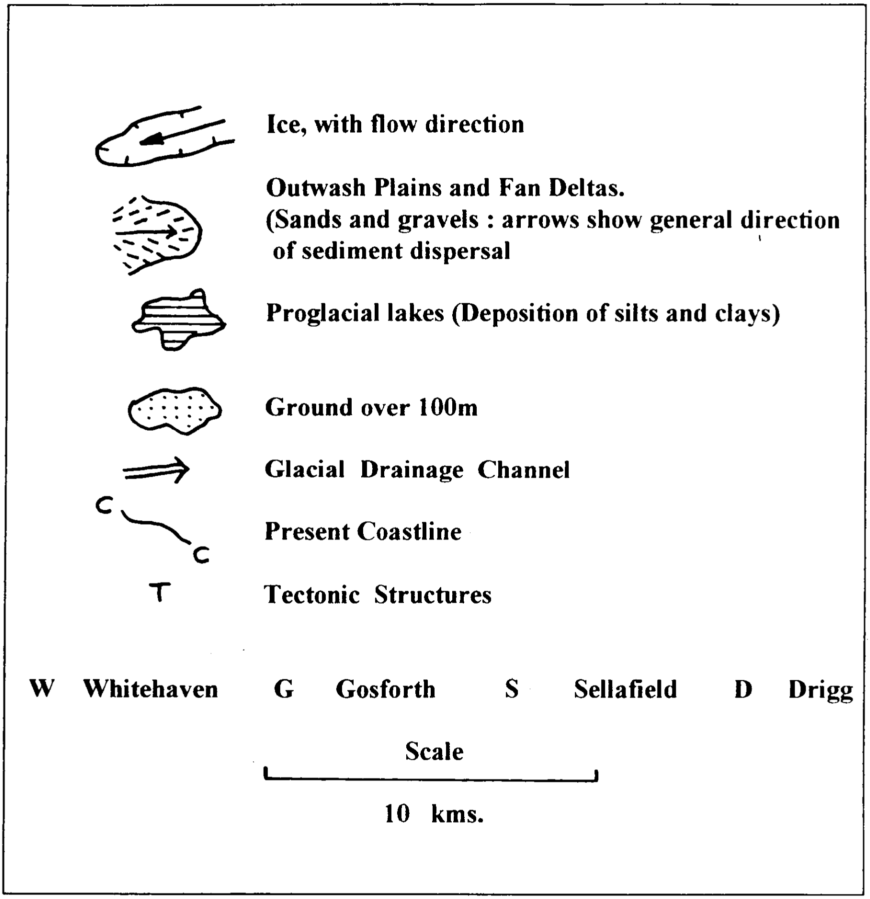
6. Retreat of ice after the Gosforth Oscillation. (16,500 - 15,000 BP) (Figure 2c)
Oscillating retreat of Irish Sea ice stream and continued downwasting of Lake District ice to form retreating glaciers restricted to main valleys. Maximum retreat of Irish Sea ice to some way offshore, with possible pro-glacial lake extending continously from St Bees to beyond Muncaster Fell.
Deposition of upward coarsening deltaic sandur outwash sands and gravels on coastal lowland. Sea level possibly + 8-10 m OD.

7. The Scottish Readvance. (c 15,000 BP) (Figure 2d)
Readvance of ice only a small way inland of present coastline between Whitehaven and Sellafield, at most 4 kms. inland south of Drigg.
A glacitectonic thrust terrain produced by this readvance along the narrow coastal strip, and seen to best effect in the St Bees push moraine. Sediments both compressionally and extensionally dislocated and generally overconsolidated. Distinctive terrain of elongated kettleholes and sub parallel ridges aligned NE-SW.
Ponding up of valleys and accumulation of fine-grained glaciolacustrine deposits. Local deposition of deltaic sandurs.
Sea level possibly + 8m OD

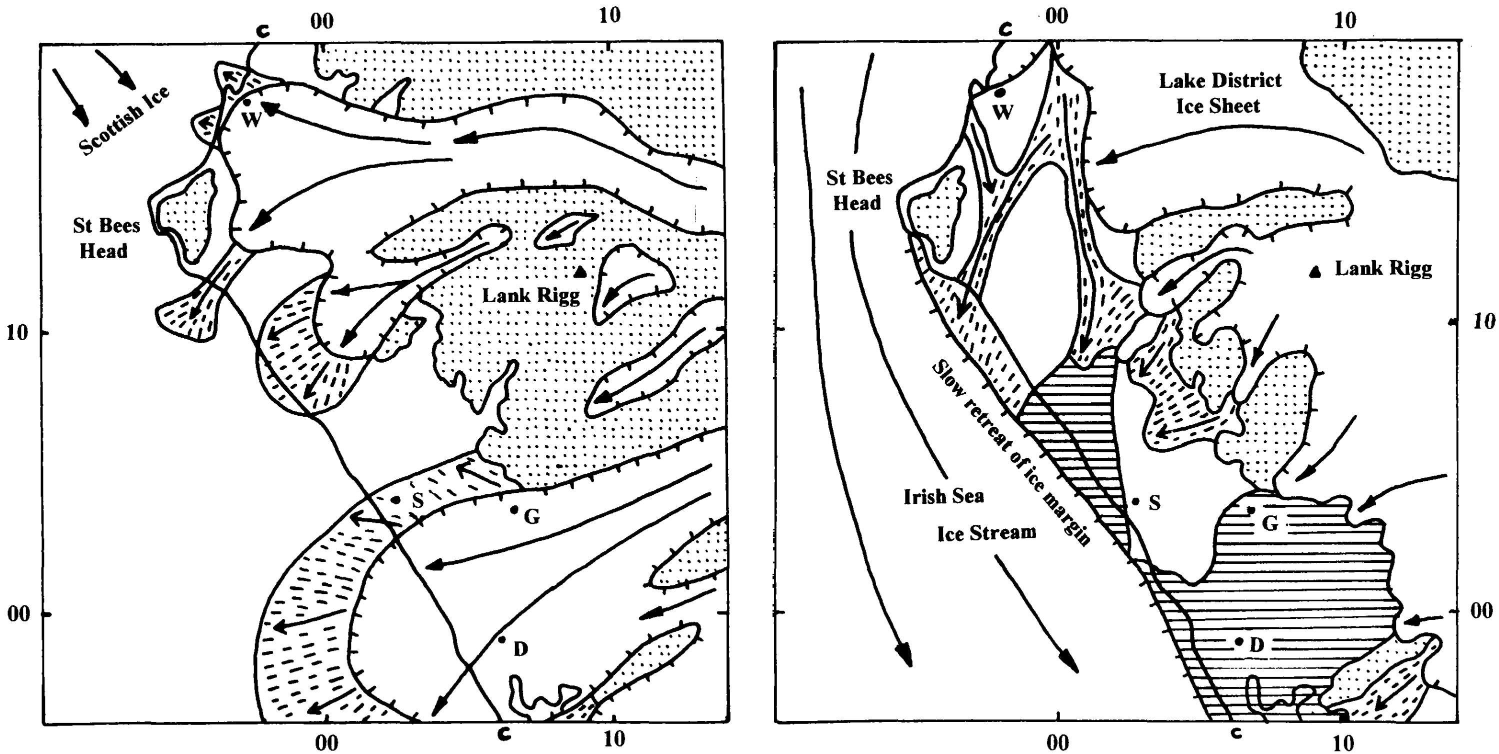
8. Late stage Deglaciation after Scottish Readvance. (15,000 - 13,500 BP)
Rapidly retreating ice margin well offshore. Coastline close to present line.
Initiation of post glacial fluvial drainage pattern. Deposition of highest river terrace gravels. Enhanced slope erosion owing to sparse vegetation cover.
Sea levels close to OD.

9. Windermere Interstadial. (13,500 - 11,000 BP)
Complete melting of glaciers in the Lake District. Establishment of tree and shrub vegetation. Rapid incision of present valleys.

10 Loch Lomond Stadial. (11,000 - 10,000 BP.)
Deterioration of climate with corrie glaciers in mountains.
Widespread frost. Enhanced erosion.



Key to Figure 2a-d (Redrawn after Browne 1997 Figure 1.11.1)

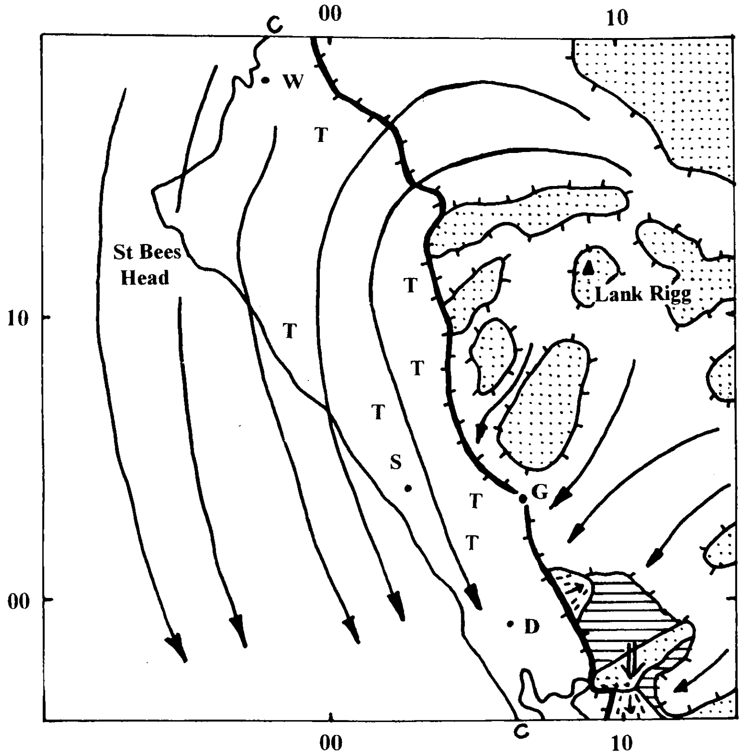


2a Build up of Main Late Devensian Ice Sheet c. 26,000 BP

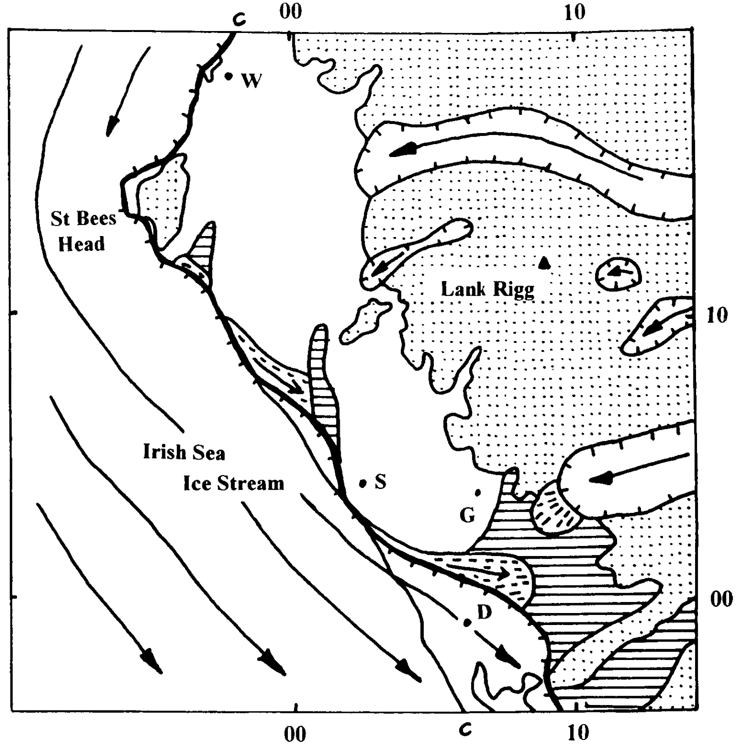
2b Retreat of Ice of Main Phase Late Devensian Glaciation c19,000 BP

Figure 2 (a & b) Episodes During the Late Quaternary History

Figure 2 (c&d) Episodes During the Late Quaternary History



2c Early Deglaciation after the Gosforth Oscillation



2d The Scottish Readvance

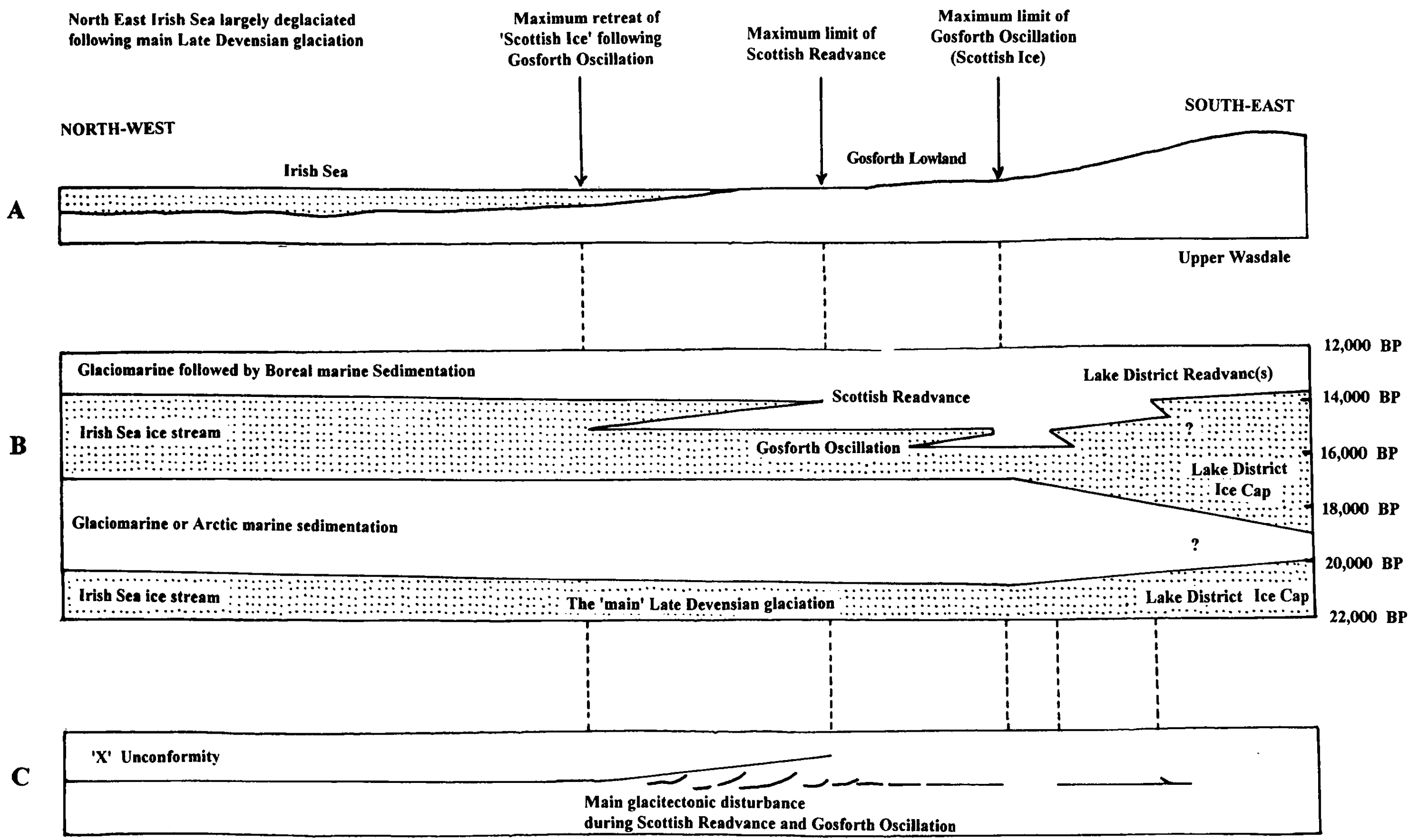


Figure 3 A. Schematic transect across the Sellafield are showing the limits of glacial advances and retreats.
B. Conceptual model of ice distribution through time 22,000 – 12,000 BP.
C. Conjectural extension of the X unconformity onshore beneath the Gosforth Lowland.
(Redrawn after Browne 1997 Figure 1.5.1)

Discussion

This is arranged in four sections in which representative questions and implications generated by the recent studies are considered. The first part deals with some issues that arise from estimates of magnitude, distribution and occasion of local Quaternary erosion. The second considers interpretations of Quaternary sediments and landforms in the study area and notes some reactions already registered. The third relates the new studies to Quaternary history in north Cumbria and the last attempts the same for coastal Cumbria south of Ravenglass.

Denudation studies

Possible effects of future changes in ground water movement on the safety of waste disposal have had to be considered. A potential cause of such change is significant erosion in the repository area. As part of the risk assessment, appraisal of past erosion over a relevant time span was undertaken. The extent and thickness of residual Quaternary sediments on land and under shelf seas round Britain were determined and then related to the likely contributory area (Clayton 1996). The 'final estimate' of average depth of erosion over that area was 125 - 155 m, 25 - 35 m being in the most recent glaciation. Four of the eight major Pleistocene glaciations were of comparable magnitude to that glaciation. By far the greater part of all Pleistocene erosion was by ice though only some 16% of the last 472 ka BP was taken by glacial episodes (figures for the earlier part of the Pleistocene were not given).

Clayton also estimated the volume of rock removed, mainly by ice, from corries and glaciated troughs in the Lake District to be equivalent to overall Lake District erosion of 110-120 m.. It would have taken several glaciations to produce these larger features. Erosion in the British uplands ranged from 200 m, as estimated for the West Highlands, to much less in the drier eastern British uplands. The overall estimate for glaciated uplands was about 75 m and the relation of that figure to estimates of total volume of accumulated sediment implies that the less resistant rocks of the lowlands experienced 200 - 300 m of cumulative erosion mainly in the 4 - 8 principal glaciations.

Clayton had earlier (1974) apportioned Scotland and northern England among five zones of glacial erosional intensity. Most of the Lake District was placed in the zone of greatest intensity and the rest of Cumbria, upland and lowland, in the zone of nextmost intense erosion. The associated descriptions are, (i) for most intense zones 'ice moulding even on high summits with lower divides streamlined' and (ii) for lowlands in the next zone 'preglacial forms lost: planar slopes on soft rocks and rock drumlins or knock and lochan topography on hard rocks.'

In a general conclusion, Clayton (1996, p139) noted that his findings 'conflict with many statements attributing little more than the modification of older landscapes to our past ice sheets, or those which imply that periglacial stages have witnessed the most rapid and lasting changes in the shape of our landforms.'

This interpretation has consequential implications for Cumbria. Episodic increase in the separation of upland and lowland areas through different rates of erosion during glaciations would have been accompanied by progressive stripping of softer rocks from the upland margins so expanding the Lower Palaeozoic outcrop. The more rapid denudation of the lowlands would facilitate deepening of upland valleys though excavation by ice of valley rock basins would not depend wholly on erosion of the peripheral lowlands. Valley deepening and its headward extension would be concentrated in major ice discharge routes now identified as the glacial troughs. The Lake District would become increasingly divided, each glaciation further enhancing efficiency of ice discharge. There would be an accompanying concentration of steepest slopes along sides of glaciated troughs, at trough heads and corrie back walls. Bases of very high steep valley sides would be particular sites of high rock stress. At times of rapid ice loss, newly-steepened and re-steepened slopes become potential sites of rock-dilation, slope failure and scree formation. Rapid and substantial erosion followed by rapid ice loss would tend to generate isostatic disequilibrium with potential neotectonic responses.

Clayton's proposition that little can now remain of pre-Quaternary landscapes is important yet difficult to evaluate. What would remnants look like: what was there before? Perhaps the contrasts in interfluve relief between the southeast and higher, wetter west of the Lake District give some indication. Marr (1916), quite familiar with the work of ice, considered smooth crestlines, more prevalent east of Dunmail Raise, to be remnants of an older landscape while McConnell (1939) and Parry (1960) believed they could recognise surviving parts of a landscape shaped and increased in height range by alternating periods of uplift and relative stability. There are extensive areas of bare rock in the fells, abraded, plucked, grooved, striated by passage of ice but they don't tell how much rock was moved, what shapes were lost. Streamlined hills up to a kilometre or so in length, several hundred metres high, may be testimony to ice-moulding but not to how much rock was moved. Nevertheless, on both Upper and Lower Palaeozoic rocks within and round the fells there are localities with fairly level surfaces cut across rock structure, some among the gentle interfluve country of the southeastern fells. Long reaches of the stepped crestlines between Borrowdale and the Thirlmere valley, benches and summits on the Silurians between the R. Lune and Duddon estuary and, patchily, on the limestones have undoubtedly experienced ice erosion: can eroding ice create such forms or have they survived it? Local proximity of such landscape facets and deep glaciated troughs imply very substantial lateral variations in erosion intensity.

That the most recent glaciation was not a simple event is affirmed by the recent studies in West Cumbria. How was erosion distributed in time through individual glaciations? There are several drumlin tracts in Cumbria and, like those elsewhere in Great Britain or Ireland, they tend to be discrete or narrowly connected, and many lie well behind the outer limits reached by ice in the most recent regional glaciation. The frequent association of drumlins with sands and gravels, overlain, reworked, and incorporated in bedded form, suggest that much meltwater was present in the ice sheets before and during occasions of drumlin production. Much drift was moved and emplaced in those times: how much new erosion took place at the same time? Locations of drumlin tracts demonstrate that formative conditions were restricted in both time and place.

In the matter of new erosion of bedrock the drumlin field across north Cumbria is instructive. Drumlins were produced in east-moving ice streams crossing Stainmore and moving through the Tyne Gap. Erosional grain there conforms to drumlin alignment. The abandonment of those routes, not wholly synchronously, was probably initiated by an accelerated southward movement of ice in the northern part of the Irish Sea basin: so was the disruption of the eastward-sloping surface of ice in the Solway area that had largely driven the eastward ice movement. Consequently, thick ice in Cumbria moved to the Solway creating a drumlin grain from the northern foot of the Howgill Fells to the Workington area.

Along this new ice path, up to at least 300 - 400 m OD, the dominant grain of bedrock erosion is at various angles to the local strike but parallels drumlin alignment on the limestones from Orton almost to Penrith, on the Penrith Sandstone hills further north, on the Greystoke limestone country, Warnell Fell to Cockermouth, Setmurthy Common, and on the hills near Arlecdon. There is testimony here not only to thickness of drumlin stage ice but to its erosional effectiveness. Even so, the scouring and moulding does not say how much rock was newly carried away. Drumlins and erosional grain in valleys tributary to the main ice stream suggest the extent, if not the degree of erosion during the drumlin stage. The Lowther, Ullswater, Matterdale, middle Caldew, Keswick-Bassenthwaite valleys provide the main examples of this relationship.

Drumlin stage ice from the north and northeast reached the Nirex study area along a front that extended east from Whitehaven for 10-12 km. Its effects there appear not previously to have been separately identified or considered. Ice trajectories show this ice was not directly from Scotland: any Scottish material it may have carried would have been reworked or taken on an extended journey. Nevertheless, this ice must be taken into account in attempts to explain Scottish material in the drifts on hills east of Egremont. For it to have produced the deformation structures recorded in drifts of the readvance terrain further south it must have taken a large and sharp deflection to the east, and one somehow enforced by the offshore part of the icestream. It might here be noted that in the Whitehaven area perhaps only about a third of the width of the north Cumbria drumlin ice stream was still east of the present coastline, the rest 'offshore'. Was that latter part in its turn, coerced to change course by a truly Scottish ice stream further west?

The B.G.S. reconstruction of the GOS stage (Fig 2) shows an ice stream entering the area from the north-east at some time after decline or 'retreat' of the main Late Devensian ice. This ice stream is neither described nor explained in the recent work and there is also in the reconstruction an unexplained incompatibility between ice trajectories and a 'notional confluence of ice sheets' which may be taken also as limit of the GOS readvance. The given trajectories could not be synchronous with the confluence nor could they produce a confluence which took such a course. Moreover the position of confluence seems to require an ice surface height greater than the GOS readvance ice, as mapped, could have attained.

Readvances

Readvance has been a dominant theme in studies of glaciation in Cumbria since Trotter (1922) proposed that the region experienced post-maximum incursions of ice, and it dominated the recent work in the west of Cumbria. Huddart (1997) found some aspects of those studies problematic. Noting difficulties in establishing precisely the furthest extents of readvance ice, he asks whether more than one incursion is required to account for all phenomena ascribed to readvance, and how many quite separable readvances are identified with certainty in the local sediments. In respect of contrasts in interpretation of onshore and offshore sediments, two readvances recognised onshore and the single X - unconformity offshore, he looks for improved means of correlation. Better understanding of onshore sequences requires, among other things, more certain criteria for identification of glaciomarine sediments, in situ and reworked. Thirdly, he pointed out the need for a more firmly based local chronology supported where possible by absolute dates; is there any evidential basis for the dates given in the reconstruction of local glacial history to the various stages or events?

The variety of uncertainties remaining despite the intensity of investigation is shown by the following examples. The GOS limit was drawn 9 - 10 km east of St Bees Head and at about 100 m OD. The margin is continued at similar height to the vicinity of Gosforth. From St Bees to Seascale, the 'Nirex' SR limit extends scarcely a half kilometre inland and reaches hardly above 50 m OD. In contrast, south of Gosforth the GOS limit is shown to continue south-east across the lower ground where the SR ice margin extends 4 km beyond the present coastline: at Holmrook it is little short of the GOS limit. The change from north-west to south-east in relative positions of the two readvance limits has a clear implication for relative behaviour of ice masses but one that is neither remarked upon nor explained. Possibly not all parts of one or both limits, as drawn, are synchronous. It might have been that ice from

Wasdale impeded further inland advance of GOS ice, but evidence for that having been the case was not presented.

Spreads of thin drift have been mapped on the higher ground within GOS limits mainly between St Bees Head and Egremont. On the St Bees Head upland there are strike and till fabrics at sites above SR limits (Huddart 1972). Their alignments, WNW - NNW, may have some compatibility with main glaciation, drumlin stage, and GOS readvance ice movements, the last as implied by drift deformation structures. To which stage do they belong? It would be valuable, to aid clarification of various local episodes of glaciation, to compare characteristics of the thin upland tills with those ascribed to main glaciation and GOS readvance, and with those of tills on the hills above Gosforth and beyond over which drumlin stage ice may have passed.

The division of much of the readvance territory into glacitectonic thrust and glacially overridden terrains is based on styles of deformation seen in exposures and inferred from landforms. Overridden terrain is by far the more extensive. Mapped areas of thrust terrain are long and narrow, most are coastal and so within or alongside SR limits. Several other mapped areas of thrust terrain follow steep valley sides. The question so posed is how such a pattern of deformation effects arose and whether it might be, if only in part, an artefact of how exposures are disposed.

Huddart (1997) noted that the set of linked cross-slope meltwater channels between Calder Bridge and Gosforth, taken by Trotter et al (1937) to have been formed along changing margins of readvance ice, is more likely to have developed subglacially and to be of a sort with channel systems at Corney and Bootle (Smith 1967). From the crestline south of Ennerdale, uplands and valleys leading down to Calder Bridge and Gosforth carry a suite of col, valley side and valley floor melt discharge channels. The subglacial formation of part of this suite was outlined by Huddart (1967). The formative environment requires an ice cover with a south or southeast sloping surface from the area north of Ennerdale. Ennerdale would thus be ice-filled and the highest local subglacial meltwater routes, Black Pots, over 450 m OD, led out of upper Ennerdale.

This is a complex area almost wholly above the mapped GOS readvance limits. Its landforms and sediments could derive from passage of main and/or drumlin stage ice. Both would have extended south over the coastal lowland and beyond: the limit reached by the drumlin stage ice stream from northern Cumbria is quite unknown. To determine the sequence of events that produced col and valley channels, their sediments, the upland tills above the GOS limits and the drumlins of the coastal lowland would be to elucidate a significant part of late glacial history not fully resolved in the recent studies.

Accumulations of deltaic sands and gravels, up to 67 m OD, have been taken to mark positions of a readvance ice front discharging sediment into an ice-impounded lake in lower Wasdale. Altitude of delta foreset bed surfaces indicate approximate lake levels from time to time. At highest levels, lake water would have extended across Miterdale and into Eskdale in the absence of ice masses in those areas. In any event, lake exits would have operated at about delta surface levels. Traces of both exits and other sediment input points may survive. It is difficult to see how, as suggested, lake levels indicated by delta altitudes could have been controlled by exit channels across the crest of Muncaster Fell. Even if channel form there is compatible with function as lake overflow, there are incompatibilities of altitude.

The interpretation of much lowland drift, especially sands and gravels, as water transported and laid down proglacially or subglacially is relevant to the onshore-offshore contrast referred to earlier. Offshore sediments have been described as 'predominantly deposited in a marine environment even those [of] the Late Devensian glaciation' . Proglacial sands and gravels onshore imply meltwater discharging at ice margins. That requires a relationship between bed topography, ice thickness, and ice surface slope sending meltwater into the readvance areas of west Cumbria. It means that the water in question was not able to take other courses in the lower area offshore and that the ice offshore was not floating as an ice shelf. When meltwater was directed from ice west of the present coastline to the onshore readvance ice margins the part of the ice sheet contributing water and through which the water passed was, in effect, land ice. Whatever the predominance of marine sediments offshore, there were times and places when ice in the northeast part of the Irish Sea basin was land ice.

Implications for northern Cumbria

The proposition that an ice mass extended eastward in the GOS event beyond Egremont and Cleator Moor and up to 100 m OD creates expectation that readvance would be represented onshore further north. Known events in the latter part of the glaciation are represented north of Whitehaven by drumlin stage and Scottish Readvance sediments and landforms. A more extensive Scottish Readvance than that defined by Huddart (1972) was advocated by Trotter (1929) on the evidence of a widespread thin diamict cover over much of the north Cumbrian lowland. Huddart et al (1977) considered the upper till rather less extensive, but sediment released from residual ice cover following drumlin formation has to be taken into account as source for a final sediment drape.

No equivalent of the GOS readvance has been reported from the area north of Whitehaven though it might have been expected as far inland as, say, Branthwaite and Greysouthen. There is now an incentive to look for evidence for phenomena not explicable in terms of drumlin stage ice, active or subsequently quiescent. Inability to locate convincing evidence there would make it more difficult to explain the readvance south of Whitehaven.

The Scottish Readvance margin in northern Cumbria has been shown (Huddart 1972) to pass offshore near Allonby, north of Maryport. The proglacial deposits near Harrington were taken to indicate an adjacent ice margin in a now offshore position. The apparent inability of that ice to push further east between Allonby and Workington contrasts with its passage across the plateau west of Carlisle. That stretch of coast, Allonby to Workington, does face the high ground, Criffel to Dalbeattle, that deflected late movements of Scottish ice into Nithsdale and the Dee valley. Even if an 'ice-shadow' effect operated, features on the Cumbrian side potentially relevant to readvance may be noted. There is, or was, a N - S esker across drumlin grain at Harrington, and there are channels near Maryport (Ellenbank, Allerby, and between R. Ellen and R. Derwent near Dearham) and north of Distington that also are discordant to drumlin grain. The highest point of these channels is below 70 m and all except one are within 3 km of the coast. The channels are open at each end and cross ridges. Though they probably carried meltwater, directions of flow and whether as overflow of ponded water or ice constrained sub-glacially remain to be determined. The change at about 50 m OD in the Ellen valley from open aggraded reach to narrow incised reach, and the unusual ridge-top terrain, 70 - 90 m OD, at Hayton, quite near the three northern discordant channels also call for explanation which, whether involving readvance or not, will further understanding of local landscapes.

Implications for the coastlands of southwest Cumbria

Identification of GOS sediments on the coast at Ravenglass and representation in reconstructions of glacial history of lakes in Eskdale during readvance episodes (Browne et al 1997) generate immediate implications for the coastal tract southeast of the Sellafield study area. As in north Cumbria, the only late readvance previously recorded is the Scottish Readvance (Huddart 1972, Huddart et al 1977). Effects of main glaciation ice and of any local equivalent to the drumlin stage have not been differentiated. Proximity of fellfoot to coast from Waberthwaite to Millom gives little room for representation at the surface of all postulated episodes in the last glaciation.

The Lake Eskdale proposition is testable. There may be lake sediments (to what extent and elevation?), evidence for location of an ice barrier and for points of sediment input from any ice barrier, shoreline features, up-dale sedimentation to old lake levels, outlet points and routes.

The Waberthwaite area, adjacent to where evidence for a lake would be looked for, is enigmatic. It lacks the long coastal exposures so informative of glacial sediment sequences at Selker and further south. Glacial landforms of the coastal plain are low and subdued. Long, low-gradient, coast-parallel channels could be related to ice front diversion of water including from a lake but the circumstance is complicated by the presence of not dissimilar channels in the lower part of the fellside channel system (Smith 1967) which have been associated with thicker ice than at readvance ice margins. Nevertheless, this is an area seemingly favourable to incursion of readvance ice. On the coastal plain that would have largely been over older drifts. Clearly, this is an area that must be further examined.

Landforms and sediments in the Whicham valley, inland from Silecroft, hold some prospect to differentiate events in the latter part of the glaciation. The grain of ice eroded rock in and near the col to the Duddon valley tells of ice moving at some time southwest into the Whicham valley. Lake sediments up to 45 m OD have been recorded there (Bryant et al 1985). It is possible that determination of highest lake level was exercised by low (below 50 m OD) points on the col to the Duddon valley. As to an impounding barrier, Scottish Readvance moraine as presently delineated would not have served for lack of height and sufficient extent. Inland from that moraine, the mouth of the Whicham valley is almost closed by a sand-gravel mass attaining about 60 m OD and with a flat on its flank at some 30 m OD. Emptying of lake was, perforce, south across or past the gravels and any ice then remaining. Re-examination of mound and adjacent terrain might well determine provenance and travel of sediments and development of morphological features so clarifying relations with the nearby Scottish Readvance terrain.

The south end of Low Furness rather mirrors the Solway coastland, sediments and meltwater channels of readvance ice lapping onto a drumlin tract with its own channels. Huddart et al (1977) recorded the salient evidence for readvance, the contrast in lithology and fabric between older and readvance till, the accumulation of proglacial sands capped by the upper till up to the Roose - Roosebeek marginal channel. Rose and Dunham (1977) noted the division, Ireleth to the vicinity of Furness Abbey, between drift types. To the east, clasts from thin tills show derivation from the north, probably the Coniston area. To the west, on both sides of the Duddon estuary, drift is thicker, up to 90 m thick, and more complex with erratic material from the west of Cumbria and south Scotland notably in an upper till. Rose and Dunham suggested inland and coastal ice masses met and mingled drift in a zone Millom - Askam - Barrow. North-south low-gradient channels on the coastal plain reach the coast near Millom. East of the Duddon estuary, south of Askam, low (below 30 m OD) open ends of meltwater channels face north and west towards Millom. They lead to the Furness Abbey - Roose channel which is probably an older feature, but the local topography would permit any readvance or late ice in the Duddon estuary, that reached the present 30 m contour to discharge meltwater into the older channel.

In the east of Low Furness, the younger drifts appear to overlie drumlin stage drifts. One readvance stage has been identified and its correlation with readvance deposits between Waberthwaite and Millom and Scottish

Readvance phenomena elsewhere in Cumbria considered possible (Huddart 1997).

The Roose - Roosebeck readvance sand-till terrain may be complex in origin. The broader north-eastern part is a low plateau with marginal gullies and embayments, gentle culminations to 30 - 43 m OD and a rather subtle WSW - ENE grain. The narrow southwest fringe is highest in the northwest (30 m OD) and southeast (13 and 27 m OD) with an intervening low area. The sediments are best known from the southwest fringe, cliffs between Westfield Point and Concle and the Roosecote sand pits. The larger, higher part is poorly exposed. Development of the bipartite character of the readvance sediment terrain awaits full explanation.

At Roosebeck the channel fronting the readvance sediments reaches the east coast of Low Furness and there the readvance limit leaves Cumbria to follow an unknown course for an unknown distance. It leaves as well an interesting question: if the same ice mass produced readvance phenomena from east of Carlisle to east of Barrow, how is it that there is such little variation over that distance in the altitudes of the readvance limits ascribed to it?

Conclusions.

The wealth of recent work in West Cumbria has produced a new, refined and detailed account of the Quaternary. Sedimentary environments, offshore and onshore, remained distinct for much of the period. The proposition of late ice readvance into Cumbria was reaffirmed. No evidence, however, was put forward to confirm a late glaciomarine episode affecting coastal Cumbria. The recognition of deformation features in glacigenic sediments to determine ice movements was a notable innovation in Cumbrian glacial studies.

As is usual in the case of major new studies, fresh questions arise, not all older ones are settled. The pervading contrast between offshore and onshore sedimentary environments remains not fully understood. Relationships between landforms, sediments and inferred processes in the onshore Sellafield area are yet to be completely elucidated. The proposed greatest extent of ice readvances in the study area has consequences for where invading ice may have reached in adjacent parts of coastal Cumbria. Conditions which drove Scottish Readvance ice into Cumbria, and perhaps even beyond Low Furness, are still to be explored.

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BUILDING STONES OF SOME AREAS OF WEST CUMBRIA

This is a group of short articles by Mervyn Dodd about Buttermere and Gosforth, Margaret Fox about Eskdale, and Kath and Alan Smith about Keswick.

The articles represent the Society's response to a challenge by Eric Robinson in his Presidential Address to the Geologists' Association in May 1994 (A pattern of English Building; a challenge) that the Cumberland Geological Society should attempt to describe patterns of building stones in Cumbria. (See also the record of Professor Robinson's 1998 lecture to the Society contained in these Proceedings).

Such a response was first discussed at the Council meeting in November 1995 and subsequently at the AGM in February 1996 where it received considerable attention from members. A small group of interested members subsequently met on a number of occasions and a session presenting progress on the project was held after the AGM in February 1997.

These articles represent the success of the group in discovering and describing the building stones used in some Cumbrian settlements. Each article approaches the subject in a different way, reflecting the varying nature of the subjects and together they provide an indication of the differing 'lines of attack' that have been adopted. It is hoped that this group of articles may prompt other members of the society to conduct similar studies on other settlements in the area – there are plenty of suitable areas awaiting investigation and recording!

BUTTERMERE AND GOSFORTH, TWO CONTRASTING SETTLEMENTS

Mervyn Dodd

Buttermere and Gosforth respectively were chosen because they provide examples from the Lake District Dome and the surrounding lowlands. The contrast in natural landscape is reflected in their very different vernacular architecture. Buttermere has a wide variety of building stones, both local and 'imported', as the very hard local stone is difficult to cut and dress. Gosforth has had the advantage of an easily available local stone that can be cut, dressed and carved. Thus Gosforth had little need of 'imported' stone and used much less varied building stones.

Buttermere

Buttermere is a small Lakeland settlement mainly built on a south-facing slope in a steep sided valley. Fine-grained, thinly bedded, steeply dipping Skiddaw Group rocks are exposed or are very close to the surface, by the roadside along which the village extends.

West of the lake, Ennerdale Granophyre, a pale pink rock with rather small crystals, outcrops from Sour Milk Gill and Red Pike north-west as far as Scale Force. According to Pedder and Macdonald's 'An account of St James Church, Buttermere' (written in the late 1940's), the present church, built in 1840 and extended in 1933, using Ennerdale Granophyre from quarries (scrapings?) at the foot of Red Pike. Its strongly developed vertical jointing gave masons some scope, so it was carefully dressed and coursed for the walls facing the road but the rear walls are random blocks over slate coursing. Church records tell of a continuing problem with waterproofing. Whether this was the fault of the stone or of the builders is not mentioned. Some very dark Borrowdale Volcanic Group rock is also used in the walls. As is generally the case in the village, decorative features, lintels, sills etc. are of more easily cut New Red Sandstone, probably from West Cumbria rather than the more distant Eden valley.

The older farms and cottages are truly vernacular, plain and 'no nonsense' in style, probably dating from the main period of building in stone in Lakeland valleys, the late 17th and 18th Century. Some are 'Long House' in type, with house and barn under the same roof. The house walls are whitewashed rubblestone blocks of very mixed sizes and often are built over huge boulders. Outbuildings and barns normally have bare walls, mainly in Ennerdale Granophyre and Borrowdale Volcanic Group rocks squared for quoins. The generally subrounded edges of these boulders suggests they have been transported glacially or fluviglacially rather than quarried. Outcrops of the BVG in Warnscale Bottom and part way up the Honister Pass were possibly too distant for easy transport along the poor roads of the 17th and 18th Centuries. Skiddaw Group rocks are used sparingly in coursing and originally as lintels where recent alterations have not occurred. Recent rebuilding and alterations have usually used New Red Sandstone around doors and windows.

Late Victorian buildings such as the 'Bridge Hotel' and 'Trevine' have horizontally laid Skiddaw Group stone walls with the mortar deeply recessed to imitate dry stone walling and with the slate edges chamfered to shed water. This style was common in late Victorian buildings in the Lake District.

We don't know where these Skiddaw rocks came from. Old map evidence is equivocal. The 1861 First Edition 'One Inch' O.S. map names High House Quarry in approximately the same position as the quarry (NY 173 172) near the National Trust car park. However this quarry was not shown on the first edition of the Ordnance Survey '25 inches to the mile' map (1863) but appeared on the second edition in 1899. It has thinly bedded blue-grey stone that cleaves quite well. Sheila Richardson in her 1995 'Tales of a Lakeland Valley; Buttermere' quotes an elderly resident as saying his father used stone from that quarry to maintain the road between Hause Point and the top of Honister Pass. An older quarry was shown on the first edition of the '25 inches to the mile' map by the farms nearest the Church but not on the 1899 edition. There is little trace on the ground of this quarry. Another possibility is the Slate Fell (NY147 304) quarry, near Cockermouth.

Quoins, door and window surrounds in these late Victorian buildings use a variety of stone. A coarse, pale, Carboniferous sandstone, possibly from either the West Cumbrian Coalfield or from an abandoned quarry at Brigham (NY 084 304) has been used for some cornerstones and corbels. Generally however, door and window surrounds are in finer grained, more easily worked New Red Sandstones.

Lakeland slates, usually of Honister type, are by far the most used roofing material, the regular courses of purple Welsh slates on the 1871 Parish Room (formerly the village school) appearing rather inappropriate. The older buildings have very heavy, thick, blue-grey, rather soft, rough-cut slates, which could be Skiddaw Group material extracted before the present Century. If these were Skiddaw Group material we can only guess where it was quarried. Late Victorian buildings and recent reroofing have used much thinner cut, pale green Honister slate or second hand mixtures of slates.

Gosforth

Gosforth is one of the larger villages of the West Cumbrian lowlands south of the Coalfield, where glacial and fluviglacial deposits cover the Triassic St. Bees (Sherwood) Sandstone. It is an old settlement, land grants in the parish being documented from 1160 onwards and the 4.5m high Viking Gosforth Cross, carved from a single block of red sandstone, being 10th Century in age. Without removing a sample for testing, it appears to be Triassic St Bees Sandstone, which would be rather surprising, as St Bees Sandstone is normally fractured, strongly stratified and jointed and a single piece of such dimensions seems unlikely.

The oldest buildings date from the 17th Century. Most of the older part of Gosforth existed before the middle of the 19th Century, as little building took place between the publication of the 1st and 2nd editions of the Ordnance Survey '25 inches to the mile' map in 1863 and 1899 respectively. Building since 1945, which has made little use of local stone, has given the village a more obvious centre than the 19th Century pattern of apparently unconnected groups of houses. More recent architectural styles and conservation practices have led to stripping of render off some old cottages exposing the original New Red Sandstone walls, a partial return to traditional choices.

Render and stucco cover the original walling material of most pre-20th Century buildings, but the stone exposed in 'bare' walls is almost entirely the warm red to chocolate coloured Triassic St Bees Sandstone, sometimes decoratively dressed. A recently survey of Whitecroft, a triangular area of generally small to medium size housing near the village centre, almost entirely built before the mid 19th Century, illustrates this. One third of the 36 buildings had St Bees Sandstone exposed in their front walls, half were stuccoed and the few remaining, usually rather grander houses, had plaster over ashlar, in some cases this being the original construction. Gosforth Hall Hotel and the Library, and a rather fine 17th Century building elsewhere in the village, show this modification. Problems over waterproofing the permeable and often porous sandstone have usually made necessary some form of render. The walling style and quality of the stone, particularly the cohesiveness of its matrix and its resistance to weathering vary considerably. Most bare walls are random coarse rubblestone (of varying sizes, but not necessarily poor quality). A few, usually the more expensive houses with ashlar, have decoratively dressed walls, often with large cornerstones of more regular fine-grained sandstone. One pair had irregular Borrowdale Volcanic Group boulders built into the front wall as a decorative feature, another house had a similar rock in its chimney breast, exposed by demolition of a neighbouring property.

Outbuildings and boundary walls, understandably, are built of variable, often thinly bedded and sometimes much inferior stone, which has weathered badly. Again, St Bees Sandstone, occasionally showing the softer greenish bands, dominates, with the better stone being used in cappings. Borrowdale Volcanic Group and Eskdale Granite boulders are used more often than in house walls, usually in roughly oval blocks about 0.5m long, selected by size to make walling easier. In some places these are in the traditional West Cumbrian dyke and kest, stone and soil Enclosure Act walls. These rocks have been used in a decorative coarsed manner in the rather striking Churchyard walls. St Bees Sandstone or plaster appear to be the main materials used in door jambs, window sills and lintels, as far as we can tell from the small number that are unpainted. Where cobbled pavements remain or are emerging from crumbling concrete, oval and partly rounded 'cobbles' of Borrowdale Volcanic Group rocks or Eskdale Granite up to 10cm long or so were the standard materials.

Old buildings are almost entirely roofed in Lake District slate, mainly rather pale Honister type. In Whitecroft rough cut, uneven 19th Century pale slates, laid in courses decreasing in size to the roof ridge are the most common. A very dark slate of similar age and cut, possibly of Burlington type is used on some properties. Modern re-roofing of old buildings has a greater mix of slates, some second-hand Lakeland, with a few in the regular courses of Welsh slate and some appearing to be reconstituted slate waste, as well as cheaper tiles. Tiles of various provenance roof most modern buildings.

Only chimney pats and roof ridge tiles seem to be made from materials that are neither from the Lake District nor from the immediate area. These are dominantly fired clay, probably from either an old kiln at Drigg or from the West Cumbria Coalfield.

The 1937 Geological Survey memoir and old Ordnance Survey maps locate old quarries in the neighbourhood very fully. There were many long abandoned quarries in the St Bees Sandstone north of Gosforth in the Boonwood area (NY 06-08/04-05), on the southern slopes of Bleng Fell just north of Boonwood and around Newton Manor (NY 049 039) which guesswork suggests were for local use of for poor quality building. The 'old men' talk of stone being used in the present century from quarries at Gillgrass (NY 076 043) and near Priorling (NY 057 068) above Calder Abbey. Apparently the stone from one, resisted weathering much better than the other. The memoir describes both as having thick, uniformly bedded stone, thus good to quarry and work. Ponsonby (NY 05 06) and Haile (NY 03 08) parishes also have large old quarries described in the memoir as having similar easily worked stone of good quality. At present Grange Quarry (NY 034 050) in Haile Parish and Birkhams Quarry (NX 956 154) on St Bees Head are still producing small quantities of high quality St Bees Sandstone. Bulmers Directory of 1901 suggest the freestone quarries mentioned above in Ponsonby and Haile parishes were being worked. Similarly the Priorling (Stakes Bridge), St Bees Head and Bank End Quarries were mentioned. There was no reference to Gillgrass Quarry, suggesting it may not have been worked then.

The 1937 Geological Survey 1 Inch map Sheet 37 shows boulder clay and sand and gravel capping the St Bees Sandstone in the built up area of Gosforth and just to the north. The 1997 British Geological Survey memoir of the West Cumbria District suggests these belong to the Gosforth Glacigenic and Blengdale Formations (glacial and fluviglacial deposits) of the main Late Devensian glacial stage. Large scale Ordnance Survey maps show a scatter of abandoned gravel pits north of the village. These are more likely sources of the partly rounded (stream carried?) BVG and Eskdale Granite cobbles and boulders than the small, old Wrighthow quarry in BVG andesite near Julian Holme Farm (NY 094 036). Sand pits have been worked recently near Newton (NY040 027) and Peel Place (NY 065 002) still provides large quantities of sand and gravel. Older, long abandoned or infilled pits were nearer the village. The 1997 memoir indicates that these also belong to the Gosforth Glacigenic Formation.

(A literature search of secondary sources has been rather unsuccessful. With the possible exception of Buttermere Church no information about the quarry supplying an individual building has been found. I am advised that for these two settlements no quarry sales records or estate papers are available as primary sources. The Whitehaven Record Office staff have suggested an examination of old wills, say of the main landowners historically, might help).

ESKDALE

Margaret Fox

Man has long been using stone for building in Eskdale - hut circles on the moors above the valley; Roman buildings at Hardknott; Dalegarth Hall, started in the 10th century; mills, inns and farm buildings of various ages; schools, churches and houses from the 19th and 20th centuries.

The dominant stone is the Eskdale Granite which is exposed over much of the area. The main body of the granite is coarse-grained and pink but later alteration and the development of hematite along some joints has resulted in a variety of colours from almost white through grey to salmony-pink and dark red, with occasional yellowish samples. The biggest quarry was at Beckfoot, but this didn't open until the 20th century. There were a number of smaller quarries eg near Spout House; on the lower slopes of Hollinghead Bank; behind the Outward Bound School at Eskdale Green; and at Murthwaite.

A major variation of the granite occurs in the south west. Usually referred to as granodiorite, this has less quartz and much more biotite, resulting in a dark grey appearance. This was extensively quarried near Waberthwaite from about 1840.

Most of the older buildings and side walls of some more recent ones are of rubblestone construction. Granite boulders would have been gathered from streams and fells and fitted together as well as possible. Occasional boulders of the volcanics into which the granites were intruded have been used. Large gaps between the boulders would have created a problem with weatherproofing, and many buildings have now been rendered and painted or pebble-dashed.

Slabs of granite were used for lintels; window openings were arched with smaller slabs; cornerstones were roughly shaped blocks. These may have been quarried, but outcrops do exist where the jointing naturally produces slabs or blocks eg on Hollinghead Bank. Examples of older buildings can be seen in the village of Boot.

For more impressive buildings, cobbles were dressed to give a fresh surface on the front face. These were then fitted together randomly with heavy mortaring (usually containing crushed granite) to fill the gaps. The mortaring frequently stands proud of the granite. Examples include St Catherine's Church (dating from 1798 but extensively restored in 1881) and Stanley Ghyll House at Beckfoot (1894). The granite of the latter is predominantly salmon-pink, relieved with black fine-grained volcanic cobbles. Similar pink granite can easily be found nearby on the higher slopes of Hollinghead Bank, and the volcanics in the adjacent Whillan Beck.

Roughly squared blocks of various sizes and shapes have been random-coursed for some buildings. The old High School (1863), between Beckfoot and Dalegarth, and Gatehouse (the Outward Bound School - 1896) are examples. The former shows some of the colour variations in the granite.

Almost full coursing can be seen on the front of Sword House on the Birker Fell road. An inscription on the porch dates this as 1789 (with architect's or builder's initials: IVS). The blocks of varying lengths are about 50 cm thick at the base, becoming gradually thinner towards the eaves, a technique used partly for aesthetic reasons. A quarried outcrop 100 m or so along the road may have provided the stone.

Cornerstones and window surrounds at Stanley Ghyll and Gatesyde (architect Miss Huddart?) are of even-sized worked blocks of dark grey material visually identical to samples from the abandoned quarry at Waberthwaite. St Bega's Church (1890) has blocks of a light grey granite between sandstone cornerstones and window surrounds. This is visually similar to samples found lying on the floor of Beckfoot Quarry but this quarry was not in operation at the time of building. The old quarry near Spout House probably was working, and the grey granite can be found lying around here and at several places along the bottom of the slope as far as Beckfoot, but I have not yet seen it in situ.

Most of the buildings from the late 19th century onwards use sandstone for door and window surrounds and sometimes for cornerstones. This is a brownish-red, fine or medium grained sandstone which almost certainly comes from quarries in the St Bees Sandstone. There were quarries around Gosforth, Ponsonby and Calder Bridge as well as on St Bees Head. There are minor differences in grain size, degree of sorting and compaction. A paler version used for gravestones at St Catherine's fizzes slightly with dilute HCl, but in general there is no reaction.

The Romans used St Bees Sandstone for the gates at Hardknott Fort, presumably because it could be carved with inscriptions. (The rest of Hardknott, beyond the exposure of the granite, was built from squared, coursed blocks of local volcanics using lime mortar.) No. 2 Randlehow has a carved sandstone lintel with the date 1612 but there are several indications that this may be a relatively recent addition. Sword House and the nearby Forge House (1750 - IVS) both have sandstone porches and window surrounds which are believed to be original.

Roofs throughout the valley are almost exclusively of greenish slate. The nearest large quarry would have been Tilberthwaite, just over Hardknott and Wrynose Passes. Several quarries around Little Langdale were certainly in production in the 18th century.

Boot has one brick house, the former mine manager's home (1881 - currently the Post Office). Apart from this, the main use of brick is where windows or doors have been added later.

So the man-made structures closely reflect the area's geology - mainly granite with sandstone and slate on the margins - and offer an opportunity, on the more public buildings, for visual examination of relatively fresh surfaces showing the variations in the granite.

THE BUILDING STONES OF KESWICK

R.A. and K. Smith.

Introduction

Outwardly Keswick is perceived as a 'Lakeland Town'. The local, so-called 'Lakeland Green Slate', is regarded as the material which gives the place its character, but as we hope this study will demonstrate, the heritage of a much wider array of building stones is present in the fabric of the town.

Keswick has no buildings of great national architectural merit. Nikolaus Pevsner (1967) in his classic survey of 'The Buildings of England' devotes less than two pages of the Cumberland volume to a discussion of the town. Only the two parish churches of St. Kentigern (Crosthwaite) and St. Johns, and the Moot Hall in the Market Square, are deemed worthy of favourable comment. These three buildings themselves do, however, point us immediately to the very significant inadequacies and difficulties inherent in using the local bedrock for building materials. Neither of the churches are built of local stone and the Moot Hall is constructed of a somewhat chaotic mixture of the local and imported.

The vernacular architectural heritage of Keswick is likewise not outstanding. Although many early (pre-1850) buildings still remain and are indeed 'vernacular' in the sense that they are products of local craftsmen meeting simple functional requirements and using mostly locally available materials, most have undergone significant modification as the prime function of the town has changed from market centre to tourist resort.The dramatic growth of the town from approximately 1860, with the advent of the railway and the development of the tourist trade, is amply reflected in the fabric of the town. Post 1850 building is 'polite' in quality with much of the construction reflecting the work of Victorian designers, a more formal way of life and the advent of different (although fairly local) building materials. Most of the buildings created by the Victorians as Keswick established itself as a resort town were attempts to make the buildings pleasant to look upon and aesthetically satisfying.

Twentieth Century growth of the town has been substantial. Fortunately, mainly because tourism has remained the dominant activity and expansion has not been industrially driven, much of the horrendous architectural destruction so common in small English country towns has largely passed Keswick by. Of great importance has been the development protection afforded because the town has been within the Lake District National Park area since 1951. In the present context this has meant some control on building design and construction, and the implementation of positive directives on the use of local and 'traditional' building materials.

The history of the town is well documented, but information on sources of building stone, local quarrying and the construction industry is sparse The data on which this paper is based is derived largely from detailed field mapping in the town in 1997. Street by street recording and observation of external details of properties with regard to walling and roofing materials, and of stone used in quoins, lintels, sills and other property features have provided a wealth of data for the construction of Figures 2, 3 and 4. Considerable difficulty has, however, been encountered in matching materials to specific source locations.

The Local Geological Context.

Within the Keswick district outcropping rock is a distinctive feature of the landscape, but within the narrower confines of the immediate area of the town the picture is not so simple. Most of the town is built over a series of drumlins of glacial till, which afford relatively elevated and dry sites. Along the valley of the River Greta which winds its way through the drumlins, river gravels and alluvial materials form the surface (Figure 1). It is unlikely, therefore, that any bedrock was available for use within the environs of the early town. The tills would, however, have provided a plentiful source of useful boulders, cobbles and loose material. Similar waterworn pebbles and cobbles were also at hand along the course of the Greta and along the shores of Derwentwater.

Skiddaw Group rocks form the underlying bedrock. Within short distances of the town centre, particularly to the north and west, outcrops are plentiful. The materials are mostly mudstones and heavily cleaved siltstones and sandstones. The most accessible sites would have been in the gorge of the Greta (less than 1km upstream of the town), on Latrigg and Underskiddaw to the north, or at Hodgson How to the west. (Figure 1). Although there is some evidence for quarrying at all of these locations, we hope to demonstrate that as a group these rocks are not significant in the building of the town.

The nearest potentially useful stone was the small outcrop of the intrusive dolerite at Castlehead and Cockshot Wood (both under 1km to the south). Slightly further away to the south and south east are the lavas and tuffs of the Borrowdale Volcanic Group, which are well exposed both on the route into Borrowdale (now the B5289) and south eastwards along the main route to Grasmere and Ambleside (the A591). The volcanic rocks play an important part as a source area for building stone. Overall, however, when we look at the town it is immediately obvious that the local materials were very difficult to work and presented the early masons with materials that were far from ideal.

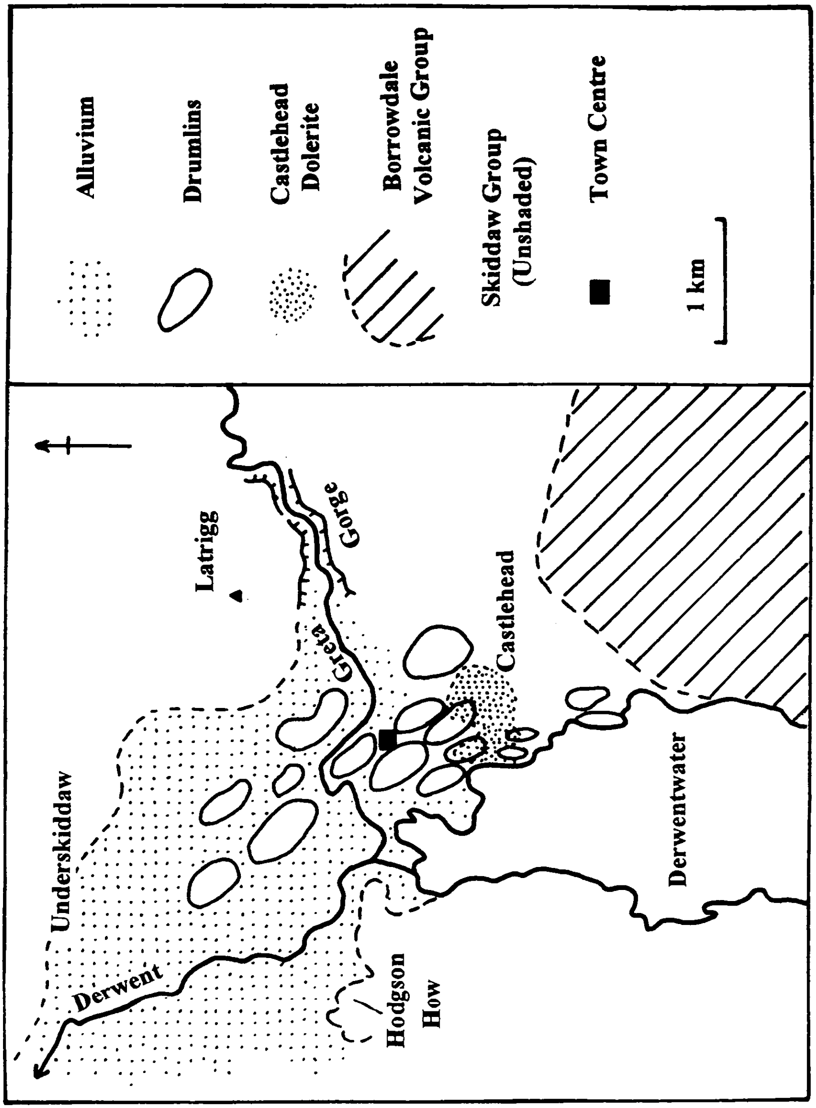


Figure 1 The Site of Keswick

The Parish Church of St Kentigern, Crosthwaite.

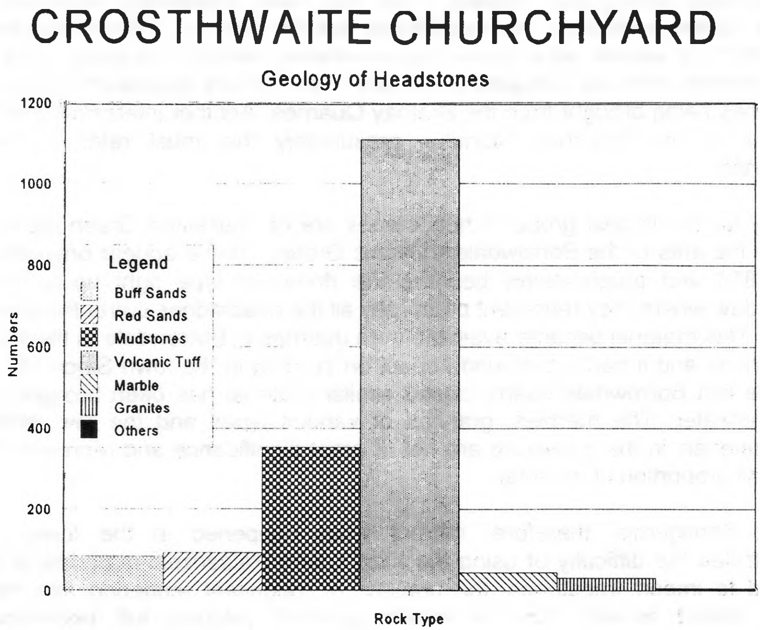
Apart from being by far the oldest building still extant in Keswick, this is a useful and instructive site to begin the description of the building stones. It is a microcosm of the history of the town. The earliest part of the church dates from 1181, but most of the present structure was constructed around 1523. The bulk of the building is made of fine grained, off white/pale pink sandstone of even texture. In places the sandstone blocks are blotched with red haematite. No records exist giving the source of the stone but in appearance the closest match is to the St Bees Sandstones that outcrop around the northern edge of the Lake District National Park in the Chalk Beck area between Wigton and Dalston (a distance of around 30 kms). The use of this imported stone points to an early realisation that the local Lower Palaeozoic rocks were difficult to work and if a freestone was required it would have to be transported. Such practice has been evident ever since. Large quantities of freestone from both the Carboniferous and Permo-Triassic strata of north and west Cumbria and the Eden Valley have been used.

In 1844 the church was extensively renovated. Two features of this work are also replicated time and time again in buildings in the town. First, most of the exterior of the building was rendered with a dull grey roughcast mortar, presumably to give a weatherproof coating. Obscuring building stones in this way presents obvious problems in a study of this kind. Secondly, a porch was added to the south side. For the first time local Borrowdale Volcanic Group lavas in crude angular blocks with thin tuff slabs to level up the courses was used in the walling, but, as in many other buildings in the town the framework for the extension, ie the butresses, archway and quoins are all of St Bees Sandstone.

The graveyard of the church is equally illuminating and sheds further light on the use of stone in the district over the last 250 years or so. A detailed analysis of all the headstones has revealed the data shown in Figures 2 and 3. Bearing in mind there are some particular difficulties inherent in such an analysis (see the note attached to Figure 2) a number of interesting trends are evident from the data. Prior to 1850-60 imported materials were being used exclusively. Three rock types dominate (Figure 3). The buff sandstones appear to be from the Carboniferous, most likely from West Cumbria. The red sandstones are from the Permo-Trias and range widely in colour and texture to include slabs from both the Penrith Sandstones and the St Bees Sandstones, most likely from the Eden Valley and West Cumbria. Both sandstones were used because they could be carved and inscribed, although it is noticeable that these more than any other rock material are heavily encrusted with lichens and severely weathered in many cases. The third group, the mudstones, figure prominently in the graveyard and have clearly been fashionable as memorials right up to very recent times. Some variety is seen, but the majority are from the Windermere Supergroup of South Lakeland with Brathay Flags being common. These materials could be worked very intricately and gave scope for some delicate carving and lettering. They also have outstanding weathering qualities. Some particularly fine headstones are the work of William Bromley (1811-1861) of whose work some documentation remains (Hughes 1974). Ledger records from his Company in the late 19th Century specifically refer to headstones being brought from the Brathay Quarries. Another interesting entry refers simply to 'Yorkshire Stone' - presumably this must refer to the sandstones.

By far the largest group of headstones are of 'Lakeland Green Slate ' (actually the tuffs of the Borrowdale Volcanic Group). These appear only after about 1850 and progressively become the dominant type right up to the present day, where they represent practically all the headstones currently being erected. This material became available from quarries in Borrowdale in the mid 19th Century and it had a profound impact on building in the town Since 1973 when the last Borrowdale quarry closed similar material has been brought in from Elterwater. The marbles, granites of various types and the few other exotic materials in the graveyard are not of great significance and represent a very small proportion of the total.

St Kentigern's, therefore, mirrors what happened in the town. It demonstrates the difficulty of using the local Lower Palaeozoic materials and the need to import freestones, the practice of roughcast rendering and the sudden impact around 1850 of locally quarried volcanic tuff becoming available.



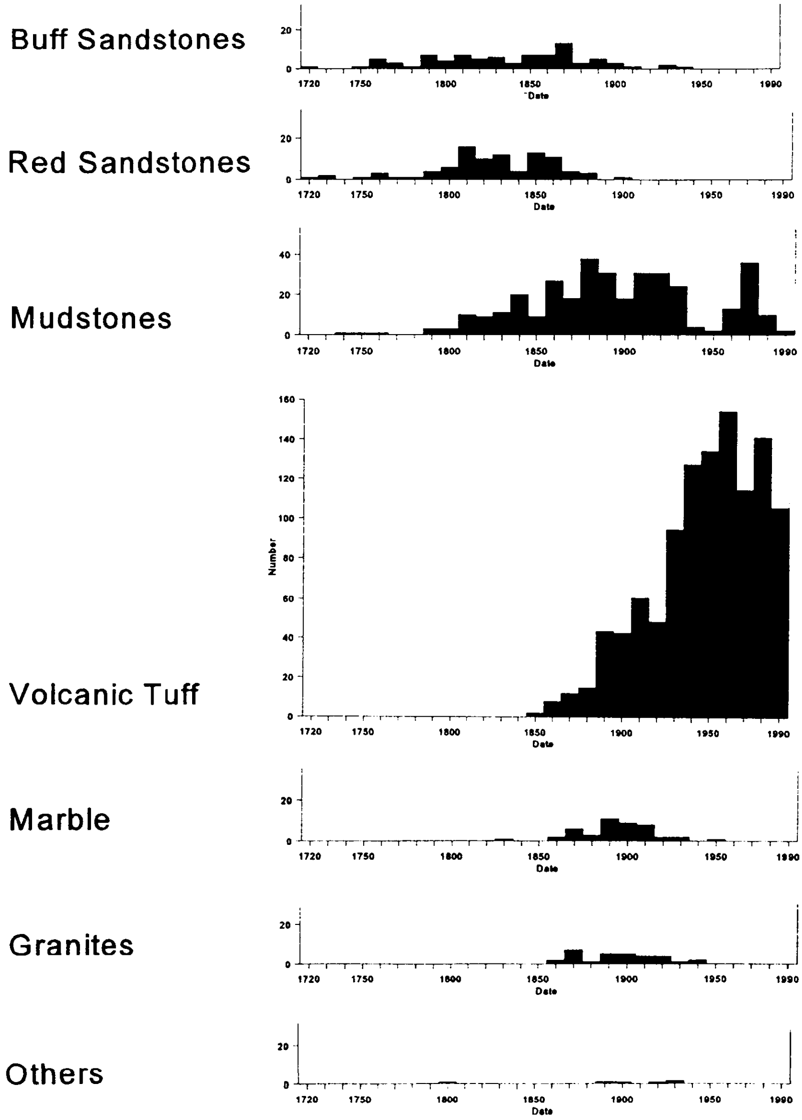
Note on the construction of Figures 2 and 3.

The earliest recorded date on each headstone has been used in this analysis. Headstones frequently record the deaths of several individuals and it can often be observed that headstones have been erected some time after the first death. The headstones inside the church are not included. No attempt has been made to subdivide the 7 lithological groups, but it must be noted that there is some variation within groups. Many of the sandstones are heavily weathered and cannot be deciphered. A breakdown of the data graphed in Figure 2 is shown below.

Rock Type	Dated	Undated	Total	%
Buff Sandstones	85	13	98	5.5
Red Sandstones	93	12	105	5.9
Mudstones	353	1	354	20
Volcanic Tuff	1110	3	1113	63
Marble	45	1	46	2,6
Granites	32	1	33	1.8
Others	6	0	6	0.3

Figure 2

CROSTHWAITE CHURCHYARD
DATES OF HEADSTONES / GEOLOGY



Based on Fieldwork 1997.

Figure 3

The Town.

Buildings in the town fall broadly into six groups (Figure 4a-f). Few properties are built entirely of one material, so it is not possible to group buildings simply in terms of their building stone.The interplay of several complex factors explain constructional details. The availability of materials has varied over time and has been closely connected to transport problems and costs. The status and changing function of buildings has a bearing on the way they were built or altered. Changing fashions and architectural design demanded different materials and techniques of construction. Our survey reveals that the age of buildings and their building stones are closely related.

Early Properties constructed of 'Gathered Stone'. (Figure 4a)

The majority of the buildings that date from before 1850, with the obvious exceptions of the two parish churches, are constructed from what is best described as 'gathered stone'. That is a mixture of materials that could be picked up and collected easily from nearby surface exposures, river banks, roadside cuttings, screes or the lake shores. As a result we see buildings constructed of choatic jumbles of what some authorities might call 'rubblestone'; material highly variable both in terms of shape and size as well as geological provenance. Visible at the base of many of these buildings are large boulders, big enough to be useful foundation material but awkward enough to have been difficult to move. They are large glacial erratics of Borrowdale Volcanic Group lavas which must have been constantly unearthed from the local tills. Around 80-90% of these early buildings are also completely roughcast rendered and in the majority of cases now painted over (usually including any freestone lintels, sills, door jambs or quoins). Clearly this frequently presents problems of deciphering the origin of the original constructional stone.

Two prominent buildings in the town illustrate the nature of this kind of construction well and are worthy of a more detailed look. First, the Moot Hall which stands on an island site in the middle of the Market Square. The present building dates from 1813 and mirrors many other buildings of a similar date. The quoins are ashlared Penrith Sandstone (now painted off-white). In the walling it is possible to detect rounded cobbles and boulders of Borrowdale Volcanic Group lavas and tuffs, the distinctive red basal volcaniclastic breccia (Borrowdale Volcanic Group) from Cat Gill (NY 270 209 - south of the town on the Borrowdale Road), irregular pieces of Skiddaw Group mudstone and oddments of Triassic sandstone all crudely mortared together. The second building, the St Herbert's Centre (originally Crosthwaite Sunday School) in High Hill was built in 1833. Again Penrith Sandstone figures prominently in the lintels, sills and butresses. However, the walls are a jumble of locally garnered material - cobbles of the Borrowdale Volcanic Group rocks, some split to give a flat face, crudely worked irregular pieces of dark Borrowdale Volcanic Group lavas, the red breccia from Cat Gill, small pieces of the Skiddaw Group, flat slabs of volcanic tuff to level the crude coursing and erratics of the Threlkeld Microgranite and the Armboth Dyke from the Thirlmere Valley.

There is some documentation about the early history of the Moot Hall (Tyson 1995a). A significant point is the constant evidence of re-using stone from earlier buildings. It was clearly a common local practice to contract out the supply of stone on major building projects. This obviously encouraged re-use as well as gathering from whatever very local sources were available. The poor value/weight ratio for walling stone in particular, always put local material at an advantage, its quality being of secondary importance, especially for the more humble buildings.

Figure 4a shows that much of the inner part of the town contains buildings of this group. They are best seen along Main Street, south east of the Market Square in the Derwent Street area and on sections of the Penrith and Borrowdale roads. Most of these buildings were originally domestic dwellings, small workshops and commercial premises. Most have since undergone significant alteration and enlargement, particularly those with frontages on to Main Street, now the main commercial centre. The majority are still, at most, two storey buildings, typically now white painted with in many cases the quoins and perhaps the other freestone features picked out in black.

Although the bulk of the 'gathered stone' in these buildings is Borrowdale Volcanic Group materials there is no clear evidence of precisely where it originated. Dark andesites and basaltic andesites predominate and are abundant in both the Naddle and Borrowdale valleys. Cobble walls with split cobbles giving a fair face are common, but there are some walls containing crudely worked dark angular blocks. It is noticeable that nowhere over the outcrop of the Borrowdale Volcanic Group south and east of the town can abandoned quarries of any size be located. A thorough examination of the first edition 6 inch to one mile (1:10,560 scale) Ordnance Survey maps (Sheets LXIV and LXX) which date from 1862 reveals nothing, whereas quarries on the dolerite at Castlehead and workings at various points on the Skiddaw Group outcrop are clearly marked. It may be that Borrowdale Group material was brought in from further afield, which seems highly unlikely. More likely is the possibility that there was sufficient surface stone around to be gathered or simply riven in small quantities from outcrops. A small piece of evidence that supports this view (unfortunately of a rather late date) is contained in a solicitors letter of 1891 in the Cumbria Record Office (Broach and Gandy 1891). It complains that two men were taking stone from Falcon Crag (NY 270 205) on the Borrowdale Road south of the town) and selling it for house building and that this was 'to the prejudice of the Lord of the Manor and to the danger of the public'. It is unlikely to be an isolated example or the first time the practice had occurred. Falcon Crag is conveniently situated by the road and has many easily accessible outcrops and aprons of scree. In such an irregular area as this it is impossible to see evidence today of the amount of stone that may have been removed in the past.The floor of the Borrowdale Valley still has large quantities of loose debris around and it cannot be discounted that some of it could have been moved on the lake. There is well documented activity of ore and other cargoes being moved on the lake from early times to Crow Park, near the present landing stages (Bott 1994).

The Castlehead Dolerite (Figure 4b).

This rock is seen only in a relatively small number of buildings. It must have been some of the earliest quarried stone used in the town, but from its first appearance round about 1840 it was only used for about 20 years. Given the highly accessible nature of this quarry on the eastern edge of Castlehead Wood (less than 1 km from the Market Square) there must have been other reasons why it was not exploited more. The dolerite is strongly jointed and was capable of producing good blocks of variable size, but some large enough to be used as very substantial quoins. It seems possible the quarry was opened specifically to build the new Parsonage (now Holy Name House) for the new St Johns Parish Church which was completed in 1838. The contracts and specifications for this work still exist (Marshall Papers 1838) and confirm the use of the Castlehead quarry. Interestingly the cost of the walling stone was calculated at three shillings and four pence per yard, compared with two pounds twelve shillings per square yard for the roofing material. The string course labels and copings were to be done with Coniston flagstones, illustrating that material was being transported considerable distances and, perhaps more important, possibly confirming this type of material was not available from Borrowdale at this date. In an even more telling quotation from the specification we read " ... provide and lay good Coniston flagging to the kitchens, scullery, larder, store room and passage ; lay the cellar floor with Borrowdale flags ". The implication seems to be that the Borrowdale material was inferior, a point that later in the century would have been challenged by local suppliers.

The dolerite was used also in the building of St Johns School (1840), the Keswick Library (now the Battersby Hall) (1849), some adjoining houses in St Johns Street, the nearby Bethesda Free Chapel (1851) and a large house - The Hollies (1846) in High Street. Interestingly in all these buildings there are other materials mixed in with the dolerite, occasional large chunks of andesite, thin pieces of tuff to level up sections of the work and the use of both sandstones and dressed volcanic tuff for lintels and sills. Elsewhere in the town the dolerite was used in a few domestic buildings - notably in a fine house at the west end of Main Street (now the Labour Club) where it was used only in the front facing, but here with Penrith Sandstone quoins, lintels sills and door jambs. This building shows the distinctive calcite veining in the rock to good advantage.

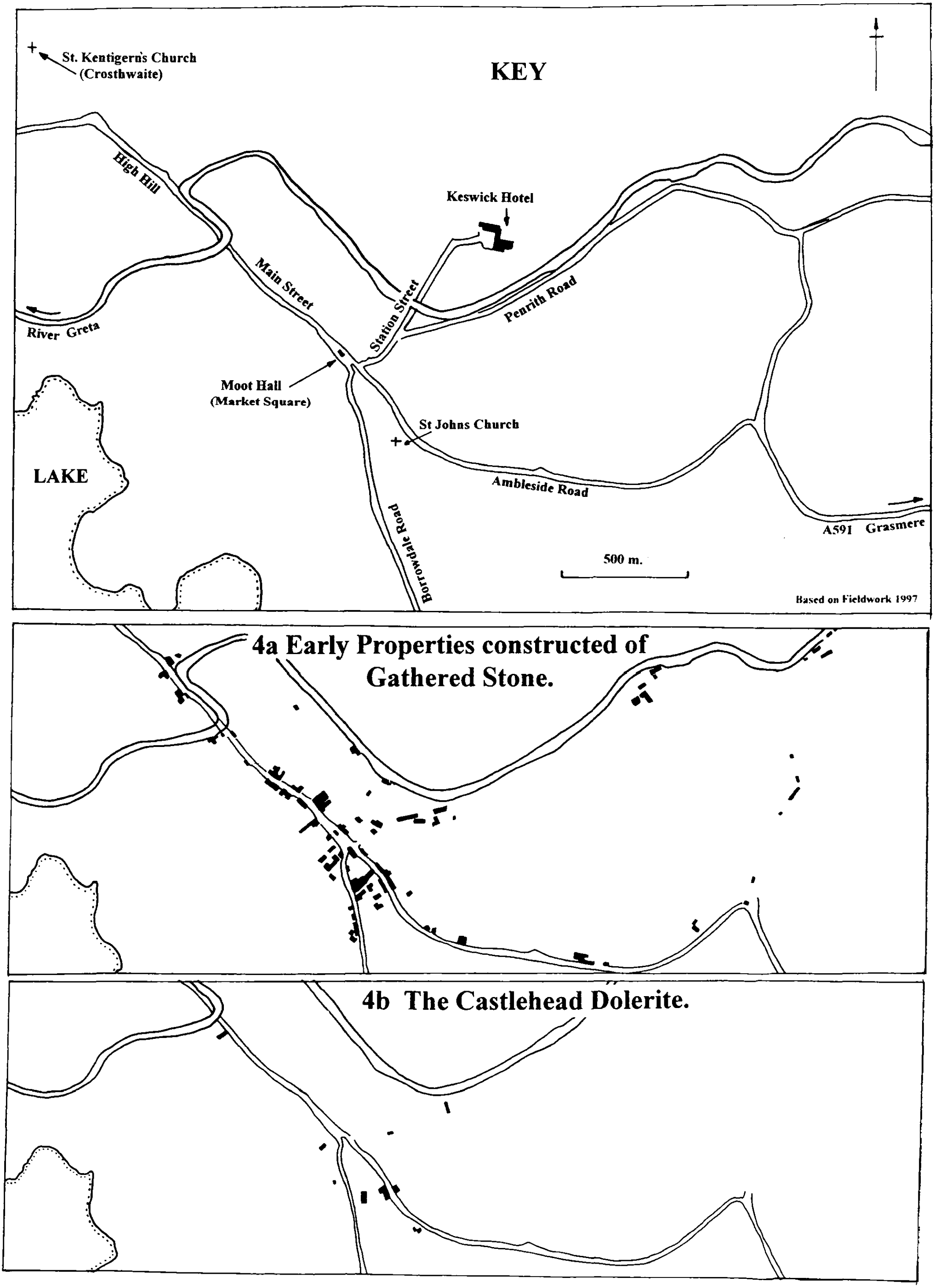


Figure 4, 4a, 4b

Borrowdale Volcanic Group Tuffs (Figure 4c).

This material known locally as 'Lakeland Green Slate' more than any other typifies Keswick It is probably the most common building stone in the town. Because of the style in which it was used by the Victorians and the fact it has continued to figure prominently in the 20th Century buildings it seems to have assumed greater prominence in peoples minds than it deserves. The common perception is that this is the 'traditional', local and acceptable material. For example there has has been much local controversy very recently against the use of red Triassic sandstone for a new pedestrianisation paving scheme. In reality sandstone is commonly seen and has been used 'traditionally' for longer than the Green Slate in considerable quantities. From the mid-1850's the tuff was brought into the town in increasing quantities and in the hands of the Victorian masons and designers the town was progressively transformed as the resort function developed. What was created was in almost total discord with the vernacular of the region. Buildings of great bulk, three or more stories high with the Victorian flair for ornamentation, decoration and complex design began to appear.

The tuffs are within the lowest formation of the Lower Borrowdale Volcanic Group and they strike NE-SW along a faulted outcrop from mid-Borrowdale across to Honister and the head of the Buttermere Valley (Figure 5). They are sea green in colour, generally of very even texture and so strongly cleaved that in many cases bedding is totally obscured. They have been worked extensively across the outcrop - at Ashgill, Dubs, Yew Crag and Honister, at Rigg Head below Dalehead and at four locations around Grange-in-Borrowdale - Goat Crags, Dalt, Castle Crag and Quay Foot. All are now abandoned.

The tuff could be worked into even flat slabs which formed an ideal walling stone. Good quality sawn blocks could be laid dry. Slabs long enough to form sills, lintels or door jambs were harder to come by and hence relatively expensive. To work the material further was difficult. Pyrite staining in some exposures detracted from the appearance and hence reduced its value. The bulk of the material is relatively thin, under 30 cms, and much of it less than half that; this clearly presented some constructional difficulties particularly at the corners of buildings. It is interesting to see how the masons were able to accommodate this new material. The more prestigious buildings were able to afford the larger more even slabs and to use pieces sawn at both ends. It is not uncommon to see superior material on the fronts of buildings, smaller more irregular slabs on the side walls and even gathered stone or brick on rear walls and outbuildings. The Keswick Hotel (1869), alongside the old railway station has some fine stonework with sawn slabs up to a metre long. Similarly the Keswick Museum and Art Gallery (1898) has some tightly laid masonry of good quality. Compare these buildings with the terraces at the opposite end of Station Road (Numbers 37-47) where the slabs are thinner, shorter, frequently not sawn at both ends and pyrite stained. The Methodist Church in Southey

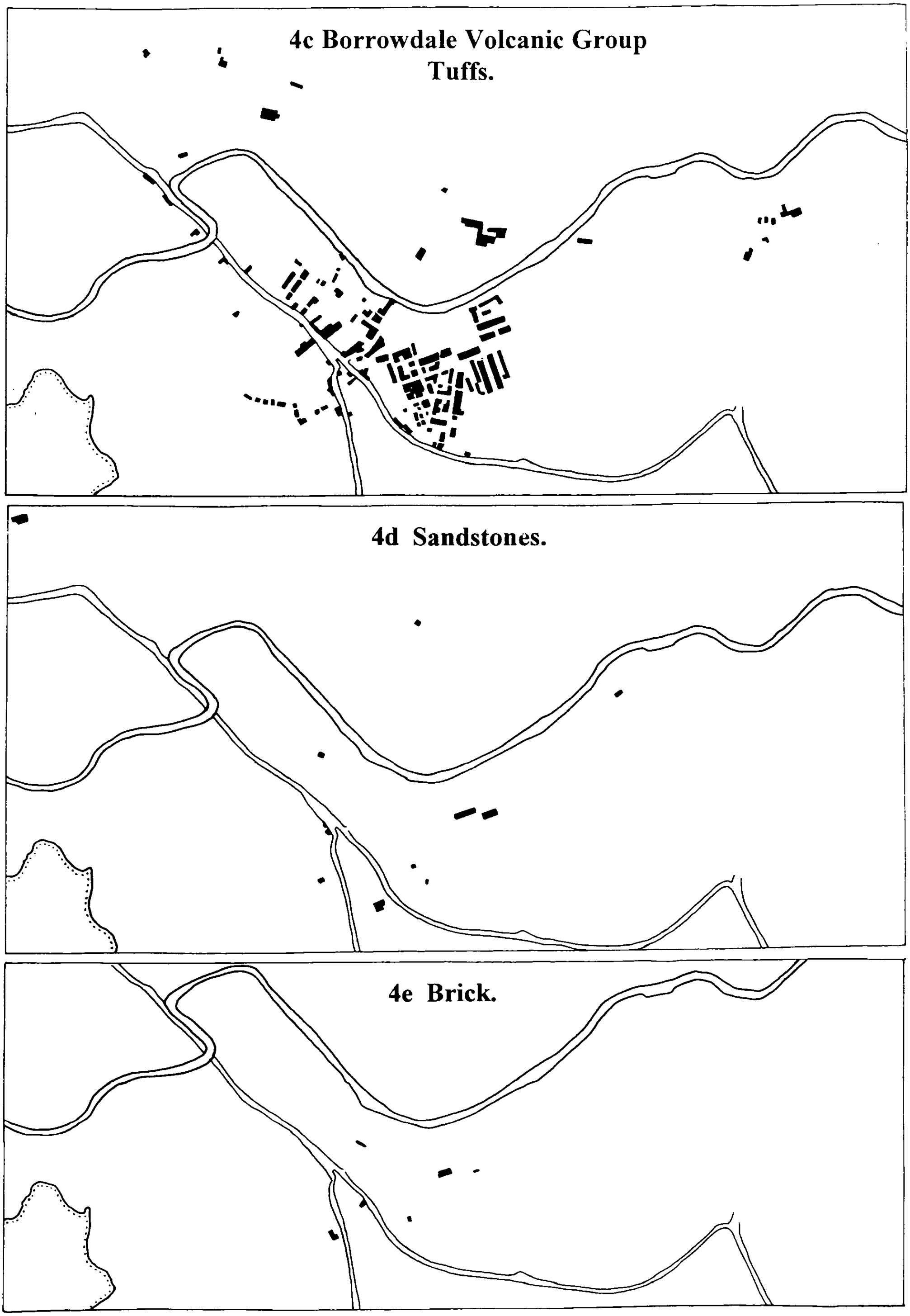


Figure 4c, 4d, 4e

Street equally shows the contrast between large good quality blocks on the original part of the building (1863) and the much inferior, irregular pyrite stained blocks on the Church Hall extension at the rear (1909). There are in fact very few buildings that are made entirely out of the tuff. One example is the terrace in Southey Street containing the Easedale Hotel, No. 3 and No. 1 Blencathra Street. There are tuff sills and lintels to the windows and tooled tuff blocks to the corners of the terrace, but overall the effect is of a plain rather severe building. Where it has been possible to use large worked tuff slabs to produce shaped sills and lintels or bold door jambs of more ornate design, the effect is one of great solidity and substance. This effect is well seen at Greystones (1863) on St Johns Street, or at the Crosthwaite Rooms (1879) on Main Street. In the vast majority of these buildings, however, where the tuff is used as walling, sandstone is used extensively as well. By incorporating either Penrith Sandstone or the St Bees Sandstone, the masons were able to create the ornate, highly decorated villas, terraces and neo-gothic houses that are the hallmark of Victorian Keswick. The area between the Penrith and Ambleside Roads on the eastern side of the town, laid out in straight formal plots, contains the main concentration of this type of building. Station Street, Stanger Street, Lake Road and the Heads are in a similar style. Typically the buildings have chunky sandstone quoins, often emphasised by bevelling and alternating in size, bold sandstone lintels and sills and often ornate carved doorways in matching or even contrasting sandstones. There may be added ornamentation at the eaves or the addition of sandstone courses between the tuff slabs. The tuff was also useful for garden walls, steps and paving where the mottled material from Quay Foot (sometimes called the Rainspot Slate) was frequently used to good effect.

It is slightly puzzling why this very useful building stone was not used to a greater extent before the mid 1850s. A complex set of factors seem to have affected its exploitation. The fundamental problems of handling and transporting slate in the Lake District have been discussed by Tyson (1984 and 1995) and undoubtedly in the early 19th Century the cost of moving the stone worked against its widespread use, particularly for walling. Roofing slates on the other hand were of a higher value, as was noted in the prices quoted earlier for St Johns Parsonage, and could bear the economics of longer journeys. The workings at the top of the Honister Pass date back to he 18th Century and possibly even earlier (Tyler 1994), but there seems no record of building stone being moved from there in any quantity. The emphasis was always on winning good quality roofing materials. Moreover, it is known that the route down into Borrowdale was treacherous and hence most of the trading seems to have been down the Buttermere Valley to Cockermouth. Postlethwaite (1913) suggests the Rigg Head quarries were opened about 1832, but again, although fractionally nearer to Keswick, but of difficult access, they were focussed on fine slate of roofing quality. It was the quarries in the floor of the Borrowdale valley close to Grange-in-Borrowdale that supplied the bulk of the building stone. Quay Foot was the first to be exploited producing some fine mottled and figured stone (the Rainspot Slate). Castle Crag, Goat Crags and Dalt came later. Castle Crag produced both light and dark material but much of it was disfigured with pyrite. The lower quarry there, did however, yield some very fine rather silky slate. Castle Crag was abandoned in 1930 but Dalt continued to supply building stone until 1973.

The impetus to open these quarries must have come primarily from the increased demand for stone as Keswick began to grow. Being only 8-9 kms away and with an essentially valley route into the town, transport became manageable. A significant technological development at the same time was of importance. In 1856 the Hunter Rotary Saw was invented. This enabled the large clogs of slate to be cut across the cleavage into manageable blocks, which could then be split along the cleavage into required pieces. Progressively most of the slate trade, including products from the Honister Quarries, became concentrated down the Borrowdale route, the railway at Keswick (much nearer than Cockermouth) allowing material to be exported further afield.

Sandstones (Figure 4d).

We have demonstrated already that sandstones both of Carboniferous and Permo-Triassic age have been brought into the town from the earliest times. Few buildings in Keswick are without it. Buildings made entirely of sandstone are a conspicuous feature as well. Figure 4d does not distinguish between the variety of types found, all are good freestones and once the railway came to the town in 1865 it became increasingly available. The earliest and most conspicuous sandstone building in the town is St Johns Church which was finished in 1838. The stone is Lower Carboniferous Sandstone from a quarry at Lamonby (NY 412 362) north of Greystoke (Figure 5). There are substantial terraces in both Penrith and Carboniferous Sandstone of almost identical design to those in the tuffs within the Victorian quarter of Helvellyn and Blencathra Streets.Other sandstone buildings are scattered throughout the town. In Main Street some of the commercial buildings are faced with sandstone - notably both Barclays and Midland Bank.

It is a very common practice to paint over the sandstone work, particularly noticable on the Victorian building constructed with the tuffs. There is no obvious reason for this. The sandstones do not need weatherproofing. There is a local fashion derived from painting over the early rendered building. It is tempting to suggest that in someway it may be a partial response to blot out the imported sandstone to show off the local tuff to advantage.

Brick (Figure 4e).

Red brick looks very conspicuous and out of place in Keswick, but it was used for a handful of buildings at the end of the last century and at the beginning of the 20th Century. The best examples are a long terrace block in Helvellyn Street (numbers 17-23), Goodwin House in Southey Street, some smaller houses in Wordsworth Street and the Alhambra Cinema in St Johns Street. There are also a few groups of small brick terraced houses of late 19th Century date (Little Hills, Standish Street). Brick is also commonly seen in chimney stacks and frequently around windows, doorways and as quoins of some of the smaller older properties built of gathered stone.

Post 1900 Properties of Modern Construction (Figure 4f).

Property of this age is quite extensive, but is of little real interest to this present study. The continued use of the Borrowdale Volcanic Group tuff is of notable. Progressively this has become a decorative stone, seen in either dry stone feature walls or in cladding and paving, but adding to the visual presence of this material in the townscape. Pebble dashing and surface rendering, so much a feature of the early vernacular has been carried through extensively into modern building. Lake District National Park Authority planning regulations has enabled these features to be enforced on the most modern developments. Any constructions using brick or concrete are invariably rendered.

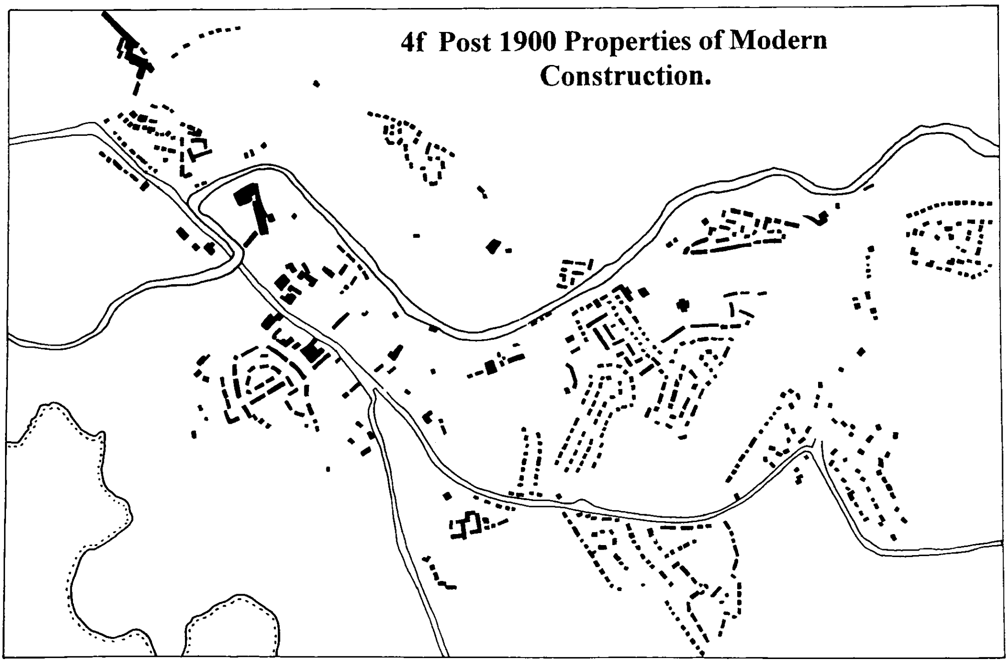


Figure 4f

Some Concluding Observations.

We have said little about roofing materials. Almost all of Keswick is currently roofed with Lakeland slate, either from the Borrowdale Volcanic Group or from the Burlington Quarries in the Windermere Group. Roofing gets replaced more than any other part of a building and there are obvious difficulties in examining roofing at close quarters. Slates laid in diminishing courses, larger, wider slates at the eaves and shorter, narrower slates at the ridges, dominate. Most of these undoubtedly came from the Honister quarries and Rigg Head. Most ridge stones are either sandstones or tiles. Welsh slates also exist in significant numbers, particularly on some of the Victorian terraces of the 1870's and 1880's. Their uniform size and somewhat 'foreign' blue/purple colour makes them slightly conspicuous. It is noticeable how Welsh slates are frequently associated with some of the less prestigious and 'cheaper' Victorian building. As a product they were highly competitive on price with local materials. Tyson (1995) noted that as early as 1676 Welsh slate imported via Dublin into Whitehaven could compete with the heavier local material. Most modern properties are tiled, but universally of a grey/green colour in keeping with the local Lakeland materials.

The insignificant amount of Skiddaw Group rock in the town needs some comment. This is the underlying bedrock and the most accessible material to the town. Clearly its friability and fissile nature made it an almost worthless building material. Alex Clifton Taylor (1962) says "... it was used only for the most uncouth kind of building" - a very apt description. There are buildings made of it in Threlkeld and some of the other local villages but apart from fragments and cobbles in a few of the early buildings in the town the material is scarce. It is possible that more is present beneath the rendering of the 'Gathered Stone' properties of Figure 4a, but overall it must have been rejected at an early date. Tyson (1995a) records that when the Moot Hall was rebuilt in 1571 slates for roofing were brought from a quarry at Underskiddaw and carried on mens back to Applethwaite and then on horseback to Keswick. As a roofing material it always proved unsatifactory, difficult to work and susceptable to weathering. It did have some use as hardcore for road making. A few dyke rocks in the Skiddaw Group were sought after. One local one near Long Close Farm on the flanks of Dodd about 2 kms out of the town (NY 240 267), yielded a useful felsite type material which was use for building in Millbeck, but is also seen in a part of the Keswick Cottage Hospital.

It is also interesting that there is so little evidence of the Threlkeld Microgranite in the town. Although this stone was extensively quarried from the late 19th Century and could easily have been brought the short distance directly from the quarries by rail, only one significant building was constructed from it. This is the Roman Catholic Church of Our Lady and St Charles in High Hill, begun in 1928 and completed in 1965. There is some use of the stone in the riverside walling on High Hill, but apart from that little is to be found. The material is used extensively on the outcrop and in the church at St Johns in the

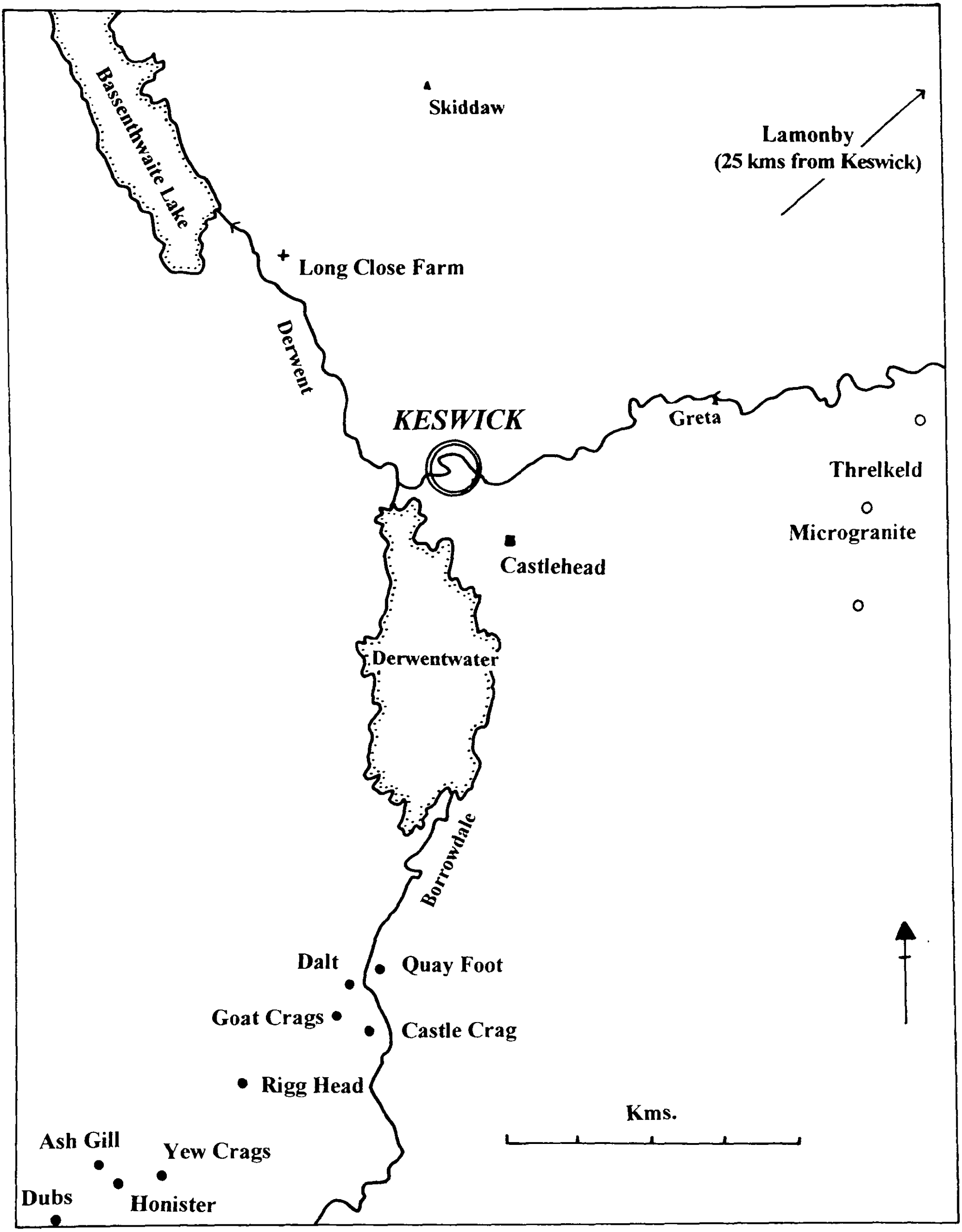


Figure 5 Quarries in the Keswick Area

Vale. Its suitability as a building stone is well demonstrated by its extensive use on the Thirlmere Dam project in the 1890's. Admittedly the quarries were particularly orientated towards the production of roadsets, kerbstones and aggregate, but its almost non-appearance in the town is a puzzle.

There are only a few 'exotics' to be seen in Keswick. Fortunately the town has largely escaped the import of polished facades and ornamental igneous materials. Amongst those seen are the National Westminster Bank which has facings of Shap Red Granite within surrounds of imported granite from Spanish Galicia, and Woolworths, with panels of black gabbro from South Africa. There are some polished red Ross of Mull granite pillars at the Keswick Hotel and Southey Street Methodist Church has a similar set in red Peterhead Granite. The War Memorial in Wivell Park is an interesting piece of Portland Stone with prominent fossil fragments and distinct bioturbation features.

A number of major questions remain unanswered. We have been unable to produce a satisfactory and precise answer to the exact sources of the gathered Borrowdale Volcanic Group materials in the early buildings. Much more work is necessary on the sandstones in the town, since it is clear there is a range from the Lower Carboniferous to the Triassic, and little has been done to find exact matches to specific quarries. It is hoped, however, we have given some broad indications of the pattern of building in Keswick over the last few hundred years.

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Dr. R.A. and Mrs K. Smith
[redacted]

EXCURSIONS

EXCURSION TO THE SKIDDAW GROUP IN THE BUTTERMERE AREA - STRUCTURES AND SEDIMENTARY FEATURES

Leader: Dr Barry Webb (Open University)

21 April 1996

15 members of the Cumberland and Westmorland Societies braved an unfavourable weather forecast to meet Dr Barry Webb at Lanthwaite Green. The aim of the day was to examine the middle part of the Skiddaw Group (Loweswater and Kirk Stile formations) and particularly the sedimentary structures and features recording their deformation history. Dr Webb had surveyed the area in the late 80's for the BGS and the results of his labours are published in the BGS 1:25000 map - 'Lorton and Loweswater'.

The Loweswater and Kirk Stile formations are very largely greywacke sandstone, siltstone and silty mudstone deposited from southerly derived turbidity currents. They were affected by massive submarine slumping during Llanvirn times. These fine grained formations often appear featureless and are difficult to divide without good fossil control (mainly graptolites and microfossils).

Turbidites are well seen in the Loweswater Formation where they are important in working out the way-up of beds. The two formations have been heated-up although they rarely attain true slate grade. Remote sensing techniques indicate a small igneous intrusion south of the area which has also affected the sediments though this so called 'Crummock Water Aureole' is mostly south of the area examined.

The excursion concentrated on two localities. The morning was taken up with the an ascent up Whin Ben north of Gasgale Gill as far as Gasgale Crags (about 600m) where the Gasgale Thrust could be seen. Near the base there was evidence of the Loweswater Formation being hornfelsed by the aureole. There were signs of small mining trials where, doubtless, early miners had sought copper, lead and zinc. Hot convective liquids associated with the aureole probably played a part in zinc being leached out of the sediments. The Kirk Stile Formation is typically a pale mudstone which, in general, takes little cleavage though Dr Webb's detailed mapping pointed to more cleavage where the rocks are more compressed. Often two sets of cleavage are visible. Interbedded are greywackes showing convoluted bedding and slump fold structures. Further up the hillside small harmonic folds, some with boudinage, suggest proximity to the thrust zone, but it is hard to say how much folding is due to Caledonian forces and how much is pene-contemporaneous slumping and slides when the sediments were unconsolidated wet muds. Further up slope right angle cleaved slates were seen together with quartz veining. Overturned strata indicated the Gasgale Thrust zone.

The second locality concentrated on the Loweswater Formation on the lower slopes of Loweswater Fell. Cleavage in these fine to medium grained sandstones was hard to discern as it was close to the direction of bedding. The Formation displays some parallel lamination but otherwise has few sedimentary structures. There are, however, examples of convoluted bedding and bottom structures on truncated erosion surfaces providing some way-up indicators.

At the end of the day the persistent drizzle eventually developed into serious rain but not before Dr Webb had been enthusiastically thanked for his leadership.

GEOLOGY OF THE SCAWGILL - SPOUT FORCE AREA

Leader: Dr R. A. Smith (CGS)

May 1st 1996

A group of 13 members met at Scawgill Bridge(NY 177 257) on a cold, spring evening. The first exposure examined was in a small, disused quarry on the north side of the B5292 about 50m west of Scawgill Bridge (NY 176 257). A massive microdiorite is exposed which was probably worked for roadstone or building material. The rock is medium-grained, and greenish grey in colour. Parts of the intrusion have been classified as spessarite (plagioclase exceeds alkali feldspar and amphibole and pyroxene exceed olivine) and markfieldite (showing intergrowths of feldspar and ferromagnesian minerals). The rocks here form part of a north - south trending igneous intrusion between 1 and 2 km long and about 300m wide. There are few exposures but from this locality the intrusion can be seen to form an area of relatively hummocky topography on the fell side to the south.

The party then returned to Scawgill Bridge (NY 177 257) to examine the Loweswater Formation in the large disused quarry next to the bridge. The quarry provides one of the largest continuous exposures of the Skiddaw Group, with relatively undisturbed, well-bedded rocks dipping to the west at about 16°. The turbidite sandstones and siltstones show good examples of Bouma units. Sole structures, cross-laminations, parallel laminations and convolute bedding are all clearly visible. Brown, weathered nodules occur in the lower part of the quarry and may be diagenetic in origin. The quarry and the debris slopes beside the track further up the valley (NY 178 257) are fossil localities with 9 species of graptolite from the *Didymograptus deflexus* zone recorded, however the poor weather prevented a fossil search on this occasion.

Further up Aiken Beck the impressive Spout Force (NY 181 260) was visited. The leader pointed out that the waterfall occurs where the beck crosses a prominent rib of higher ground on the south side of the valley. It was suggested that the rib may be caused by a band of more resistant rock although direct evidence of this has not been found. The locality also lies within the Loweswater Formation.

The party continued along the north bank of Aiken Beck above Spout Force past a prominent landslip on the south bank. About 200m above the force the form of the valley narrows dramatically (NY 184261). This appears to be caused by a small outcrop of an igneous intrusion which was examined with some difficulty in the bed and banks of the beck. The rock is similar to the rock seen west of Scawgill Bridge and has also been described as spessarite/markfieldite.

The beck was then forded just above Spout Force which allowed further examination of the rib of higher ground at the waterfall.

The leader was thanked for providing a varied and rewarding start to the evening excursion programme.

LIMESTONE FEATURES OF THE EASTERN FRINGE OF THE LAKE DISTRICT

Leader: Tom Shipp (CGS)

May 15th 1996

The meeting began at the eastern edge of Askham village (NY 506 235) where the leader explained that the purpose of the excursion was to examine the Lower Carboniferous outcrops between the meeting point and Heughscar Hill (NY 487 232) and to see the effect of geology on the landscape in the panoramic views. There is no published, recent lithostratigraphic map of the area but Garwood's 1916 biostratigraphic map of the Shap area was discussed on the visit.

The first locality visited was Howe Gill, above Askham at NY 503 231. Here the limestones are seen in natural exposures and small, old quarries. The regional dip is eastwards as a result of the Tertiary uplift. There is much evidence of solution weathering of the outcrop; pavements are widespread although they have frequently been removed by to provide arable land. The rock itself is pale grey, occasionally stained with hematite and containing good specimens of *Palaeosmilia*. The party followed a sinuous dry valley westwards towards Riggingleys Top. A stream runs in the valley in wet weather and a prominent swallow hole occurs close to the first exposures at Howe Gill. The valley was probably cut by meltwater from a mass of ice in the Tarn Moor area to the south west. Erratic boulders from the Borrowdale Volcanic Group litter the valley floor. The view to the south shows the Ashfell Limestone and Ashfell Sandstone on the hill top at The Riggs above Heltonhead (NY 498 219).

The party continued up the dip slope of Heughscar Hill following similar horizons to those seen at Howe Gill. The pavements in this area have clearly been partly removed for wall building and are often absent close to the drystone walls. A broken wall, probably robbed from an adjacent pavement of fairly brecciated limestone, was examined south east from the summit of Heughscar Hill at NY 490 229. The rock is highly fossiliferous with *Palaeosmilia*, *Syringopora*, *Dibunoplyllum* and *Siphonodendron* being common as well as brachiopods and gastropods.

The summit of Heughscar Hill (NY 487 232) provides excellent views. To the south east, the escarpment of Knipe Scar is the type locality of the Asbian Knipe Scar Limestone. In the south, the hollow around Moor Divock is occupied by the Skiddaw Group before the ground rises towards Barton Fell and the High Street range. To the south west across Ullswater, faulted inliers of Skiddaw Group rocks form areas of fertile ground within the craggy, rough pastures developed on the Borrowdale Volcanic Group. Devonian conglomerates form Mell Fell to the west.

The scarp face of Heughscar Hill at NY 485 235 is formed from Chadian limestones. The spring line at the base of the scarp is clearly visible and the valley floor is underlain by the Skiddaw Group.

Although the Ashfell Sandstone is not exposed on the summit of the hill, it was examined on the way back to Askham at NY 495 233. The exposures here have been created by surface diggings for building stone.

As darkness descended the leader was warmly thanked for providing an excellent evening visit to a relatively unfrequented area of particularly attractive scenery and interesting geology.

GLACIGENIC FEATURES AND COAL MEASURES, MOCKERKIN AND DEAN MOOR

Leader: Dr Mike McCormac (BGS)

29 June 1996

A dozen of us met at Mockerkin Tarn on a grey, chilly, Saturday, June 29th. Mike McCormac, our leader, first took us to a point overlooking the gravel mounds and kame complex near Mockerkin Tarn near the exit of the Pardshaw

Channel, all the deposits correlating at 130m OD to this and the Distington Channel. He suggested ice decay in situ with fluvideltaic action was a better model of events than the 1920s Dixon model of a proglacial lake with subaqueous deposition. The upright form and steep sides of features like the initial channel draining Mockerkin Tarn and the absence of strandlines of a proglacial lake argue against the Dixon model. The symmetrical conical Foulknott Hill (NY 080 237) was probably formed below a vertical chute in the ice.

We proceeded to look at features in Lamplugh parish, our first stop being by Beck Farm (NY 076 197). A glacifluvial mound with an esker like form showed a 3m high fresh cross section. Foresets of coarse glacifluvial sands dipped at 12° and were overlain by up to 2m of crudely stratified lodgement(?) till with a sandy clay between 2 very stony layers, whose clasts were dominantly Skiddaw Group rock. There was no evidence to date this till. We then looked at Thistle Gill, just west of Kirkland (NY 073 180). This is a straight, N-S trending, dry, steep sided, rock-cut channel etched into the Seventh Limestone, with sands, gravels, symmetrical mounds and an esker at its distal end. We were shown a small patch of stromatolites, the remnant after savaging by a collector, Our final stop before lunch was near Woodend Farm (NY 072 215) at a small, symmetric, steep-sided, N-S trending esker. There was a spectacular 4m high section through workings in outwash. The underlying sands showed steep cross bedding both east and west with small faults (synsedimentary/compaction features?) forming a graben extending into the overlying gravels.

After lunch we followed the upper part of the heavily faulted Coal Measure succession on the east slopes of Dean Moor, below its summit, High Park (NY 043 212). The top beds were part of the Whitehaven Sandstone, topographically higher than on the coast but transgressing lower stratigraphic levels inland. We looked at the upper part of 2 wooded gills above Moorside Parks Farm (NY 051 208) where there were abandoned small scale coal and sandstone workings. The sequence was dominated by friable, thinly bedded shales, sometimes fossiliferous, sometimes with nodules, with occasional thin sandstones. Two stratigraphic markers, the Countess Pit Sandstone (forming a small waterfall) and the Cleator Moor Coals Triplet were pointed out to us.

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GEOLOGY OF THE SOUTH SOLWAY COAST BETWEEN MARYPORT AND DUBMILL POINT

Leader: Dennis Dickins (Cumbria Environmental and Geological Services)

July 3rd 1996

The visit began at Swarthy Hill (NY 069 402) where the leader outlined the geological history of the Solway basin.

The Solway Firth lies on the line of the Iapetus closure and the suture (Iapetus convergence zone) dips beneath the Southern Uplands at 15 - 20°. Recent geophysical surveys have confirmed post-orogenic extensional faults on both sides of the Solway; these resulted in crustal sagging and the deposition of Devonian to Namurian sediments in the area of the present day Solway. The Maryport Fault on the south side of the Solway links with the Stublick - Ninety Fathom Fault System of the Northumberland Trough. Thicker sediments on the northwest, downthrown side indicate that it was a growth fault, i.e. active during sedimentation in response to regional thermal relaxation subsisdence. Fault movement appears to have ceased and equilibrium appears to have been reached by Late Westphalian where thickness differences are less marked. At the end of the Carboniferous reverse faulting and basin inversion occurred, due to crustal shortening deformation, raising the Solway area and allowing reddening and erosion of the uppermost Westphalian strata during the Permo-Triassic uplift. The basin then sagged and this resulted in Jurassic sedimentation, followed by a further phase of inversion during the Alpine uplift. It is likely that Cretaceous Chalk was deposited (inferred from apatite fission track analysis) over the whole area then removed by erosion, however there is no sedimentary evidence for this. In the Quaternary the late Devensian glaciation had major effects in the area. Following the warmer phase of the Windermere Interstadial between about 15,000 and 11,000 years BP, corrie glaciation took place on the high ground abutting onto the Solway.

Swarthy Hill is a drumlin which has been eroded to form an old cliff line with a raised beach at its foot. The party ascended the hill to view the drumlin tract towards Crosby. The form of the Devensian drumlins indicates ice movement towards the south south-west. Isostatic uplift about 15,000 years BP caused a sea level low. The Flandrian Transgression 6,000 - 7,000 years ago drowned coastal woodlands and allowed deposition of marine alluvium between the drumlins. A further phase of isostatic uplift resulted in the raised beaches in the area and lacustrine alluvium between the drumlins indicates that lakes formed where basins became impounded as sea level dropped. At the northern end of Swarthy Hill drift exposures were observed. The sandy boulder clay is poorly sorted and contains sub-rounded pebbles.

The second locality visited was at Maryport Golf Course (NY 045 383). The party walked south along the raised beach and made ground. The leader showed specimens of pebbles cemented in beach sand which pass down into glacial deposits. The St Bees Sandstone is well-exposed in the wave-cut platform. It is a fine to medium grained, micaceous, massive or fissile, cross-bedded sandstone exposed here on the hanging wall side of the Maryport Fault. It is difficult to differentiate tectonic and sedimentary dips in stacked sand bodies; dip appears to be towards the north north-east or northeast at this locality. The rock appears darker in colour lower down the foreshore where it is more saturated with sea water. A good example of desiccation cracks was observed.

In deteriorating weather the party visited Dubmill Point (NY 076 458) which provides an excellent vantage point to view the geomorphology of the area. The Swarthy Hill drumlin is clearly visible with the old cliff line and the raised beach along which the road has been constructed. The presence of this raised landform has affected the colonisation of the area.

SANDSTONES AND FLUVIAL FEATURES OF THE LOWER CALDER VALLEY

Leaders: Mervyn Dodd and David Livesey (CGS)

July 17th 1996

The visit began in Calderbridge where it was explained that the Nirex drilling programme had produced evidence which led to the subdivision of the previously undifferentiated Triassic sandstones of West Cumbria into three formations as shown in the following table.

The excursion followed the south and east banks of the Calder downstream from Calderbridge Church to beyond the Sella Park Hotel. The nearest Nirex borehole to the route is Borehole 7. The three sandstone formations can be distinguished on the gamma ray and sonic logs by abrupt changes at the upper boundaries of the formations. The fluvial facies in the Calder Sandstone has higher sonic and gamma ray log values.

The fluvial cycles of the Calder Sandstone were examined on the right bank of the river immediately above the bridge in Calderbridge. The dip direction was seen to be about 225°.

Triassic Sherwood Sandstone Group

ORMSKIRK SANDSTONE FORMATION	Finer and more even-grained than Calder Sandstone. Weathers distinctive orange-brown. Friable, poorly sorted, aeolian. Up to 250m thick.	Exposures very limited. Only on Seascale beach and by the mouth of the River Calder.
CALDER SANDSTONE FORMATION	Consists of an aeolian facies and a fluvial facies. **Aeolian Facies.** Distinguished from St Bees Sandstone by its coarser, more rounded, better sorted, frosted quartz grains, much less mica, limited shale bands, more uniform colours. Derived from the NE. Total 390m thickness in three packets. **Fluvial Facies.** Harder and better cemented. Variable grain sized, re-worked aeolian sands. Some colour variation. Occurs in 5m thick cycles fining upwards. Finer grained and less porous. Total 110m thickness in three packets.	Exposures between Calderbridge and Sellafield are mainly of the atypical fluvial facies.
ST BEES SANDSTONE FORMATION	Fine grained, subangular, quartzose and micaceous, well cemented, variable in colour with interbeds of shale. Fluvial with channel and tabular cross bedding and laminations. Provenance from the south. 340 - 650m total thickness.	Widespread exposures in West Cumbria.

Southeast of the bridge the cricket field occupies a river terrace and a line of former river cliffs can be seen about 5m above the level of the present river. It was explained that rejuvenation features are extensive in the Calder Valley. Incised and ingrown meanders with 10 - 15m rock exposures on the outer bank occur, plus a gorge section through a thick sandstone unit.

About 100m downstream from the bridge, thinly cross-bedded sandstones are seen in a right bank river cliff with an artificial cut. This section follows the dip which is downstream. Following this the river enters a gorge with the dip clearly displayed in the right bank. By the bridge to Pelham House the dip is fairly steep and there are no shale partings.

A pronounced bend occurs at NY 035 058 where the river turns left through a right angle to follow the strike. The dip direction here is also about 220°. At the next bend to the right at NY 036 056 is a small quarry with thick posts of sandstone just above the gorge. There is then a further bend to the left. A NW - SE fault is shown on the map close to these bends but the cause of the abrupt changes in direction is not clear, although the dip and strike of the sandstones have a strong influence. The narrowness of the river at this point may be related to the hardness of the rock. The thinly bedded sandstones in the left bank close to a collapsed bridge contain one of the few paler beds of sandstone.

Downstream from these bends the valley becomes wider and the river shallower. A left hand bend at NY 034 054 close to the Sella Park Hotel causes the river to follow the strike with large scale cross bedding exposed in the right bank, as well as a possible small channel.

River gravels at the following right hand bend contain much Borrowdale Volcanic Group material. Although the volcanics crop out extensively in the upper Calder catchment this deposit may represent a re-worked boulder clay.

A river cliff on the east bank at NY 036 052 shows what may be aeolian beds overlying fluvial beds. The fluvial beds are pale in colour and thinly bedded. Following an erosive horizon there is a massive, tabular bed followed by steeply cross bedded, friable, millet seed sandstones.

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THE LOW FURNESS ORDOVICIAN INLIER

Leader: Dr Eric Johnson (BGS)

27th April1997 - (Joint Meeting with the Westmorland Geological Society)

A large group met at Askam Brickworks where the leader explained the background geology. The Ordovician rocks which form the Low Furness inlier are brought to crop in the axial region of the northeast plunging Lowick Anticline; they are bounded to the east by conformably overlying Silurian strata and elsewhere by unconformably overlying and down-faulted Carboniferous strata. Although the inlier is only about 6 km^2 it contains the three major stratigraphic units, Skiddaw Group, Borrowdale Volcanic Group and Dent Group (Windermere Supergroup) that form the Ordovician succession in the main Lake District Lower Palaeozoic inlier. The relationships between the three groups in Low Furness differ from those in the main inlier and provide critical evidence for Ordovician structural evolution.

The purpose of the field trip was to examine sections in the three groups of rocks and to discuss the evidence that they provide for interpreting the structural evolution of Furness and the Lake District in the Ordovician.

The first locality visited was Greenscoe House Brickpit (SD 2250 7642) where the intensely deformed upper Arenig/lower Llanvirn silty mudstones of the Skiddaw Group were examined. Laminations show inconsistent dips due to syn-sedimentary deformation. Cleavage is a prominent feature and is interpreted as the main, early Devonian phase i.e. which affects all the Lower Palaeozoic rocks. Minor slickensided fault planes are much in evidence. The mudstones are sufficiently soft to provide a vital natural resouce for the long-established brick making at Askam-in-Furness. Unlike the harder, northern Lake District Skiddaw Group rocks they have not been affected by burial metamorphism; this is consistent with the interpretation of regional thickness variations in the overlying Borrowdale Volcanic Group. The dark grey mudstones show much rusty weathering and small veins of a slippery, white, talc-like mineral. A search for fossils revealed a few graptolites, one good specimen was found where cleavage coincided with bedding.

At Greenscoe Quarry (SD 222 760) exposures of the largest outcrop of the Borrowdale Volcanic Group in Furness were examined. The leader noted that the locality provides vital clues about the onset of mid-Ordovician volcanism and the structural setting for the Borrowdale Volcanic Group. Earlier workers have described this locality as a neck or vent which was a possible source of the Borrowdale Volcanic Group, an untenable view in terms of scaling parameters of volcanic processes and distribution of volcanic successions. The outcrop is about 400m by 150m and is assumed to be part of the Borrowdale Volcanic Group rather than a discrete group. It is interpreted as being deposited on the flank of a rift zone where the volcanic sequence is relatively thin. At Millom Park, in the hanging wall side of the Kirkby Fault, there are 2 - 2.5km of volcanics and on the other side of the South Borrowdales Lineament the Borrowdale Volcanic Group is 7 - 8km thick. The low burial grade of the adjacent Skiddaw Group provides additional evidence for this locality being on the margin of a rift zone.

The quarry exposes a mixed section of volcanogenic sedimentary and pyroclastic rocks with andesite intrusions (Greenscoe Formation) preserved within a vent. Close to the south-west side of the quarry entrance an andesite intrusion is exposed. The pale-grey, weathered rock shows spots of orange and cleavage produces a platy fabric. A one metre wide, sheet-like mass of mudstone is caught up within the andesites giving evidence of an intrusive origin. The sheet is now almost vertical but was probably emplaced sub-horizontally. The original lower surface is chilled while escaping gases and interaction with the host sedimentary rock at the upper surface have lead to the development of a quench breccia. The evidence suggests that the Skiddaw Group was lithified before the intrusion of sill-like andesites.

In the main body of the quarry are extensive exposures of the tuffs of the Greenscoe Formation. Lower in the formation there is more Skiddaw Group material and the clasts are finer. Further up the sequence the clasts become larger and the amount of andesitic material increases, indicating that as the pile of pyroclastic and sedimentary material thickened it was broken by increasingly violent explosions. The occurrence of a thin sandstone band demonstrates the steep, tectonic dip of the bedding in the quarry. When the dip is removed and bedding returned to the horizontal, the distribution of tuffs suggests that they are preserved in a crater. The crater is a relatively small structure and consistent with a maar-type crater formed by andesite intrusions interacting with either groundwater or ponded surface water.

The party then examined the section of Dent Group rocks in the road cutting at Green Haume (SD 2201 7555 to 2205 7545) opened in 1996. During construction the contact of the Dent Group resting unconformably on the Skiddaw Group was revealed at the northern end of the cutting. The boundary between the competent limestones and soft mudstones may be partly faulted. The dark, massive limestones of the Dent Group (the High Haume Limestone of Rose and Dunham) indicates the late Ordovician marine transgression and deposition close to the contemporary shoreline. The rocks here are Ashgill age although they are younger elsewhere in the Lake District. A smooth brown surface of a void in the limestone exposed during the road construction has a coating of calcite. It is unclear when the void formed, it may be as old as Neogene or as recent as the Quaternary.

Further south along the cutting there is an upward passage to thickly-bedded limestones and then calcareous siltstones (the High Haume Mudstone of Rose and Dunham) showing a gradual change to deeper water deposition.

Zones of alteration are indicated by colour variation. Close to the top of the siltstone there is more nodular bedded limestone many small thrust-faults were observed, intersecting bedding at a low angle. The thrust-faults formed during compression in the early Devonian, Acadian orogeny.

Above the siltstone the white to pale-grey, High Haume Tuff Formation is exposed on both sides of the road. It is about 10m thick and contains abundant pink feldspar crystals. The chemistry of the rock is different to that of the Borrowdale Volcanic Group. This is overlain by a few metres of Ashgill Formation with some mixing of the tuff and sediment.

The boundary between the cleaved Ashgill Formation and the uncleaved Carboniferous Basement Beds is clearly exposed in the cutting. On the west side of the road the boundary appears to be faulted, however the boundary appears more complex on the east side with the Basement Beds resting against both the Ashgill Shale and the underlying tuff.

The meeting concluded by a brief examination of the extensive Carboniferous exposures in the cutting.

TURBIDITES AND OTHER ROCKS OF THE WINDERMERE SUPERGROUP

Leader: Dr John Gunner (CGS)

May 5th 1997 - Joint meeting with the Furness Geological Group

The purpose of this field meeting was to examine the Windermere Supergroup rocks in the Hawkeshead area; specific references were made to the use of the various lithologies for building stones. Weather conditions were poor and prevented visiting more exposed localities.

The first site visited was Brathay Quarries (SD 357 016) in the Brathay Formation. Extensive use has been made of the Brathay Flags from these quarries as building stone, notably in Ambleside Parish Church. The massive, blue-black mudstones have paler laminations mostly up to 5mm thick, although some 4 - 5cm thick were observed in blocks on the quarry top. The spacing of the laminae and the pyrite-flecked bedding planes are useful in distinguishing the Brathay Flags from other Silurian formations when seen in buildings. Concretions, up to 20cm in diameter, are also common at certain horizons. Water levels in the main quarry vary considerably, depending on recent rainfall and amounts of pumping by the quarry company. On this visit the party was able to venture down the ramp at the quarry entrance where the cleavage in the rock was visible, however the quarried blocks are bounded by bedding and joint surfaces.

The party moved on to High Cross Planatation Quarry (SD 328 985) to examine the upper part of the Brathay Formation and the overlying Birk Riggs Formation (formerly the Lower Coldwell Beds). The quarry was probably used for roadstone and wall building material. A variety of turbidite structures were observed in the Birk Riggs Formation on the southeast side of the quarry. These included graded sandstone units with flute and load casts including some flame structures. The intervening muddy units show a cleavage which is weaker and refracted in the sandstones. The Brathay Formation appeared to be less distinctive than in Brathay Quarries but the characteristic buff-coloured laminae and concretions were present. On the northwest side of the quarry prod marks on a bedding surface showed up well in the wet conditions. A small fault in the northern corner of the quarry provoked much discussion although there was no consensus of opinion regarding its movement. The main tectonic structure in the quarry is a monocline dipping to the southeast.

In the afternoon the cutting on the southeast side of the Outgate to Ambleside road at SD 356 003 was examined. The cutting lies in the Wray Castle Formation (formerly Upper Coldwell Beds). The beds are remarkably uniform and consist of massive greywackes up to 1m thick. There are surprisingly few sedimentary structures except for some cross-laminations and parallel laminations. At the north end of the quarry masses of brecciated rock were overlain by undisturbed beds. Slickensides were observed on beds at various points in the cutting which was probably used as a source of roadstone.

Coldwell Quarry (SD 359 010) was reached by walking along the track from Dan Becks and the rocks of the Coldwell Formation were examined. On the spoil heaps fragments of blue-grey calcareous mudstone showed signs of bioturbation and fossil fragments were tentatively identified. In the quarry itself the intersection of the widely spaced bedding planes and major joints was observed. This allows the rock to split into huge slabs and it was suggested that these may form the very distinctive vertically-set slabs used for hedge building in a restricted area between Outgate and Hawkeshead. Cleavage is present in the quarry but the rock does not split readily along it.

THE RIGS SITE AT AUGHERTREE FELL

Leader: Fred Lawton (CGS)

21st May 1997

A large party assembled at Uldale on a cold spring evening for the first of a series of meetings to examine Rigs sites in Copeland and Allerdale.

The first locality examined was close to the road at NY 263 374 where the leader described the geological setting. The immediate locality lies close to the top of the Carboniferous Fifth Limestone whereas Uldale is on the Sixth and Seventh Limestones. To the southeast Basement Beds, resting unconformably on the Skiddaw Group, occupy the low ground. The series of prominent sink holes trending approximately east northeast - west southwest on the south side of the road was examined. It was suggested that the distribution of the sinks is probably related to a fault. Some of the holes have fills of glacial material whereas others have been used for tipping. Large Carrock Fell gabbro erratics indicate ice movement from the east. It was suggested that the quarry close to the road to Baggra Yeat may have originally been a sink hole and it is the only hole with dimensions which fit previously published descriptions of this area. The top of the Sixth Limestone forms the quarry floor.

Walking northeast towards the minor road junction at NY 268377, sandstone beds are exposed in some of the sinks. Heather on the surrounding fellside also indicates non-calcareous rocks.

North of the road at NY 270 379 a swallow hole is exposed, although there is little evidence of surface water elsewhere. The party moved on to the mainly dry melt water valley at Gillhead, referred to in the Cockermouth memoir as Aughertree Trough (NY 268 381). The valley shows the typical "box-shaped" cross section as other meltwater channels in the area and is part of a system of channels running towards Ireby.

After a brief visit to the ancient settlement near Town Head the visit ended at Gillhead Quarry (NY 267 382). The quarry is in a downfaulted block of the First Limestone with distinctive wavy bedding. Generally only small fossil fragments occur but one well-preserved Lonsdaleoid coral was found in situ.

THE WEST CUMBRIAN IRON ORE FIELD

Leaders: Mervyn Dodd (CGS) and David Kelly (CGS)

June 7th 1997 - Joint meeting with the Liverpool Geological Society

A large party met at Croasdale top where the background geology of the orefield was explained and specimens of specularite, massive and kidney ore from the immediate area and from Frizington Parks mine were passed round for examination.

The visible drifts of the Knockmurton mines east of the road which were worked spasmodically from 1852 to 1917 were not examined on this visit and the party concentrated on the slightly later Keltonfell mines west of the road. It was noted that together these mines were the only major hematite workings in the Skiddaw Group. The ore was very irregular and of poorer grade than most of the limestone ores, being silica-rich. It occurred in veins dipping east or northeast at 40° to 80°.

At Keltonfell the ore was worked from three main shafts and transported via the Rowrah and Keltonfell branch of the Whitehaven, Cleator and Egremont railway. Specimens of ore and country rock were examined on the tips where the "top slicing" method of mining was explained. Workings along veins A -B and H - I can be identified by a series of collapses to the north of the tips. The northwest - southeast trending C Vein was examined at the northwest end of the workings where the fault cavity hading at 70° is exposed at a collapsed mine entrance. Evidence of the fault drag is visible in the bedding of the Skiddaw Group cavity walls. Ore was also won from No. 4 adit lower down the slope at the end of the vein. The party returned to the cars via the foundations of Number 3 shaft which was 600 feet deep.

The party then moved on to examine the Parkside and Crossgill mines at the end of the Holebeck spur railway. These are the largest of several mines which worked a huge 40 acre flat up to 40ft thick in the Namurian First Limestone and another large body in the Asbian - Brigantian 4th Limestone. Here a block downfaulted between two, parallel northeast – southwest trending faults and two younger northwest-southeast faults contained the orebody. The mines were worked after the opening of the Whitehaven, Cleator and Egremont railway in 1855 until the 1920s. Subsidence in this area has altered the landscape and evidence of this was seen at the Birks Mine across the Cycleway. The ore here was in the First Limestone beneath a Permo-Triassic cover. Going east along the Cycleway, the tips of the Parkside Mine are visible to the north. A signal box marks a branch of the former railway. 6000 tons of ore were extracted each year from a shaft 1000 feet deep. The party walked past the Crossgill Mines and examined a Borrowdale Volcanic Group tuff boulder which was transported from Bardon Roadstone's Gill Scaur quarry near Millom. The "metal box" built to transport Lingla Beck across a subsidence area of Scalelands mine in 1880 and the adjacent landfill site were visited before returning to the road at Parkside.

The afternoon was spent in Eskdale where there have been many small mines and trial pits in with the largest being the Nab Gill Mine. Others were at Ban Garth, Blea Tarn and the South Cumberland Mine.

Nab Gill mine was opened in about 1870 (then the Whitehaven Iron Mine of Whitehaven Iron Mines Ltd.) and in 1875 the Eskdale and Ravenglass narrow gauge railway was constructed to transport ore to the coastal main-line railway at Ravenglass. Production figures include:

1876 9135 tons
1880 8280 tons
1882 3621 tons

The Whitehaven Iron Mines Ltd. went into liquidation in 1882; since then small amounts of ore have been produced, the last being in 1918.

The visit began at the old railway terminus at the remains of Boot Station where remnants of the office, blacksmiths' shop, change house and loading bays can be seen. The bed of the inclined tramway to the higher levels is clearly visible.

The geology of the area was viewed from here. The north-northwest trending vein lies up the fellside along the line of the gill which has presumably been eroded along the same fault within the Eskdale Granite which guided the mineralising fluids. The relief of the gill has been considerably altered by mining operations. There were many small branch veins. The vein dipped at 65° to 80° to the northeast. There were several minor branch veins, evidence for some of which can be seen further up the fellside.

The mine was worked from a series of five levels, connected by several shafts with irregular "robberies" in between. There was also open cast workings on the fell top.

The Eskdale Granite, the largest plutonic outcrop in the Lake District, was examined in loose specimens during the walk up the fell. It is an Ordovician granite, possibly associated with the Borrowdale Volcanic Group, rather than a Devonian granite like the Shap and Skiddaw masses. Much of the rock is coarse grained and equigranular, containing much quartz, chloritised biotite and a little plagioclase. Porphyritic and equigranular microgranites form sheet-like masses within the granite.

The collapsed entrance to No.5 Level is southwest from the foot of the tramway. Here the vein was only 0.15 - 0.20 metres thick and the average was only between 0.76 and 1.06 metres. The maximum recorded was 6.1 metres close to the fell top.

There is little to see at No.4 and No.3 Levels. Specimens of kidney ore fragments ("pencil ore") are common on the slopes, as is ore containing brecciated granite clasts. Quartz is the predominant gangue mineral, although calcite and dolomite are recorded. Manganese oxides are recorded from the tips on the fell top.

At No.2 Level a branch vein up to 30cm thick is seen on the west side of the main vein. It contains brecciated kidney ore in bands with the convex surfaces facing inwards.

The open stope in a branch vein west of the main vein above No.1 Level shows a spectacular view of the open fault cavity, dipping northwards, which has been cleaned out of ore completely. In the opencasts on the fell top the same branch vein and the main vein may be examined. In some of the open cuts the microgranite walls of the vein appear to be unusually altered, possibly connected with the effect of the mineralising fluids. The unmineralised fault continues northwards and is said to crop out on Ill Gill Head (Wast Water Screes).

On descending to below No.1 Level, the scree on the west side of the vein was noted as containing good examples of kidney ore.

THE RIGS SITES IN WASDALE

Leader: David Livesey (CGS)

July 2nd 1997

After assembling in Gosforth members travelled to the road beneath Buckbarrow to view the first locality which is on the fellside at approximately 700 feet above sea level (NY 135-137 055-058). The contact between the basic andesites of the lower Borrowdale Volcanic Group and the Ennerdale Granite is easily identified from the road by an obvious colour change and forms a horizontal line at the base of the crag. Three prominent veins cut both the granite and the volcanics. Hand specimens of transitional rocks from close to the contact at NY 1355 0575 were passed around for examination. At Greendale Gill a fault brings the Borrowdale Volcanic Group rocks down to the level of the lake. The Wasdale valley lies mainly in the volcanic rocks which come into contact with the Eskdale Granite at Greathall Gill.

The second Rigs site visited is on at the lake shore beneath Middle Fell and lies astride the road to Wasdale Head (NY 181-182 072-074). On this visit the following sequence was traced up from the lake shore. The lowest rock in the sequence is a fine-grained dark grey lava with prominent phenocrysts of a ferromagnesian mineral, possibly pyroxene, which stand proud on weathered surfaces. This is succeeded by a well-bedded tuff. On the northwest side of the road the tuff continues, with evidence of minor faults and rip-up clasts. Above the tuff there is another lava. The coarser lava with 5-10mm plagioclase phenocrysts which is described in the Rigs documentation was not identified on this visit, possibly because the section examined was slightly further along the lake shore than the one described in the site report.

The Rigs site where Lingmell Gill passes close to the campsite is on an alluvial fan. This site was visited by a short walk from the campsite car park to a point on the fan at NY 1830 0740. It was the scene of a major flash flood in August 1938 when 9 inches of rain fell in 36 hours on a small, steep upland catchment on impermeable rocks with relatively sparse vegetation. A bridge was swept away and boulders piled against a wall. At one point the boulders lie in a belt 20 metres wide on either side of the stream making the ground 2 metres higher than the surrounding fields. Fresh boulders are in evidence and the debris grades finer towards the lake.

The party then moved on to Down in the Dale to view another Rigs site in a pit section (NY 1840 0825) beside the sharp bend in the road northwest of the bridge. Here there is a grassed section of an apparently inactive fan which is part of a series formed on the flank of Yewbarrow. The material is layered and there is some induration. A hard pan layer occurs 10-15cm from the top of the section.

Lack of time and deteriorating weather prevented a visit to the remaining Rigs site which lies in Gable Gill (NY 1995 0935) 100m above the bridge. Here part of the isolated outcrop of Eskdale Granite is exposed in the stream bed.

THE LOWER CARBONIFEROUS IN THE SHAP DISTRICT

Leader: Eric Skipsey

<u>July 12th 1997</u> - Joint meeting with the Westmorland Geological Society

A group of members from both societies met in Shap village and proceeded to Shap Abbey (NY 548 153). Beneath the bridge highly cleaved Ordovician slates were seen, unconformably overlain by reddened Carboniferous basal beds with an irregular contact. Here, the basal beds are a sandy conglomerate containing clasts of Shap Granite and sparse evidence of braided channels. No fossils were evident, and while dating is consequently hard, it seems unlikely these beds are equivalent to the late Devonian Mell Fell conglomerate.

The party then moved on to a location adjacent to the B6261 at NY 573 123 where a group of large glacial erratics sit adjacent to the road (they have probably been moved from their original field sites). Nearly all are Shap granite and display a variety of weathering: some quite rotted, some bleached quite white. There are occasional signs of lineation of large feldspar phenocrysts, perhaps as a result of cooing patterns within the melt. Xenoliths are present. While formerly these were seen as bits of country rock caught up in the granitic magma, the presence of large feldspars grown within and across the margins of the enclaves now suggest some form of primitive granite inclusion.

Moving on to a bridge over Birk Beck near Scout Green (NY 590 077) an exposure of basal beds further up the sequence than that at Shap Abbey was examined. Here, a fine sandy matrix containing rounded pebbles and clasts of Lower Palaeozoic volcanics with some evidence of rippling was noted. 50m up stream a more massive sandstone outcrops in the river bank, and represents a still slightly higher horizon. The sand grains are better cemented and there is evidence of cross-bedding. This the start of a fining-up sequence which is also exposed at Tebay Bridge (NY 635 058).

At NY 599 075 (an unclassified road immediately west of the northbound motorway bridge) a grey-green conglomerate with notable feldspar clasts and a carbonate cement was observed. The green colour probably derives from chloritisation in a marine environment, and the feldspars show some kaolinisation. The clasts were probably brought in by occasional mudflows. Further up the road at NY 600 075 small outcrops of carbonaceous shale containing shell fragments were noted.

The party then moved to a disused quarry at Knott (NY 641 085), near Orton. The quarry exposes Ashfell Limestone. Marked cross-bedding is evident in a massive grey limestone with abundant fragments of marine fossils, marking the beginning of a marine transgression. The light colour and fragments suggest an active marine environment. Ascending the hill a series of small quarries expose successively higher beds. A rich fossil fauna is present including productids and *Siphonodendron*. Some chert nodules are seen, in places forming stringers up to 0.5m thick. The ground above these quarries contains few exposures inferring the presence of shale horizons within the Potts Beck Limestone (basal Asbian). The Potts Beck is very 'knobbly' with indistinct bedding very reminiscent of its lateral equivalent, the Urswick Limestone.

The party then moved on to Knott Summit (NY 646 092). Some areas of ground in this area are very peaty, likely to be evidence of shale horizons above the limestone. The view from the summit is of the Asby Limestone pavement, one of the most extensive pavement areas in the country. It is now covered by Limestone Pavement Orders, the former mineral rights belonging to Lord Lowther having been bought in.

GEOLOGY OF THE SEDBERGH AREA

Leader: Alan Diggles

<u>July 20th 1996</u> - Joint meeting with the Open University North West and Yorkshire areas

A large party met on a hot summer's day in Sedbergh. The leader explained that the geology of the area has been influenced by two major events, namely the emplacement of granite into basement rocks to the east in pre-Carboniferous times and the later earth movements which produced large scale faulting. The granite which lies some 500 metres below the surface in the Wensleydale area is thought to have had a controlling effect on the Pennine boundary faults which resulted in the two areas of rigidity, the Alston and Askrigg Blocks.

As the sea encroached in early Carboniferous times the blocks remained dry land in the initial stages so that the lowest Carboniferous strata do not occur locally. The rigid blocks withstood the uplift and folding which occurred later in the Carboniferous during the Variscan Orogeny.

The party visited a small, disused quarry off the path to the summit of Winder Hill at SD 660 928. The quarry is in the Silurian Coniston Formation rocks west of the Dent Fault. Fine-grained turbidites with large flute casts are inter-bedded with mudstones. The exposure shows folding, faulting and cleavage of Caledonian age.

About 300 metres further down Settlebeck Gill there is an exposure of the conglomerate on which the town of Sedbergh is built. This has been interpreted as a post-orogenic deposit, possibly of Devonian age.

The party then travelled to examine the stream section off the A683 near Rawthey Bridge at SD 710 979. The upper Ordovician, calcareous Cautley Mudstone is exposed in a faulted inlier. A lamprophyre dyke is exposed in the stream bed and may represent late stage activity at the margin of the granitic intrusion. The dyke here is about 1 metre wide and has biotite crystals clearly visible in a fine red/purple groundmass.

The afternoon was spent following the Sedgwick Trail which was opened to commemorate the bicentenary of the birth of Adam Sedgwick in Dent. The well-documented trail is 600 metres long and is a series exposures of Silurian and Carboniferous rocks in the River Clough.

THE RIGS SITES AT CRUMMOCK WATER

Leader: Alan Smith

3 September 1997

A full account of the sites visited during this visit can be found in the Society Proceedings, Volume 6, Part 1, pp 47 - 62.

THE CARBONIFEROUS AND PERMO-TRIASSIC OF WEST CUMBRIA

Leaders: Mervyn Dodd (CGS) and David Kelly (CGS)

25 & 26 October 1997 - Joint weekend meeting with the Open University (NW) Geological Society and Manchester Geological Association

25 October

The party spent the morning visiting Florence mine, Egremont and the afternoon visiting the Knockmurton and Kelton Fell area. The latter area is described in the account of the June 7th 1997 field trip in these proceedings.

26 October

The party met in Sandwith village and spent the morning studying the Saltom Bay coastal section, beginning with the younger beds at the cliff top.

The St Bees Sandstone Formation (Triassic) is the lowest formation of the Sherwood Sandstone Group in west Cumbria and was examined in the cliff sections above Barrowmouth, Whitehaven between NX 960 158 and NX 958 155. Much of the formation is of red, cross-bedded sandstones deposited on a sandy braidplain in semi-arid conditions. Close to Birkham's Quarry at the southerly end of the section the exposures are about 100m above the base of the formation. Excellent examples of sedimentary structures were examined, notably strongly cross-bedded sandstone units with erosional bases which represent migrating channel bars. Palaeocurrent directions show a predominantly southerly source. Other structures include planar beds of upper flow regimes and soft sediment deformation features. This particular locality provides panoramic views of the Solway Basin.

The southwesterly dip exposes progressively older beds further north along the section. Shale partings become increasingly thick and mudstone-clast conglomerates become more common. This demonstrates a transition to sheetflood, flood plain deposits.

The transitional boundary between the St Bees Shale and the overlying St Bees Sandstone is taken as the arbitrary Permian-Triassic boundary in west Cumbria. This transition is well-illustrated in the disused quarry behind the Marchon chemical factory at NX 962 159. Lower in these exposures shales begin to dominate the inter-bedded sandstones. Both rocks are highly micaceous, indicating the subaqueous nature of the deposits. The laminated beds show good examples of symmetrical, wave ripples and desiccation cracks. Asymmetrical, current ripples also occur and rip-up clast conglomerates are common. Paler beds indicate reduction of the iron compounds.

The St Bees Shales form the steep, grassy slope from the base of the cliffs down towards the shore, lying beneath the cap of sandstone cliffs above. The shales are not exposed here but their incompetent nature means that they are prone to slope failure and this is illustrated by land-slip scars, a deformed mine tramway and old mine buildings tilted back towards the slope at 15° by the rotational slippage.

The upper beds of the St Bees Evaporites (Permian) are not exposed but specimens of anhydrite were found close to the ruins of the old alabaster mine at the foot of the Barrowmouth tramway at NX 957 157). Mining ceased when the alabaster passed into anhydrite. The anhydrite was also extracted from a drift mine within the Marchon chemical plant where it was previously used in the production of sulphuric acid. The upper evaporite beds have been interpreted as supratidal, sabkha deposits.

The lower part of the evaporites comprises the 4m thick, yellow-brown Saltom Dolomite, often referred to as Magnesian Limestone. This was deposited in marine transgressions during the upper Permian and the lower part contains fragments of the underlying breccia. Vugs containing calcite crystals occur as do stunted bivalves such as *Schizodus*. The beds here form the sea cliff and wave cut platform at NX 960 161, and is were reached by a difficult scramble.

Red and purple breccias and conglomerates known as Brockram (Permian) occur at various horizons within the Permian of Cumbria. They generally represent alluvial fans derived from the upland mass of the Lake District. At Barrowmouth the breccia is 1 - 2m thick and forms the base of the Permian; it may represent a thin piedmont gravel rather than an alluvial fan deposit. The clasts include Coal Measures sandstones, dolomitised Carboniferous limestone and Lower Palaeozoic rocks from the Lake District, including Ennerdale Granite.

A dramatic feature at Barrowmouth is the angular unconformity between the brockram and the underlying Coal Measures sandstone. This was observed on the wave-cut platform at Barrowmouth. The breccia lies on an irregular erosional surface and penetrates eroded joints in the sandstone.

The Upper Coal Measures in the Whitehaven area include reddish-purple, medium to coarse grained sandstones known as the Whitehaven Sandstone. At Barrowmouth these beds form the lowest part of the sequence beneath the brockram. The rocks are clearly oxidised and contain pellets of hematite but no coal seams. The beds were previously thought to represent a unit separated from the rest of the Coal Measures by an unconformity but it is now recognised that the base of the reddened beds is not always at the same stratigraphic horizon. It is now interpreted as being formed by secondary oxidation at the end of the Carboniferous during a period of low water table associated with uplift during the Variscan orogenic effects and the change to the arid conditions of the Permian.

In the afternoon the party visited the section to the north of Whitehaven harbour where the Whitehaven Sandstone is well-exposed in the old sea cliffs above the raised beach between the former site of the William Pit (NX 975 188) and Redness Point. Here the rocks of the Whitehaven Sandstone are Westphalian C in age and lie above the Unnamed H seam. A series of sandbodies are seen separated by bounding surfaces. Each represents a series of migrating dunes and ripples in a channel. Planar cross-bedding is a common sedimentary structure and indicates a palaeoflow towards the south-east. The sandbodies are structurally complex and contain lag conglomerates and erosional horizons. They are consistent with the sands deposited today in braided channel systems.

Walking northwards from Redness Point the party then examined the Countess Sandstone (Upper Carboniferous). This is of Westphalian C age occurring 90m above the Bannock seam. A fault, downthrown to the north, is clearly exposed, throwing the purple Whitehaven Sandstone to the south against the Countess Sandstone.

At Parton Cliffs (NX 977 199), close to the ruins of an old brickworks, the base of the cliffs are formed from a 4m thick siltstone within the sandstones. Several examples of well-preserved plant material including *Calamites*, *Neuropteris*, *Annularia* and *Asterophyllites* were found. These deposits were probably formed close to a channel which overflowed on to the adjacent bank or plain.

The sandstone itself was examined just north from here. It is yellow-brown and fine to medium grained. Flutes and scours occur at the base of beds, cross-beds, siderite nodules and coaly horizons are common. At one point a lag conglomerate of siderite and coaly masses occurs in a channel which also contains a collapsed block of laminated sandstone.

Other Excursions

The following excursions were also held during 1996 and 1997.

8 June 1996	Borrowdale Volcanic Rocks in Great Langdale Leader: Dr Mike Branney (BGS)
16 June 1996	The Quaternary Geology of the Borrowdale Valley Leader: Dr Alan Smith (CGS)
4 September 1996	The Geological Collection at Tullie House Leader: Steve Hewitt (Tullie House)

LECTURES

THE GLACIAL DEPOSITS OF THE NORTH OF ENGLAND: THE ENGINEERS VIEW

A lecture by David Hughes, University of Newcastle-upon-Tyne,
on 25 September 1996
at Castlegate School, Cockermouth

Introduction

On 20th September 1996 (i.e. just five days prior to this lecture) both the local and national news media released details of a proposed canal to be constructed across Northern England, at an estimated cost of around £6 billion. The purpose of the canal is to link the Irish Sea at Port Carlisle with the North Sea at Tynemouth, and to allow the passage of ships of up to 15,000 tonnes displacement. If this gargantuan project ever goes ahead it will involve massive excavation and construction works along a 70 mile (110 km) route across countryside which is mostly underlain by glacial deposits. As part of the detailed planning and design work for this project it will be necessary to carry out extensive ground investigations to establish the thickness and geotechnical properties of the underlying strata, including the widespread glacial deposits. However, for preliminary feasibility study purposes much use is likely to be made of existing ground investigation data from the region. Although in no way connected with the canal project, the Geotechnical Group at Newcastle University is currently carrying out research into the geotechnical properties of glacial tills, and a particular aspect of this work is a study of the glacial succession in Northern England. The purpose of this lecture is to illustrate the extremely variable nature of the glacial deposits in our region and to show how this affects civil and mining engineering projects.

Most of the landscape of the northern counties of England (Cumbria, Northumberland, Tyne and Wear, County Durham and Cleveland) has been formed by glacial activity during the Quaternary period. The last major glaciation to fully cover Northern England was the Late Devensian or Dimlington Stadial ice sheet which existed from about 26,000 years to about 13,000 years before present. The Late Devensian ice sheet laid down virtually the whole of the glacial deposits found in Northern England today, although some of these deposits are likely to be reworked materials from earlier glaciations. This resulted in considerable thicknesses of glacial till materials in the lower lying coastal and valley areas, and it is in these areas where townships, industrial developments and most infrastructure works exist or are planned. In many of these areas the glacial deposits overlie Coal Measures strata; hence opencast coal mining is also present. *(The Scottish term "till" is used nowadays in preference to the older expression "boulder clay", and is briefly defined as a poorly sorted mixture of clay, silt, sand, gravel, cobble and* *boulder sized material deposited directly from glacier ice. Many engineers, however, still prefer to use the term boulder clay as this accurately describes the maximum range of particle sizes contained within this deposit.)*

Opportunities to study exposures of the lowland glacial deposits have been provided over the past fifty years by opencast mining in this region. During the last twenty years or so, extensive geotechnical investigations into the glacial deposits have been carried out in connection with opencast mining and have provided more detailed information than that available to earlier researchers.

Ground Investigations

The topic of geotechnical investigations for mining and construction works is very extensive, and only the briefest account of explorations for opencast coal projects can be attempted here. Firstly, openhole rotary drilling (with core sampling) takes place for mineral prospecting purposes, and during this stage the overall thickness of the glacial succession is proved. Then, for the glacial deposits, direct investigation usually involves both cable-tool percussion borings and trial-pitting by backhoe. In cohesive strata (tills and laminated clays) tube samples are taken at very close intervals, and in granular horizons (sands and gravels) in-situ penetration tests are carried out. Piezometers are frequently installed in the boreholes, especially in the more permeable (granular) strata in order to estimate the groundwater conditions and to predict possible inflows into excavations. A wide range of tests is performed in the soil mechanics laboratory, but particularly important are the shear strength and consolidation tests, the results of which are used by engineers in the design and analysis of structures such as spoil mounds, embankments, excavated slopes, piled foundations etc.

Glacial Deposits

In the coalfield areas the overall thickness of the glacial deposits is commonly 5 m to 20 m, ranging from as little as 1m where bedrock is close to the surface, and up to 60 m or more in the pre-glacial buried channels which dissect the underlying rockhead. Frequently, where the total thickness of glacial drift exceeds about 5 to 8 m, a tripartite succession occurs in the form of a lower till, overlain by a middle sand (and gravel) on laminated clay, or both; which in turn are overlain by an upper till. The base of the upper till can vary from less than I m to over 20 m below the ground surface. In some locations a more complex succession with additional layers of sand and gravel and/or laminated clay is evident.

The colour of the tills forming the Cumbrian coastal deposits has resulted from the colour of the source rocks which were excavated and redeposited by the ice sheet. Initially grey tills were deposited by advancing Lake District valley and piedmont glaciers, but then these local glaciers were incorporated into a combined Scottish - North Lake District ice sheet which deposited red till over the local grey till. The red tills predominate nearer the coast, the grey till tending to become more evident further inland. There is much controversy over the occurrence and mode of deposition of the upper tills in Cumbria with the Loch Scottish Readvance and/or local re-advances in the Late Devensian, and glaciomarine models all having their supporters. At many of the now restored Cumbrian opencast coal sites often only the lower till was recognised, which was usually grey in the eastern part of the coalfield and red in the western part.

In Northumberland and Durham the upper till is usually red or reddish brown and overlies a lower grey till, except where the succession is only a few metres deep, then normally only red till occurs. A popular interpretation is that the whole succession was deposited as a grey lodgement till by a single ice sheet advance, and that the reddish colour of the upper till is solely due to post-glacial weathering. There are, however, some aspects of the composition of the glacial succession, which do not seem to be adequately explained by this single deposit and weathering concept. These include the red (upper) till generally having a much lower stone content (gravel, cobbles, boulders) than the grey (lower) till; also the frequency and extent of the sand/gravel and laminated clay layers which in some cases are well over a square kilometre in area.

In the County of Tyne and Wear an extensive glaciolacustrine deposit is often associated with difficult geotechnical engineering problems, and is referred to by D B Smith (1994) in his BGS memoir of the Sunderland area as the "Tyne and Wear Complex". Towards the end of the Late Devensian glaciation eastwards flowing meltwater issuing from retreating western ice was cut off by northern ice, so creating a series of ice-dammed lakes, the largest of which was the Glacial Lake Wear. The resulting Tyne and Wear Complex deposits are generally interbedded laminated silty clays and clayey silts, plus occasional fine grained sands, stony clays and gravels. The thickness of this formation is commonly between 5 m and 15 m, but can be up to 55 m. These deposits are highly compressible and of low shear strength.

Civil and Mining Engineering Aspects

As stated earlier, glacial deposits generally overlie the shallow coalfields in northern England, and these are frequently associated with earthworks and slope instability problems at opencast coal mining sites. The upper and lower tills as engineering materials are themselves usually adequately strong in relation to the heights of spoil mounds and excavated slope faces that are normally required at opencast sites. However, it is the presence of more permeable sand/gravel layers and lower strength laminated clays which result in earthworks and slope failures. The granular materials can be a source of seepage, which may be short-lived if the material is a lens of limited extent, or may cause long-term problems of ingress of water and sloughing if of large extent or subject to recharge. Experience also shows that the presence of a laminated clay layer, even if only a few millimetres thickness, can have a very significant effect on stability due to its relatively low shear strength.

Similar seepage and stability problems are encountered throughout the region in cuttings and embankments for highways, railways, tunnels, dams and reservoirs. Natural slopes, particularly those adjacent to watercourses, are also susceptible to failure.

The laminated clay deposits of the Tyne and Wear Complex have been quarried at a number of sites for brick making, and some quite spectacular slope failures have occurred. Where large buildings or bridges are constructed over these laminated clays (e.g. Team Valley Industrial Estate and the Metro Centre at Gateshead) then deep piled foundations are usually required.

Conclusion

From carrying out a large number of geotechnical investigations involving thousands of boreholes and trial pits sunk through the glacial materials, and from extensive serial exposures at opencast coal sites, it has been found that there is considerable lateral variability in the depth and succession of the glacial deposits of Northern England. This, together with their wide range of geotechnical properties, often leads to significant problems on civil and mining engineering projects.

THE DYNAMIC LANDSCAPE OF GREENLAND

A lecture by Will Higgs, Gilsland,
on 23 October 1996
at Queen Elizabeth's Grammar School, Penrith

Mr Higgs opened his lecture by stating that he was not a geologist by discipline, but that on numerous botanical trips to Greenland in the 1970's and 1980's he had developed a keen interest in the subject mainly because of the way that the geology 'jumps out' at you.

The high Arctic is an ideal area for viewing geology and geomorphological processes in action. The area exhibits a periglacial environment when not covered in ice - the best time to visit Greenland is August, when most of the meltwater has disappeared. The "cleanliness" resulting from the lack of vegetation and the clear air provides an exceptional environment in which to examine these features.

Greenland is the largest island in the world measuring 3000km N-S and 1200km E-W, a total area of 1.8 million km^2. The maximum altitude of the icecap, which occupies all but the coastal areas, is 3200m. The ice has a maximum thickness of 3500m, so the central portion of the landmass is below sea level. The total volume of ice is estimated as 2.7 million km^3.

Mr Higgs had the opportunity to visit 3 geologically very different areas, the fjord region of NE Greenland (the Staunings Alps and King Oscars Fjord area) where a Proterozoic sandstone succession up to 3500m thick was exposed, the south-west area around Søndre Strømfjord where the Laurentian Shield is exposed, and the far north-western Thule region (Piulip Nuna - "Peary Land" in Greelandic) where a thick late Pre-Cambrian succession is juxtaposed against Carboniferous, Permian and Jurassic sediments by a large fault. Mineralisation is a common feature, being associated with the widespread basic igneous dykes.

Examples of the geomorphological effects of glacial ice were described using some spectacular photographs. These included a terminal moraine banked up in front of a glacier in a situation very similar to that envisaged for the formation of Bowscale Tarn on the northern side of Skiddaw. Glaciers crushing rocks, stones melting out of glaciers and dirt cones ascribed to being the remnants of tubular crevasse fill were also illustrated. The phenomenon of ice sheets within soils was also described, a situation which demands great care when building in these areas.

Other examples of features generated by ice were illustrated, including pingos, ice sorting (which produces sorted stone circles), solifluction (the flow of soil layers downhill), frost creep and gelifluction. The mode of formation of ice ramparts was also described and illustrated. The ground initially cracks due to contraction in winter in a polygonal form, then in summer water gets into the cracks which then freezes in the winter and expands. Continued cycles of freeze/thaw give rise to ice ramparts which form along the bounding edges of the feature and which force the ground up in these areas producing polygonally shaped earth ramparts.

Mr Higgs summarised his talk by saying that the obvious relationship between physical landforms, ecology and wildlife is stunning to an ecologist - a view that was echoed by the audience who commented on the superb slides that had been used in the talk.

TRACES OF IAPETUS - THE DISAPPEARING OCEAN

A lecture by Dr Phil Stone, BGS Edinburgh
at West Cumbria College, Workington
13 November 1996

Dr Stone opened his lecture by indicating that he intended to look at the links, similarities and differences between the Southern Uplands and the Lake District and the traces of the Iapetus ocean which existed some 500 - 400my ago. The lecture was intended to be an exploration of what happened under what is now the Solway Firth.

A satellite image of the Lake District and Southern Uplands shows a number of prominent NNW trending post-Permian features associated with the opening of the proto-Atlantic Ocean. The image provides far fewer clues as to the palaeogeography 500my ago. Palaeogeographic reconstructions of that time identify 2 continental masses - Laurentia and Gondwana/Avalonia/Baltica - separated by the Iapetus Ocean. Two different Ordovician faunal provinces, one in Scotland and northern Newfoundland (Laurentia) the other in northern England and southern Newfoundland (Baltica) are apparent. These indicate a significant geographical separation of the 2 continents, which is confirmed by latitude measurements derived from palaeomagnetic data.

500my ago the Iapetus Ocean separated these continents. By 480my Avalonia had rifted away from Gondwana and was 'drifting across' the closing ocean. This drifting mass finally collided with Laurentia as the ocean closed.

In looking for evidence to support the collision model ophiolite complexes (oceanic crust on land) might be expected. Examples of these are found at Ballantrae on the northern edge of the Southern Uplands and very similar sequences are seen in Newfoundland, for example at Betts Cove. The ophiolite sequence comprises ultramafics overlain by gabbro, then a sheeted dyke sequence (not seen at Ballantrae) overlain by basaltic pillow lavas. Radiometric dates from the 2 localities are very similar at 480-490my and biostratigraphic dates further up the sequence are also comparable (Arenig to Llanvirn).

The straightforward explanation is that these rocks have been obducted onto the continental margin. However detailed trace element analysis of the pillow lavas indicate that they are not of ocean floor (i.e. mid-ocean spreading zone) origin but are of either island arc or intra-plate basalts which raises further questions.

Once the Ballantrae Complex had been emplaced the Southern Uplands thrust belt began to form. The geological units within the Southern Uplands sedimentary sequence exhibit very consistent NE-SW trends. The sequence comprises predominantly greywacke beds (a type of sandstone), which range in age from Llandovery/Caradoc in the north to Wenlock in the south. However more detailed study of sedimentary structures (e.g. graded bedding) indicates that individual formations young northwards. The formation of this paradoxical sequence has been explained by the creation of a series of thin slices of sedimentary material stripped off the ocean floor as it was subducted and assembled sequentially into an accretionary prism.

Although this explanation of the derivation of the Southern Uplands appears satisfactory from a general point of view, when the sequence is examined in more detail the situation becomes more complex. Sedimentary structures produced by turbidity currents such as flute casts indicate a current flow which was in some cases sourced from the south-east - i.e. from the direction of the supposed ocean. These flows laid down greywackes produced from the erosion of volcanic rocks. Analysis of the sequence confirms the presence of abundant pyroxenes, andesites and tuffs indicative of an island arc origin. However, rocks derived from the north (where volcanoes would be expected) contain predominantly quartz and feldspar. Dating of the rocks could give some clues as to what is happening, the analysis of Neodymium (Nd) isotopes has proved particularly useful. These show a characteristic variation of isotopic ratios dependent on the age of the material and confirm that the quartz and feldspar in the greywacke are very ancient

Analysis of geochemical samples collected from streams in the Southern Uplands indicate that they are high in chrome, nickel and vanadium (Cr-Ni-V). The stream sediments have been derived from the greywacke bedrock and is consistent with its partial derivation from ultramafic material in oceanic crust. This lay within an orogenic belt to the north-east in Scandinavia where the oceanic crust was thus obducted in the Silurian - this is the closest we will get to seeing the Iapetus Ocean crust. This pattern continues onto the Windermere Group of the Lake District.

On the south side of the Iapetus Ocean the Tremadoc to Llanvirn Skiddaw Group was deposited in a subsiding basin in an extensional passive margin setting, but how was this deep marine environment transformed into the subaerial basement for the volcanoes of the Llandeilo - Caradoc BVG? Perhaps as subduction commenced at the margin of Avalonia the compressive forces caused inversion and shallowing of the Skiddaw Group Basin and as full subduction ensued eruptions of the BVG commenced in what was by then essentially a subaerial environment. The occurrence of marine sandstones within the BVG sequence imply that the BVG must have been deposited at close to sea level.

[At this point a slight diversion ensued where Dr Stone indicated that within the BVG there are the first signs of terrestrial life in the world. Trace fossils produced by an animal thought to be something between a woodlouse and a centipede have been found which indicate that they were capable of living out of water for a limited period of time although at this stage there was no land vegetation (Johnson et al, 1996)].

Detailed information on one aspect of the relative movement of the continents is provided by examination of slates within the Windermere Group. Structural analysis of sections from the Burlington Slate quarry indicate that cleavage cuts across fold hinges, this offset cleavage suggests that there must have been some element of lateral movement (sliding against each other) as the continents moved towards each other.

Regional magnetic anomaly data indicate a significant magnetic low along the line of the Solway, probably resulting from oceanic sediments being carried down to great depths. The Lake District and Southern Upland areas to the south and north exhibit similar characteristics, the Solway and the area to the north of the Southern Uplands have characteristics similar to each other but different to the Lake District and Southern Uplands indicating a sliver of Lake District crust to the north of the "Iapetus Suture". It may be that the "Iapetus Suture" is the last and best preserved of a number of suture zones that were created during the closure and destruction of the Iapetus Ocean.

Reference

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COPPER MINES OF THE LAKE DISTRICT

A lecture by Dave Bridge, Cumbria Amenity Trust Mining History Society, at West Cumbria College, Whitehaven
11 December 1996

Mr Bridge introduced his talk by briefly describing the objectives of the Cumbria Amenity Trust Mining History Society, namely the exploration, recording and preservation of mining history in Cumbria. A prime example of this work is the Coniston copper mines in the south of the County.

Copper mining has been undertaken throughout the Lake District, the major sites being the Caldbeck Fells, the Derwent Fells and High Furness (Coniston) with smaller workings at Buttermere, East of Thirlmere and in the High Street area, the Duddon Valley and Eskdale.

There were 2 main phases of mining. The first was in Elizabethan times when German miners initially worked around Keswick and Caldbeck and later extended their activities to Coniston. The second phase was in Victorian times, peaking in the 1850's. In the early days copper was used primarily for coinage and ordnance but by the 19th century was in much demand for sheathing the wooden hulls of ships. In the 1850's the Coniston mines produced 3000 tons of dressed copper ore per year - in the second half of the 19th century 50 000 tons of ore were recovered from Coniston, more than 10 times that recovered from the rest of the Lake District.

Of the principal copper ores mined the most abundant was chalcopyrite, but cuprite, malachite, azurite and chrysocolla are all either known or reported to have been worked.

Evidence from Paddy End at Leverswater (the site of workings in Elizabethan times) in the form of mortar stones suggests that there could have been prehistoric activity. This is based on similar stones associated with bronze age copper extraction being found on the Great Orme in North Wales. Other sites of where mortar stones have since been discovered in the Lake District are Dale Head and Wetherlam.

In 1318 Edward II sent engineers to Caldbeck to look at copper and silver mines - probably workings at Upper Roughten Gill. There is some evidence that a smelting site was present between Silver Gill and Roughten Gill by Elizabethan times. Goldscope mine in Newlands was worked in pre-Elizabethan times and from 1564 German miners became involved in an industry which was already well established.

The advent of full scale mining in the mid 1500's brought a lot of prosperity to the area, up to 70 Germans were working in the area between 1564 and 1575. All excavation work was undertaken by hand using the 'plug and feathers' technique. At Goldscope a shaft was sunk and then an adit driven to drain the working. The shaft was then extended to 200' and another adit - the Great Adit, was driven from the other side of the fell. 290 yards of excavation to get to the copper ore shoot took 5 years (from 1595 - 1600). The adit was subsequently widened by lead miners. Around 1600 a pumping station was built in the mine to remove water - the water wheel for the pump was at least 20' in diameter. The pumping allowed the mine to be deepened by another 140'. The wheel was driven by water collected in a reservoir in Scope Beck, with the water being run through one of the higher adits to the wheel. A series of pipes made from hollowed-out tree trunks would probably have been used to pump up water in 30' lengths.

Work had started at Goldscope by 1567. Twelve hundredweight of copper ore per annum was won during the years 1570 to 1573 but after that the market with Queen Elizabeth I dried up. An alternative market for copper implements took over. More than 1400 ounces of silver was recovered from the copper ore in 1572 - this went to the mint in London by horse, the copper was despatched from Newcastle by boat.

At Coniston mining had reached a depth of 25' on the Bonsor Vein by 1602, an adit - the Cobblers level had been driven by 1640 and by the end of the development some 8 veins had been worked. It should be noted that a lot of these veins were reworked on numerous occasions. Following the Civil War there was renewed interest in the Coniston copper but there was no significant mining there for many years, only minor workings of copper.

In 1758 Charles Rowe took out a Coniston copper mine lease. The Elizabethan workings at the eastern end of the Bonsor vein were deepened, going down to a depth of almost 400', some 200' below the Elizabethan workings, but no adits were driven. The shaft can still be accessed to a depth of 300'.

At Tilberthwate the early workings were extended by John Barratt who, in the 1840's drove a deep adit level 3000' in length to intercept the workings some 550' below the surface. This can still be accessed via the stopes (although it is neck deep in water!). Ladders were put in the 1930's to allow inspection of the stopes, but no payable copper was identified.

In 1824 John Taylor (with John Barratt as manager) took over the mine at Coniston. He initially opened up the Paddy End vein and then moved on to develop the Bonsor vein by driving an adit some 300' below the surface and sinking 3 new shafts. The deepest shaft (New Engine Shaft) eventually reached a depth of 1200' below the adit. Significant engineering in the form of water powered pumps was required to keep the mines dry. The mine was finally abandoned in 1908.

The presence of supergene copper mineralisation on the walls and floors of the mines was discussed with some spectacular photos of deposits that had formed as a result of water movement through the working.

Mr Bridge ended his talk with a number of photos of various aspects of mine exploration in the Coniston area and a word of warning that mine exploration can be dangerous and should be undertaken within an organised and experienced group

THE RESTORATION OF MINERAL WORKINGS (OPENCAST COAL & SAND AND GRAVEL)

A lecture by Dr David Kinsman,
(Consultant Geologist, Windermere)
at Cockermouth School, 22 January 1997

Dr Kinsman introduced his lecture by providing a review of his career. Although his academic background was in geology and geochemistry (recent sedimentary environments and geochemistry, how rocks form and weather) he had a keen interest in most aspects of the natural sciences. It was the knitting together of lots of these areas that he intended to talk about.

Dr Kinsman was involved in a major joint project with the RSPB and Tarmac. The Tarmac Group recognised that their image as a sand and gravel extraction company was not as good as it could be and they sought help to improve this image. The response was that the best thing that they could do would be to undertake good quality restoration and management of exhausted workings. Tarmac did not have restoration manuals as other companies did and worked on the preconception that all land should be returned to agricultural use, or to forestry, and if this was not feasible then as an amenity, and only finally as a wildlife resource.

These days the most important part of a planning application is the plans for restoration - most planning applications go to Public Inquiry.

An example of an opencast plan in South Wales was quoted where councillors were very much opposed to the development. It was recognised that there needed to be some form of benefit that could be offered to the local population for the scheme to go ahead - for example a nature reserve. One advantage is that opencast developments are only in use on average for some 5 years, after this the locals can look forward to getting something back. The same is true for sand and gravel extraction.

If most sites are left long enough they will become scientifically interesting - lots of abandoned sites have ended up in this state (even becoming Sites of Special Scientific Interest) - for new sites the process needs to be accelerated.

The Tarmac job had some very interesting political aspects - one initiative was seeking the Department of the Environment stamp of approval. There were 3 target groups for the report - the extraction industry (e.g. site managers), - local government officers, and county wildlife trusts and professional wildlife people.

In a typical sand and gravel extraction site, for a 5m excavation depth, 4m of material will be removed and 1m left on site for the creation of landforms during restoration. In opencast coal some 60-90m of material typically needs to be removed for 1m of coal; this offers much greater opportunities for land forming, but restoration costs are much higher.

There are only limited areas of shallow coal deposits suitable for opencast, and some of these are in 'political' areas such as the Vale of Belvoir and South Wales. In contrast, Pliocene and post glacial sand and gravel deposits are very widely distributed. Since the cost of material doubles if it has to be transported 20km local sites make sense. There are hundreds of millions of tonnes production per annum but there is significant annual variation dependent on the state of the economy.

Inspection of a map of the production of crushed rock by planning region indicates that large volumes are produced in the south-west of England but that most of it is transported to the south-east where there is no hard rock available locally. Offshore production of sand and gravel is limited but is important in the south-east. It was noted that this type of abstraction is seen to have some effect on coastal erosion and that this is made worse still by the continuing subsidence of the south-east of England.

Over the period 1900-1987 some 60 000 hectares of land was used for sand and gravel extraction; this represents 0.3% of the area of the United Kingdom (the area subject to the EEC 'Set aside' policy was 3 - 5%). Of the 60 000 ha some 20% has become lakes / wetland habitat. One example of this is the Cotswold Water Park Area where there are a lot of water filled holes in a small area. Waterfowl overwinter on gravel pits, with up to 30% of some species using these localities. There has been a slight shift of populations from reservoirs to gravel pits - they are an important resource from a wildlife point of view. Investigations have taken place to establish the major requirements for the different types of wildlife (e.g. food and wildlife) and attempts have been made to knit these together to develop the ideal environment.

Wind is a very important factor at sites in the UK. Impermeable wind barriers are ineffective at providing shelter since turbulent cells are created and there is a rapid return to free wind speeds. The use of permeable barriers allows some wind through, but keeps the turbulence down with only a gradual return to free wind speed - 'see through' hedges make good wind breaks.

The ideal form for the margin of pits is gently sloping to a shallow platform and then to deeper water - however this is not in the extracting companies interest since they have to sacrifice some product to produce the gentle slope. Islands are designed with lots of promontories to cut down wave energy; horse-shoe shaped islands provide sheltered areas downwind.

These days post extraction design of sites is often agreed prior to extraction and planting of trees may take place at this time so that the trees will be well developed by the time restoration starts.

CGS LECTURES AT TULLIE HOUSE

Short talks by 4 members of the Society
at Tullie House Museum & Art Gallery , on 19 March 1997

The programmed lecturer for this evening was unfortunately unable to attend. Since it was not possible to arrange an alternative speaker in the time available 4 members of the society agreed to speak on a variety of topics.

Mervyn Dodd provided a comparison of the character of buildings in Gosforth and in the Buttermere Valley, illustrating the variations with numerous slides. This work had been undertaken as part of the Societys initiative to explore the 'Pattern of English Building' in the local area. (See the article in this volume of the proceedings which summarises the work to date)

Iver Gray spoke on the 'Rocks of the Borders, which was again accompanied by a series of high quality slides.

Steve Hewitt provided a review of the RIGS database, which is held at Tullie House, provided examples of the outputs that could be requested from the database.

Alan Smith provided some interesting thoughts on land slips with examples from the USA (Turtle Mt) and the Lake District (- lake basins generated by rock falls e.g. Goatswater, and the Lingmell fan, deposited by a flash flood in 1936).

NORTH SEA OIL AND GAS

A lecture given by Dr Richard Swarbrick of Durham University on 22 October 1997 at West Cumbria College, Workington

Dr Swarbrick reviewed the elements necessary for the formation of a hydrocarbon accumulation. These are a source rock, a reservoir rock, a trap for the hydrocarbons and favourable timing of hydrocarbon generation and trap formation.

The potential of a source rock to produce hydrocarbons is dependent on its richness (how much organic material it contains), the composition of the organic material (whether the material has the potential to generate oil or gas), and its maturity (whether it has been heated to sufficient temperatures to generate hydrocarbons). Source rocks deposited in a lacustrine environment will normally generate oils with a high wax content, those in a marine environment (high algal content) will produce low wax oils, and terrestrial (coaly) source rocks will produce dry gas (methane). Increases in temperature (i.e. increased depth of burial) will produce thermal cracking, characterised by a reduction in molecule lengths, resulting in the gradual conversion of oil to condensate, and finally dry gas.

Dr Swarbrick provided a practical demonstration of the process of hydrocarbon generation from a source rock by heating a sample from the Upper Jurassic Kimmeridge Clay Formation in a test tube. Initial heating of the sample drove off water and carbon dioxide, continued heating resulted in the formation of oil (which condensed towards the top of the test tube and produced a strong odour) and methane, which was easily ignited at the end of the test tube.

The three key properties of a reservoir rock are porosity, permeability and continuity. The initial porosity of a sandstone reservoir prior to burial is 40%, which is invariably reduced by compaction and cementation, but may subsequently be enhanced by dissolution. Permeability is a measure of how fast fluid flows through the rock, and reflects the tortuosity of the flow path.

Reservoir continuity and geometry are controlled by the environment of deposition.

A trap is an updip barrier to hydrocarbon migration. Traps can be either structural (faults and folds) or stratigraphic (at unconformities or due to facies changes). The trap must have formed prior to hydrocarbon migration and trap integrity must have been maintained up to the present day.

Dr Swarbrick described the phases of investigation associated with hydrocarbon exploration of a new area. Initially desktop studies of the region and basin analyses (e.g. gravity, regional seismic, sequence stratigraphic interpretations) are undertaken to determine if the area has the potential to host hydrocarbon accumulations. If the area looks promising, a field mapping programme would be undertaken to provide further information to substantiate the desktop study. Subsequent stages would be the acquisition of detailed seismic data, and, if interpretation of the processed seismic data indicated the presence of potential hydrocarbon traps, the drilling of wildcat wells. Although all of the previous phases of the exploration programme could provide favourable indications of the potential of the area, only the drilling of an exploration well can provide confirmation of the presence of hydrocarbons.

The various phases of the exploration process were illustrated with examples from the North Slope of Alaska (oil seeps coming through permafrost), the Gulf Coast of the USA (offshore seismic exploration) and the North Sea (exploration drilling rigs).

Dr Swarbrick then reviewed the exploration history of the North Sea. In the 1950's the concept existed that the North Sea was a basement area, but the discovery of the giant onshore gas field at Groningen in the Netherlands in 1959 sparked a major review of the prospectivity of the area. Offshore licencing commenced in 1964 and the discovery of the Leman and West Sole gas fields in 1966 confirmed the potential of the area. As exploration moved further north a large number of wildcat wells encountered indications of oil but no significant accumulations were discovered. Then, in 1969, Phillips Petroleum hired an exploration rig for a 3 well programme. After 2 dry holes the company unsuccessfully tried to sub-let the rig. The company decided to drill the third hole, and discovered a giant oilfield, finally estimated to contain more than 1,000 million barrels of oil – the Ekofisk field. This discovery established the North Sea as a major oil province.

Examples were provided of the nature of the structures in the Northern North Sea (tilted fault blocks e.g. the Middle Jurassic Brent Field), the Central North Sea (differential compaction over submarine fans e.g the Palaeocene Forties Field) and the Southern North Sea (salt diapirs overlying tilted fault blocks containing Permian or Carboniferous reservoirs e.g. West Sole). Dr Swarbrick noted that the Yorkshire coast was the best place to see analogues for the Northern North Sea with Middle Jurassic deltaic sandstones and Upper Jurassic source rocks (Kimmeridge Clay) well exposed.

The current Atlantic Seaboard 'frontier' province was highlighted, noting that structures in the area were comparable to those in the West of Scotland province which has proved to be the most recent explored wildcat area to yield commercial reserves. In response to questions Dr Swarbrick stated that he believed that the next major oil crisis from a pricing point of view, would occur in the next 5 – 15 years. Only half of the known reserves have been consumed to date, but are now being consumed at a phenomenal rate.

ROCKS AND GLACIERS IN ARCTIC NORWAY

A lecture by Tom Shipp of the Cumberland Geological Society
on 12 November 1997
at the 6th Form Centre, Queen Elizabeth Grammar School, Penrith

Mr Shipp commenced his lecture by providing the background to his presentation. In the summers of 1984 and 1994 he was involved with the British Schools Exploring Society (BSES) expeditions to mountainous regions above the Arctic Circle in Northern Norway, the Lyngen Peninsula and the Bergsfjord Peninsula. For the 1984 expedition Mr Shipp was invited along as the mountaineering leader, his main duties were to include all aspects of mountaineering training, advice on camping at low and high altitudes, safe movement on mountains and glaciers, and rescue techniques. In 1994 Mr Shipp's task was to co-ordinate the various science projects, and to take charge of the meteorological studies. Both expeditions were flown into N Norway and transferred by buses to the nearest road to the expedition area.

The Lyngen peninsula lies some 30-40km east of Tromso at a latitude of 70° N. The dominant feature is a N-S trending spine of intensely metamorphosed gabbro, which extends the whole 85km of the peninsula and is bounded by westward dipping thrust faults. Interpretation of gravity surveys has led to the suggestion that the Lyngen Gabbro takes the form of a westerly dipping wedge which may have been thrust as much as 100km eastwards from its source in the lower crustal layer off western Norway. Movements of this magnitude are not uncommon in regions of orogenic disturbance, this particular one is linked with the Caledonian Orogeny. The gabbro is bounded by metamorphosed sedimentary and igneous rocks of Cambrian to Silurian ages. These have been severely deformed and chemically altered and consist of amphibolites, phyllites, schists, quartzites and impure marbles. The total thickness of the sediments is estimated to have been in excess of 7 km.

The Bergsfjord peninsula, with its prominent icecap of Øksfjordjøkelen, lies a further 100km to the NE of Lyngen. It is largely composed of mafic and ultramafic rocks, principally pyroxene-rich gabbros which were intruded into

Mr Rigby then reviewed a selection of mines, illustrating specific features with slides. A small lead mine at Embleton near Cockermouth yielded the rare kaolinite type mineral dickite. The Rachel Wood mine at Thornthwaite and the Barrow mine near Braithwaite, both exploiting the same vein, yielded lead and zinc with minor copper, with the latter spoil tips providing good examples of cerrusite (lead carbonate). On Causey Pike a disastrous large scale investment in a roadway (from Stoneycroft to the mine), and a crushing plant at the mine was rewarded by the recovery of only a few ounces of cobalt ore. The Force Crag Mine, for a long time a significant source of galena and sphalerite, and latterly barytes, has recently yielded microscopic samples of native silver from a zone on the Laporte incline. This mine was closed in 1985 following a major collapse but good samples of barytes and sphalerite can still be obtained from spoil tips.

In the Caldbeck Fells, Carrock Mine was a major producer of wolframite (tungsten oxide), mainly during the 1st World War with later activity during the 2nd World War and the Korean War. The mine reopened during the 1970's, but owing to the depressed state of the tungsten market, work ceased in 1981. After being put onto a care and maintenance basis it closed in 1985. Five main veins were worked, these yielded a variety of minerals including bismuthinite, arsenopyrite, molybdenite and scheelite. During the 1940's and 50's some 15-20 new minerals were identified from this area. In Brandy Gill these included carminite, bayldonite and stolzite. Drygill mine yielded the world famous mineral campylite, characterised by small brown, barrel shaped crystals. Occasional good specimens can still be found if some effort is expended digging in the tips! Other mines such as Roughton Gill (pyromorphite) and the High and Low Mexico mines in Clintsgill have also yielded a variety of minerals, and gold has been reported from Todd Gill. Some 300 different minerals have been recorded from the north of England, of which over 150 have been recorded from the Caldbeck Fells.

On the eastern side of the Lake District the Shap 'Pink' (granite) quarry is noted for specimens of molybdenite, bismuthinite and pyrite, and the 'Blue' (BVG) quarry for garnets. Above Ullswater at Glencoyndale Head (an escape route from the Greenside Mine) good specimens of hemimorphite can be found, and in quarries at Johnby, near Greystoke, excellent specimens of fluorescent pink calcite and crystals of aragonite have been collected.

The Pennines have long been famous for their lead/zinc/fluorspar deposits. At Scoredale in the Hilton/Appleby area, workings at Dow Scar have yielded yellow fluorite and microscopic samples of nickellite. In Weardale, originally a lead mining area, fluorite has been mined more recently, and the Fraser Hush mine is still working with some 7-8 miners, currently working a surface drift.

Mr Rigby's talk was complemented by a 'visual feast' of photographic slides, this was followed by the welcome opportunity for the audience to examine at first hand some of the best specimens from Mr Rigby's own collection.

THE PATTERN OF ENGLISH BUILDING

A lecture by Dr. Eric Robinson of the University of London
on 25 March 1998.
at the Sixth Form Centre,
Queen Elizabeth Grammar School, Penrith

The theme of Dr Robinson's lecture was that there is a strong relationship between the building stone fabric of English villages and towns and the map of the geology of England. Geologists, and particularly local geologists with a detailed regional knowledge, have much to offer in this field. Local geologists can bring a finer focus to the study, bringing out the features which are locally distinctive.

Dr Robinson began by illustrating his theme with a traverse across Ham Hill and the southern margin of the Somerset Levels. Within this region the Ham Hill Stone has a great influence on building, dominant as a material in the east, but less so further westwards where its value was as a dressed stone capable of withstanding transport costs.

With a series of slides of different parts of Cumbria the speaker then illustrated some of the features that are regionally distinctive here. He pointed to the particular difficulties inherent in the Lower Palaeozoic rocks of the Lake District - the lack of freestones and the weight of local roofing slates for example. He stressed the need to look not just at prominent buildings and the major features of houses, but at the detailed architectural features. These often portray local distinctiveness. In the Lake District the nature of the local materials has led to distinctive features such as the use of slate slabs for fences and gateposts, the practice of slate hanging on walls, the distinctive stepped gables and round chimneys of South Lakeland and the particular pattern of roofing with the heavy local materials. The need to import sandstones as a workable freestone was also illustrated.

The paradox of retaining the use of locally quarried stone for building in the Lake District with controls on stone quarrying in a National Park were also discussed. The impact of importing stone along the railway routes and the difficulties of building with different mixtures of stone were all touched upon and illustrated.

Dr Robinson stressed the need for local Societies like ourselves, to work on local areas. Stone is a logo, one of the most important contributors to the distinctiveness of an area. Local distinctiveness must be sustained and geologists have much to contribute in describing and analysing the features of the fabric of our towns and villages.

A large and enthusiastic audience were inspired by this talk.

ANNUAL GENERAL MEETINGS

The 36th ANNUAL GENERAL MEETING of the Society was held at Cockermouth School on Wednesday February 26th 1997. President F. T. Lawton was in the chair and 20 members present. A generally successful year for the Society was reported with good attendances at lectures and field excursions. A healthy financial situation existed. M.B. Dodd was installed as the new President and thanks were expressed for all the work Fred Lawton had done throughout his Presidency in the last three years.

Following the formal business there were a series of presentations by members on the theme of local building stones, reporting on work in progress in various towns and villages in North Cumbria.

The 37th ANNUAL GENERAL MEETING of the Society was held at Cockermouth School on February 25th 1998. President Mervyn Dodd took the chair and there were 22 members present.

The format of the meeting was streamlined this year to enable the formal business to be completed within half an hour. A written report to the Society on the activities of 1997-98 was distributed to all members present and approved. The Society continues to flourish and remain in a sound financial position.

Following the meeting the February lecture to the Society was delivered by Mr Tony Rigby on the title of "Minerals of Cumbria and the North Pennines: A brief collecting guide".

ANNUAL DINNERS – 1997 and 1998

The 1997 Annual Dinner was held on Saturday March 22nd 1997 at the Derwent Lodge Country House Hotel, Embleton, Cockermouth. 34 members and guests had an excellent evening with good food and company. We were particularly pleased to present Eric Skipsey with the Charles Edmonds Award for 1997 in recognition of his contribution to the Society and to Geology in Cumbria. Following the meal, Eric entertained us with an illustrated talk on "Geology Way Out West".

The 1998 Annual Dinner was held at at the Swan Hotel, Thornthwaite, near Keswick on Saturday March 28th 1998. Forty four members and guests met for what was a very succesful evening with the largest gathering for several years. A good meal, a geological quiz and excellent fellowship was enjoyed by all. The Guest Speaker was Prof. David Huddart (Liverpool John Moores University) who gave a superbly illustrated talk on his work as a glacial geomorphologist entitled "From Whitehaven to Spitzbergen".

OBITUARIES

Walter Annis

Walter was a member of the Society for many years and contributed to our activities by leading excursions and lecturing, particularly in the early years. He will be remembered particularly, however, for his many contributions to Lakeland life in the south of the County. His 'brainchild' was the Westmorland Geological Society which he was instrumental in founding in 1973 and in which he was leading light until his death in 1997, unfortunately a few months short of seeing the society celebrate its 25th Anniversary.

A teacher, first in Stretford, Manchester and later at the Kelswick Grammar School in Ambleside he introduced many to the geology and geomorphology of the Lake District. He gave 20 years service on the Committee of Friends of the Lake District and became General Secretary of The Lake District Naturalist's Trust.

He touched the lives of many people in Cumbria with his wisdom and wit and his no nonsense approach.

Denis Wildridge

Denis was a well known figure in Workington and was a man of many parts. He will be particularly remembered in the Society for his interest in the mines and mining of Cumbria. He served three years with the British Antarctic Survey before his career as a teacher in West Cumbria. An amateur botanist he was influential as Chairman of the Maryport Natural History Society and campaigned for wildlife interests. He had other hobbies in rugby union, badminton, mountaineering and wood turning. He generously gave his time for others throughout his life.

George Rudd

George was one of the many West Cumbrians whose early interest in geology was inspired by Edgar Shackleton in the early 1960's. He was an active member of the Society in its early years. As Head of Distington Junior School he gave many of his pupils a taste of the subject, in addition to his son who remains a member of the Society. In later years he was unable to enjoy the outdoor scene as he had previously.

Eric Messenger

Eric's interest in geology dated back to his boyhood in Braithwaite when he was fascinated by trucks carrying ore from the then active Force Crag mine through the village. He was unable to attend as many Society activities as he would have liked in his many years as a member. Living in a remote Border village and working as a senior manager in the textile factory at Cummersdale he had eventually to take early retirement due to persistent ill health.

Maurice Jones

Geology was one of the many interests Maurice was able to dabble in during his long and very enjoyable retirement. When Headmaster of Whitehaven Grammar School he had encouraged the introduction of geology into the 6th Form curriculum at a time when overcrowded old buildings considerably restricted possibilities. Much as he would have liked to take part in excursions his heart problems made this impossible.

DONATIONS

During 1997-98 the Society has been fortunate in receiving donations of books and journals for the Library from Sir Kingsley Dunham and Dr Arnold Currall. In both cases extensive runs of a variety of geological journals have been given, greatly enhancing our collection at Whitehaven. There were also a number of textbooks, publications of the British Geological Survey and geological guides. The Society gratefully acknowledges these gifts, which are now all incorporated into the Society Library and are available for borrowing by members.

The Society also acknowledges the donation of a series of geoscience maps, drawings and sections of the Nirex Research Programme at Longlands Farm, Sellafield from UK Nirex Ltd.

OFFICERS AND COUNCIL.

Officers and Council elected for 1997 and 1998 are listed below.

OFFICERS ELECTED FOR	1997	1998
President	M. B. Dodd	M. B. Dodd
Senior Vice-President	F.T.B. Lawton	F.T.B. Lawton
Junior Vice-President	R. A. Smith	R.A. Smith
General Secretary	R. A. Smith	R.A. Smith
Excursion Secretary	D. Kelly	D. Kelly
Treasurer	Mrs A. Marchant	Mrs A. Marchant
Membership Secretary	F.T.B. Lawton	F.T.B. Lawton
Editor	C. J. Thompson	C. J. Thompson
Publications Secretary	G. Pinches	(Vacant)
Librarian	Mrs M. Fox	Mrs M. Fox
RIGS Co-ordinator	M. B. Dodd	M. B. Dodd
Council Members	D. Dickins	T. Rigby
	E. Skipsey	T. Blanchard
	Mrs L. Wornham	Mrs L. Wornham
Hon. Auditor	Dr. T. Dias	Dr. T. Dias

In addition Dr. F.J. Cockersole, Mr. T. Shipp, Mr. I Gray and Mr K.W. Bond past Presidents of the Society are ex-officio members of Council.

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