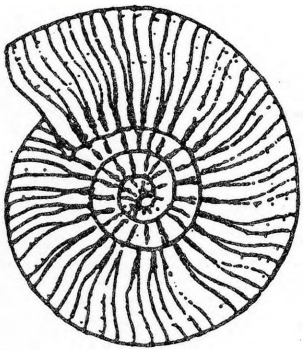
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EDITOR'S NOTES

I would like to thank all those who have contributed articles, provided lecture and excursion notes and assisted in the preparation of the Proceedings. I must also acknowledge the work over the past eight years of Eric Skipsey who retired as Editor in February 1994, his experience and support has been of great help in the production of the present 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

CARBONATE-CLASTIC INTERACTIONS IN A DINANTIAN SHALLOW-WATER SETTING: A STUDY IN THE DEPOSITION OF THE WHITE LIMESTONE MEMBER IN NORTHWEST CUMBRIA

A. D. Thurlow

Introduction

Historical Perspective

The first detailed account of the west Cumbrian limestone stratigraphy was provided by Kendall (1885) who recognised seven persistent limestone horizons, named First Limestone to Seventh Limestone in descending order (Figure 1). In 1922, Edmonds provided a classic account of the west Cumbrian Limestone Series in which relatively detailed lithological and palaeontological descriptions were presented. The thesis of Stabbins (1969) provided a detailed sedimentological description of the Limestone Series from Egremont to Bothel, whilst palynological theses relating at least in part to the north-west Cumbrian succession were undertaken by Butcher (1974) and Welsh (1980).

The White Limestone Member is an informal lithostratigraphic unit forming part of the 'Carboniferous Limestone Series' of north-west Cumbria, which crops out in a narrow discontinuous strip around the western and northern margins of the Lake District National Park. It was deposited during the latest part of the Asbian stage of the Dinantian System (Lower Carboniferous) and is broadly time equivalent with the uppermost part of the Upper Urswick Limestone of south Cumbria (Horbury, 1987, 1989), the Melmerby Scar Limestone of the Pennine escarpment (Arthurton & Wadge, 1981) and the Upper Border to Liddesdale Groups of Northumberland.

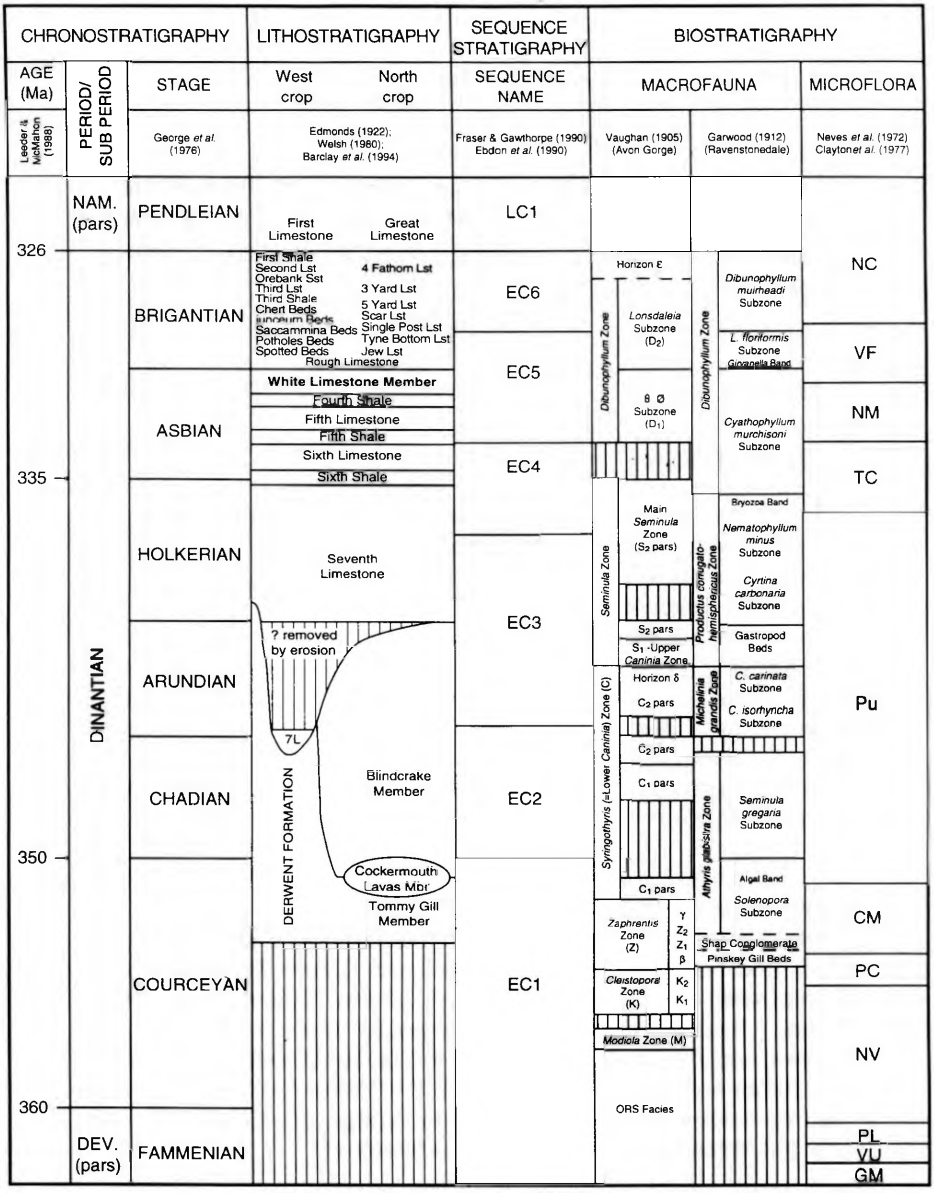


FIGURE 1. Summary stratigraphy of the Lower Carboniferous of northwest Cumbria. Vertical hatching denotes non-sequence.

Cycle W4

Across the platform interior this cycle is exclusively represented by deposits of the Grainstone Facies Group, with macrofossil-rich grainstones in the north at Kelton and Salterhall Quarries and coated grain grainstones in the south at Clints Quarry. Neither vertical nor lateral trends within this cycle are apparent, but the presence of abundant coated grains at Clints Quarry may indicate more 'open' marine conditions to the south.

Cycle W5

Deposits of this cycle are thin at Clints Quarry and only partly represented at Kelton due to a gap in the exposure and fault-related dolomitisation of part of the remaining succession. The cycle is split into two by a correlatable flooding surface, with a lower section comprising peritidal fenestral carbonate mudstones at Clints, which prograded northwards to cap a succession of lagoonal porcellanites at Salterhall, where claystone locally infills palaeokarstic hollows at the top of this peritidal unit. Unlike the major palaeokarstic surfaces and overlying claystones which mark cycle boundaries, this local development is seen as being intrinsic (autocyclic) within the prograding depositional system, with subaerial exposure and localised soil development occurring immediately behind the peritidal environment. The flooding surface overlying this progradational package brings in macrofossil-poor grainstones across the whole area reflecting shallow water carbonate sand shoal deposition. The cycle is capped by thin claystones overlying a palaeokarstic surface with relatively minor relief.

Cycle W6

This cycle is represented by grainstones throughout the platform interior, with macrofossil-rich grainstones at Clints and macrofossil-poor grainstones at Kelton and Salterhall. No vertical trends are evident within this cycle, which is capped by thin claystones overlying a slightly irregular palaeokarst surface.

Cycle W7

Cycle 7 is the last cycle within the White Limestone Member and is composed of macrofossil-rich grainstones at Clints and interbedded macrofossil-poor grainstones and porcellanous facies at Kelton and Salterhall. These interbedded deposits are interpreted as representing northerly progradation of carbonate sandbodies and the quiet water deposits formed in their lee. The palaeokarst surface which caps this cycle shows minor relief and is once again overlain by a palaeosol claystone.

Evolution Of The Northern Platform Margin

Figure 5 illustrates a correlation scheme for the White Limestone Member in the platform margin area. Cycle tops are defined by correlatable surfaces and deposits indicative of subaerial exposure, which within this region are silty claystone deposits overlying irregular palaeokarst surfaces on the underlying limestones. Seven cycles are recognised and are discussed in turn below.

Cycle W1

Behind the inferred northern platform margin of the Lake District High, cycle W1 occurs as a thick Argillaceous Facies Group-dominated succession overlying the silty claystone floodplain deposits and coal of the Fourth Shale. The cycle can be subdivided into three by two minor deepening events (flooding surfaces), the lower of which becomes increasingly difficult to pick in the more southerly sections at Clintz. The lowest portion is formed of rubbly stylonodular deposits in Clintz borehole 3 which pass laterally into deposits of the more distal homogeneous facies in Clintz 'B' and crinoid-rich packstones at Moota Quarry, representing deposition at or around wavebase of part of a slope break barrier complex. The top of this unit consists of a 40cm deposit of burrow mottled facies formed due to omission colonisation by *Thalassinoides* during a minor hiatus associated with the overlying flooding event. On Parsonby Brow, this lower portion of cycle W1 is seen to be significantly thicker than the sections at Moota and Clintz, although the contact with the underlying Fourth Shale is not seen.

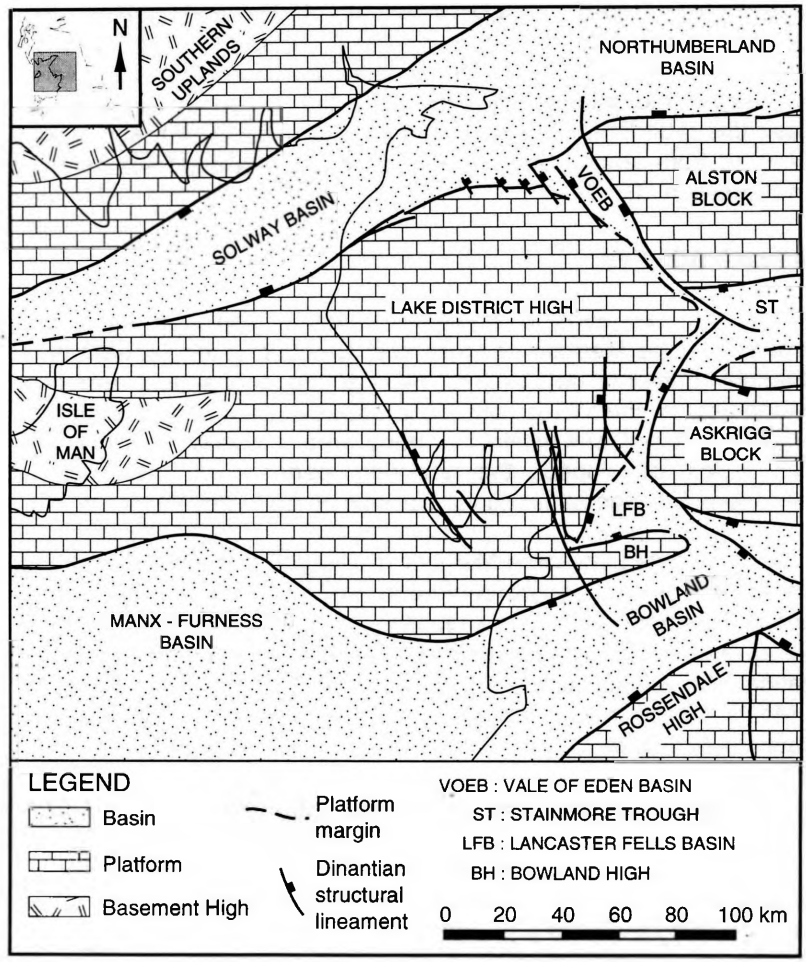


FIGURE 2. Regional structure of northwest Britain during the Dinantian.

the north by a major fault system which coincides with the line of the Maryport-Gilcrux fault (Chadwick et al., 1993) and defines the southern margin of the Solway Basin. Offshore seismic lines (Chadwick et al., 1993) and an uncored borehole at Westnewton demonstrate the intense thickening of the Dinantian succession across this fault line, in particular during the Asbian with sediments thickening from around 80 metres near Moota to around 975 metres in Westnewton -1.

Approach Adopted

This paper aims to study the variation displayed within the White Limestone Member of north-west Cumbria using facies-based palaeoenvironmental analysis to interpret the spatial and temporal development of the White Limestone Member depositional systems. Correlation of sections within the study area is attempted using the cycle styles developed, the stacking patterns of which have implications for understanding the controls on cycle development.

The White Limestone Member is described from nine locations utilising both outcrop and borehole core material, four of which: Clints Quarry, Egremont; Yeathouse Quarry, Frizington; Salterhall Quarry, Rowrah and Kelton Quarry, Kirkland come from a 'platform interior' location. The remaining five: Clintz borehole 3, Clintz Quarries B and C, Moota Quarry and Parsonby Brow are from a 'platform margin' location (see Figure 3).

Facies-Based Palaeoenvironmental Interpretations

The White Limestone Member is formed of a number of clastic and carbonate facies which are best considered separately. Individual facies are described and interpreted in the context of facies groups or associations where appropriate.

Clastic deposits are represented by eight distinct facies, summary descriptions and interpretations of which are presented in Table 1. Fifteen carbonate facies are encountered in the White

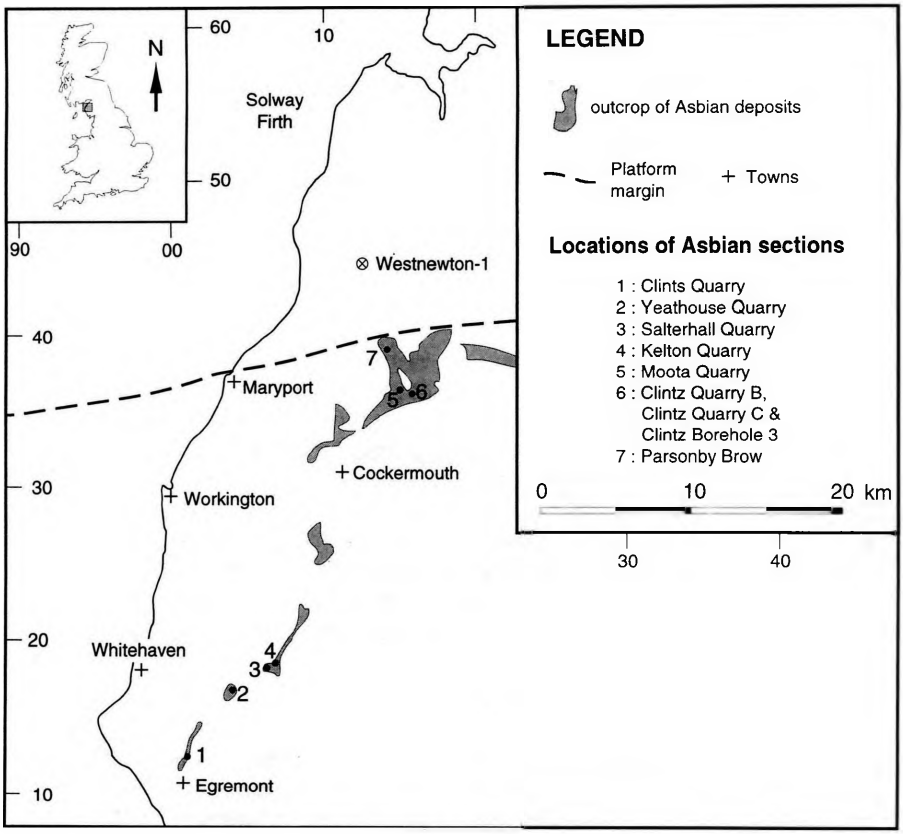


FIGURE 3. Outcrop of Asbian deposits and locations of White Limestone Member sections in northwest Cumbria.

Limestone Member, the majority of which are best considered within facies groups. Table 2 summarises the descriptions and palaeoenvironmental interpretations of these carbonate facies. Taken generally, the progression from Argillaceous Facies Group through Transitional and Grainstone Facies Groups to Mudstone Facies Group is interpreted as a shallowing trend. Argillaceous deposits consist mostly of wackestones (>10% grains in a clastic and carbonate mud-supported matrix) with subordinate packstones (grain supported fabric in a clastic and carbonate mud matrix) and are interpreted to have formed in subtidal, sub-wavebase conditions in an offshore setting. Transitional Facies Group carbonates are dominated by packstones, and indicate deposition in higher energy, more proximal settings, although the volumetrically less significant porcellanous and dark porcellanous wackestone facies are clastic-free wackestones deposited in the quiet waters of lagoons or in the lee of shoals. Deposits of the Grainstone Facies Group are represented by grainstones (grain supported fabric with intergranular cement rather than muddy matrix) and were deposited within high energy environments above wavebase in proximal settings. The Mudstone Facies Group represents deposits formed within peritidal and subaerial environments as the mudstone fabric (<10% grains in a carbonate mud-supported matrix) indicates very quiet water deposition or pedogenic growth, or alteration, within a soil profile.

Evolution Of The Platform Interior

Figure 4 illustrates a correlation scheme for the White Limestone Member in the platform interior. Cycle tops are defined by correlatable surfaces and deposits indicative of subaerial exposure, which within this region are claystone deposits overlying irregular palaeokarst surfaces on the underlying limestones, some of which show rubbly tops and spar-filled elongate sinuous root moulds (rhizocretions) resulting from plant colonisation. Up to seven cycles are recognised, termed W1 to W7 in ascending order, which are discussed in turn below.

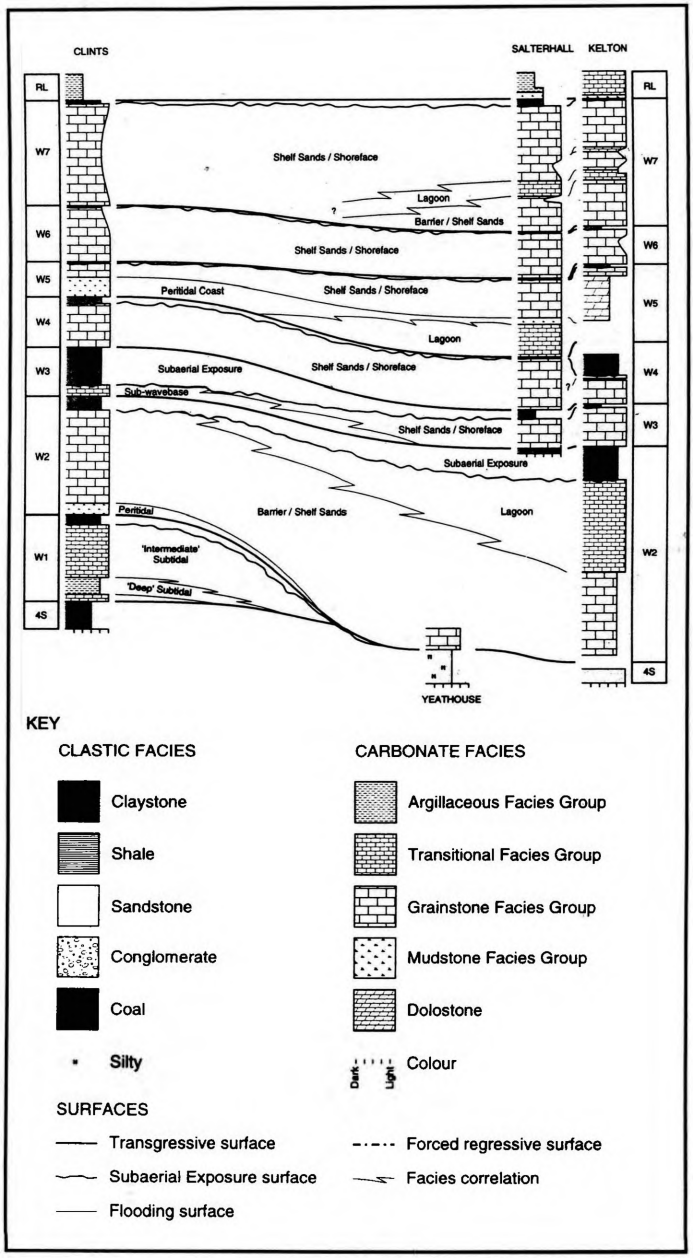


FIGURE 4. Correlation of the White Limestone Member in the platform interior. Sections are displayed using their colour profiles

Cycle W1

This cycle is only recognised at Clints Quarry, the most southerly of the sections, where the earliest deposits are of thin porcellanous facies marking transgression in this area. Rubbly stylonodular carbonates, interpreted to have been deposited in deeper water overlie these lagoonal sediments and indicate resumed transgression. These argillaceous deposits are the deepest water facies encountered in the White Limestone of the platform interior, and pass up into shallower-water crinoid-rich packstones. These subtidal deposits are capped by a palaeokarst and claystone soil, marking a major drop in relative sea level at the top of this cycle.

Cycle W2

Present throughout the whole area, flooding at the base of this cycle established shallow water carbonate depositional environments across the platform interior. Initial transgression of peritidal fenestral carbonate mudstones is only seen in Clints Quarry, as the resumed transgression, which established a large carbonate barrier sandbody with macrofossil-poor grainstones, is elsewhere coincident with the lower transgressive surface. The upper half of this cycle in Kelton Quarry shows a thick development of porcellanous facies overlying the grainstone package and records the southerly progradation of a lagoon over the barrier grainstones. The succeeding irregular karst surface and overlying cycle-top claystone is seen to cross-cut facies belts and records another major fall in relative sea-level.

Cycle W3

Cycle W3 is thin within the platform interior and is represented by sub-wavebase crinoid-rich packstones in the south at Clints Quarry, whilst shallower-water macrofossil-poor and macrofossil-rich grainstones occur in the more proximal locations of Salterhall and Kelton Quarries respectively. The cycle is capped by claystones overlying an irregular palaeokarst surface which once again cross-cuts facies.

Cycle W4

Across the platform interior this cycle is exclusively represented by deposits of the Grainstone Facies Group, with macrofossil-rich grainstones in the north at Kelton and Salterhall Quarries and coated grain grainstones in the south at Clints Quarry. Neither vertical nor lateral trends within this cycle are apparent, but the presence of abundant coated grains at Clints Quarry may indicate more 'open' marine conditions to the south.

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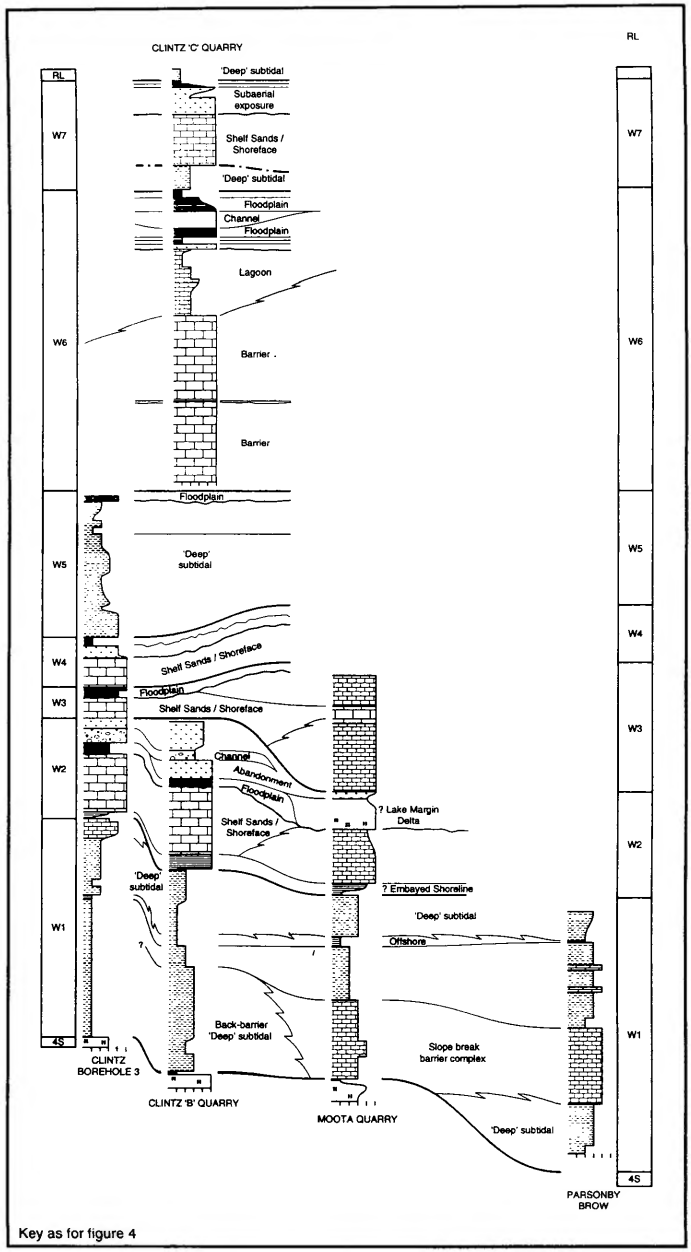


FIGURE 5. Correlation of the White Limestone Member in the platform margin area.

Here the succession consists of a basal package of homogeneous deposits which grade up into the crinoid-rich packstones of the prograding slope-break barrier complex.

The deepening event at the base of the middle portion resulted in the development of the Argillaceous Facies Group across the entire platform margin area with the homogeneous facies predominant, but with rubbly stylonodular deposits at the most southerly (proximal) section of Clintz borehole 3. Once again the thickest development is seen on Parsonby Brow, where the central section of the package is partially dolomitised.

The second deepening event is visible in all sections and is marked by a basal development of black shales, except at Clintz 'B' where the dark facies occurs as a calcareous equivalent of the black shale facies. Above this, conditions returned to their state in the middle portion of this cycle with rubbly stylonodular carbonates in Clintz borehole 3 passing northwards into homogeneous deposits elsewhere. Above these argillaceous carbonates in Clintz Borehole 3, a thin development of crinoid-rich packstones occurs which indicates the northerly progradation of a carbonate sand shoal/barrier /shoreface into this area, although the more proximal 'cleaner' sands did not make it this far north.

Cycle W2

The clastic unit which overlies cycle W1 does not overlie an exposure surface and is considered to belong to the base of W2 rather than the top of W1. It is not seen on Parsonby Brow but elsewhere consists of a deposit of brachiopod-rich black shales (generally thin) which pass up into grey laminated claystones with occasional pebbles of reworked Transitional Facies Group carbonates and intact delicate brachiopods. These deposits are interpreted as a nearshore, quiet-water, marine deposit with reworking and redeposition of adjacent karstified limestones and floodplain clays into an embayment. These deposits are interpreted to have formed during marine transgression and therefore lie at the base of cycle W2.

This cycle shows a better developed set of proximal facies compared with the underlying cycle, with macrofossil-poor grainstones in Clintz borehole 3 passing laterally into macrofossil-rich grainstones at Clintz 'B' and crinoid-rich packstones at Moota, representing deposition at or around wavebase in front of the shelf sands /shoreface.

The cycle top deposits associated with relative sea level lowstand in this cycle show a marked variation in the platform margin area. The succession is similar in Clintz borehole 3 and Clintz 'B' Quarry where floodplain silty claystones overlie and infiltrate into the karstified top of the underlying grainstones. This unit is overlain in Clintz 'B' by a bed of carbonate mudstone with subvertical and star-shaped spar-filled fenestrae, interpreted as a calcrete forming through pedogenic growth of micritic carbonate on a well drained floodplain, with the moulds of plant roots preserved as fenestrae. Later waterlogging of the soil (reducing environment) is indicated by the presence of pyrite in the sparry calcite fill to the root moulds. This pedogenic horizon is overlain by a granule conglomerate horizon, which occurs above, and presumably cuts into, the floodplain silty claystones in Clintz borehole 3, and is interpreted as a channel fill deposit. The clasts in this unit include reworked foraminifera and carbonate mudstones set in a coarse sparry calcite cement which shows evidence of growth above the water table (vadose zone). Further deposits of carbonate mudstone cap this conglomerate unit, which at Clintz 'B' are overlain by a thin brown laminar calcrete unit, indicating further pedogenic carbonate growth within the floodplain and development of a soil hardpan at the top.

The succession in Moota Quarry is different as it displays a thin unit of coarsening-up silty sandstone with abundant grey clay-grade material resembling the floodplain silty claystones at the same horizon in the Clintz area. This small package is interpreted as representing deposits of a lake margin delta formed within the floodplain. The nature of this deposit suggests that it may be equivalent to the floodplain silty claystone deposits at Clintz, and their is no expression of the carbonate conglomerate channel-fill event. These clastic deposits at Moota are overlain by a thin brown laminar calcrete, which

represents soil hardpan development following delta abandonment and/or filling of the lake.

Cycle W3

Deposits of this cycle are thin in the Clintz area but thicken towards Moota Quarry, where the top of the cycle is not exposed, but the cycle is observed to be subdivided by a minor deepening event. Only the lower portion of the cycle is preserved in Clintz borehole 3 where the cycle consists of macrofossil-poor grainstones, which pass northwards into a package of burrow-mottled wackestones grading up into macrofossil-poor grainstones in Moota Quarry. This package is overlain by a minor deepening event with further burrow-mottled wackestones and packstones above at the top of the quarry. The cycle is capped in Clintz borehole 3 by 30cm of silty claystone with pebbles of reworked grainstone, overlying an erosive surface with a marked angular discordance to the bedding orientation in the core. These floodplain deposits are interpreted to have also formed above the uppermost beds (no longer exposed) in Moota Quarry and to have cut down through the upper part of this cycle to only preserve the lowest 60cm of grainstones in Clintz borehole 3.

Cycle W4

This cycle is only known from Clintz borehole 3 where it consists of a package of partially dolomitised macrofossil-poor grainstones overlain by a thin deposit of carbonate mudstone and silty claystone indicative of pedogenic carbonate formation and subsequent floodplain sedimentation following a fall in relative sea-level.

Cycle W5

This cycle, which is also only recorded in Clintz borehole 3, marks a major change in depositional style in the platform margin area, with a return to deposits of the deep subtidal Argillaceous Facies Group. The cycle commences with homogeneous

wackestones and passes up into rubbly stylonodular deposits with a rich macrofauna. A minor deepening event occurs above this, with deposits of the dark facies passing up into further rubbly stylonodular wackestones. This argillaceous carbonate package is directly overlain at the top of the cored section by a thin claystone unit, demonstrating a substantial fall in relative sea-level.

Cycle W6

Whilst the lowest beds of this cycle are nowhere seen, it is envisaged that the base cannot be far below the base of the exposure in Clintz 'C' Quarry, which is the only recorded exposure of the remainder of this cycle. The succession begins with thickly bedded macrofossil-poor grainstones punctuated by a minor palaeokarstic surface with prominent spar-filled rhizocretions beneath. This surface is seen as being autocyclic within the system, occurring through the localised buildup of the barrier sand unit above sea level. The thick grainstone package is gradationally overlain by nearly 2 metres of dark porcellanous wackestones indicative of deposition within a lagoonal setting. The cycle top deposits overlying this progradational package are varied and begin with a thin bed of grey laminar calcrete rich in black carbonaceous rootlet material. This is overlain by pockets of claystone underlying a thin coal. A non-fossiliferous coaly shale overlies this, which passes up into a thick package of floodplain silty claystones cut through by a laterally extensive 50cm thick channel sandstone unit displaying well developed point bar accretion units. The shape of this channel unit may indicate deposition within a braided fluvial regime. The unit is capped by a 25cm coal, the thickest development seen in the pre-Brigantian succession of this area.

Cycle W7

The final cycle of the White Limestone is also only known from Clintz 'C' Quarry in the platform margin area, where it begins with a thin unit of black shale full of articulated Productid brachiopods in life position, marking transgression at the base of the cycle. Carbonate deposition is represented by a 70cm basal unit of homogeneous

wackestones sharply overlain by a thick bed of macrofossil-poor grainstone. This juxtaposition of vastly different facies types is inferred to have come about through a sudden drop in relative sea-level (forced regression) which resulted in development of the much shallower water grainstone facies directly on top of the offshore argillaceous homogeneous carbonates. The cycle is capped by a thick development of pedogenic amalgamated nodular carbonate, floodplain silty claystones and a thin coal, marking the end of White Limestone Member deposition.

Evolution Of The Northern Lake District High

Figures 6 to 9 show a representative set of schematic palaeoenvironmental reconstructions for the White Limestone Member during various stages of relative sea-level.

Based upon the above descriptions of the palaeoenvironmental evolution of the White Limestone Member depositional system in the platform interior and platform margin settings, it can be seen that broadly similar patterns operate in both areas. The White Limestone Member is composed of seven cycles, only the lowest of which is not developed across the whole area. These seven cycles form the building blocks of two larger scale depositional units, here termed 'megacycles', the lower megacycle comprising cycles W1 to W4, and the upper megacycle comprising cycles W5 to W7.

The boundary between these two megacycles is prominent, but has a different expression in the two areas. In the platform interior, this boundary marks a change in the progradation direction of the depositional systems with apparent southerly progradation in the lower megacycle changing to apparent northerly progradation in the upper megacycle. The boundary is marked in the platform margin area by a major deepening event, with the lower megacycle showing a progradational trend with component cycles (W1 to W4) showing successively shallower water facies. Trends in the upper megacycle are less clear, but the return to deeper water subtidal argillaceous carbonate deposition at the base of the upper megacycle (cycle W5)

is clearly an important event above the shallowing trend in the underlying megacycle.

In order to understand the depositional history of the area, it is important to consider the controls operating upon sedimentary systems. Much debate exists over the controls of Asbian carbonate deposition in north-west Britain. Ramsbottom (1973, 1979) interpreted Dinantian sedimentation in terms of eustatic fluctuations, whilst Johnson (1992) attributed Dinantian cyclicity in west Cumbria to tectonic oscillations of the Lake District Dome, and Horbury (1987, 1989) described the Asbian-age Urswick Limestone from south Cumbria in terms of high frequency eustatic variation superimposed upon lower frequency pulsed tectonic subsidence.

The cyclicity within the White Limestone Member operates on three different levels, which are attributed primarily to three different controls. The highest order cyclicity is mostly masked by the two lower order scales but is likely to be controlled by the main factor driving the depositional systems: sediment supply. It is this factor which controls the development of normal progradation and commonly results in the vertical stacking of successively shallower water deposits. This style of cyclicity is evident where shallow-water grainstone units build up above sea-level and become karstified with an overlying palaeosol development, which results in a localised subaerial deposit and overlying flooding surface with no potential for correlation (e.g. cycle W4 at Kelton Quarry).

The next order of cyclicity within the White Limestone is at the 'cycle' scale and is responsible for regionally correlatable cycles, which may be internally divided by flooding events of regional extent (e.g. cycle W5). Due to the regional nature of these cycles, their controlling factor is interpreted to be extrinsic to the depositional system. Major falls in relative sea-level were necessary to form many of the cycle top clastic deposits which overlie palaeokarstic surfaces, which may even form on sub-wavebase argillaceous carbonate deposits and therefore could not have formed through normal progradation. The similar style of facies stacking patterns in both the platform interior and margin locations, coupled with the similar styles

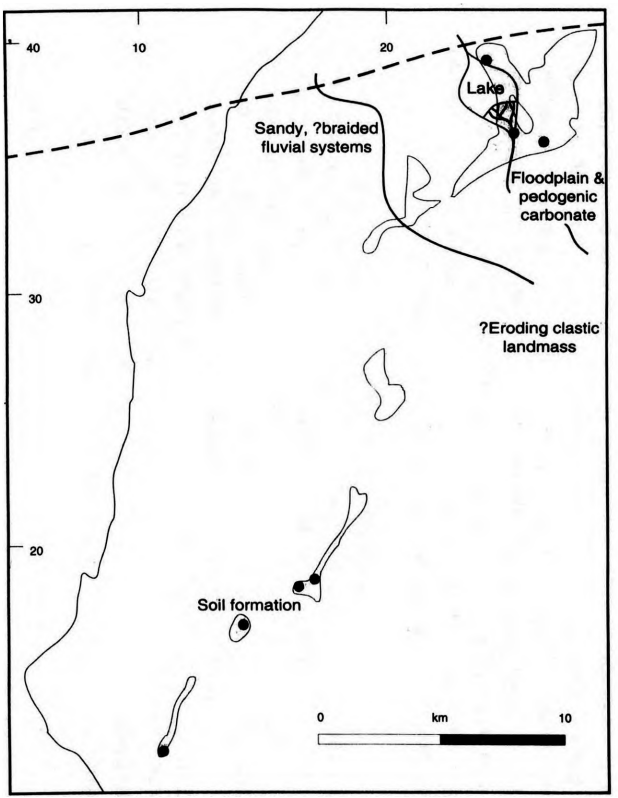


FIGURE 6. Schematic palaeoenvironmental reconstruction of the White Limestone Member during periods of low relative sea-level.

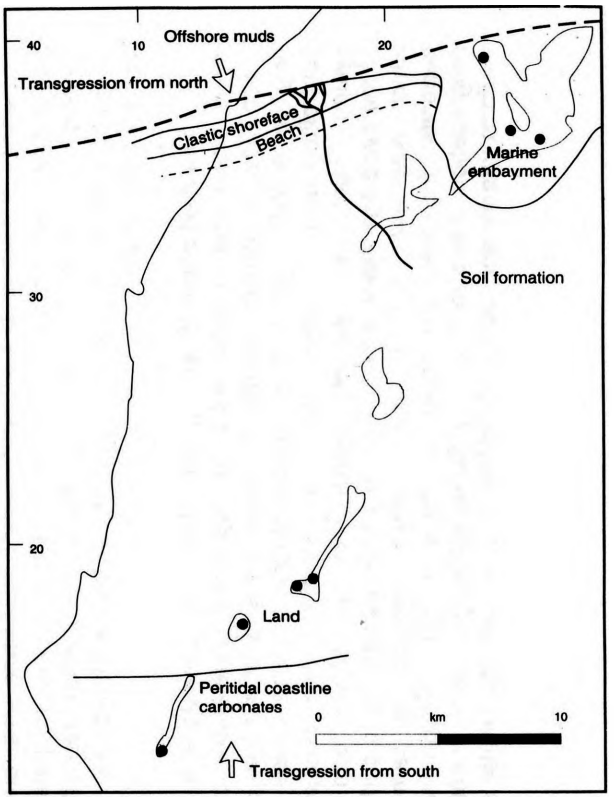


FIGURE 7. Schematic palaeoenvironmental reconstruction of the 'lower' White Limestone Member during transgression

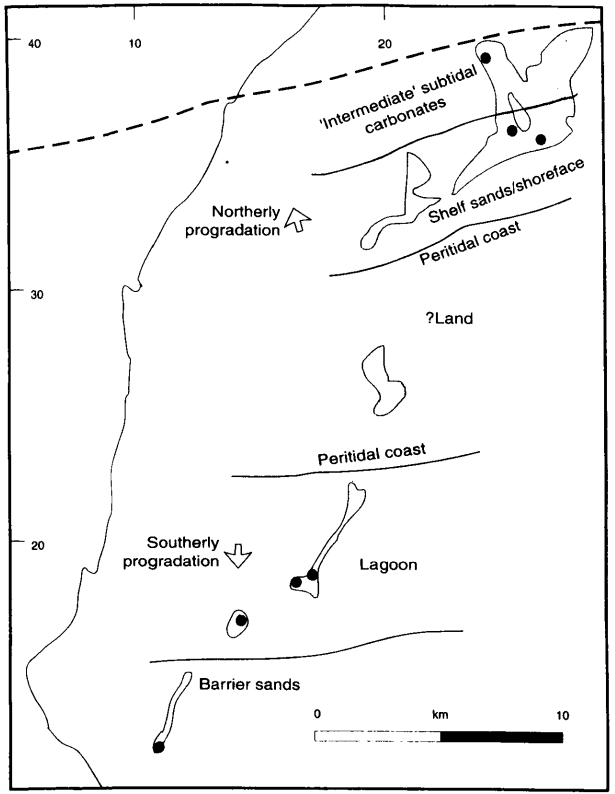


FIGURE 8. Schematic palaeoenvironmental reconstruction of the 'lower' White Limestone Member during periods of relatively high sea level.

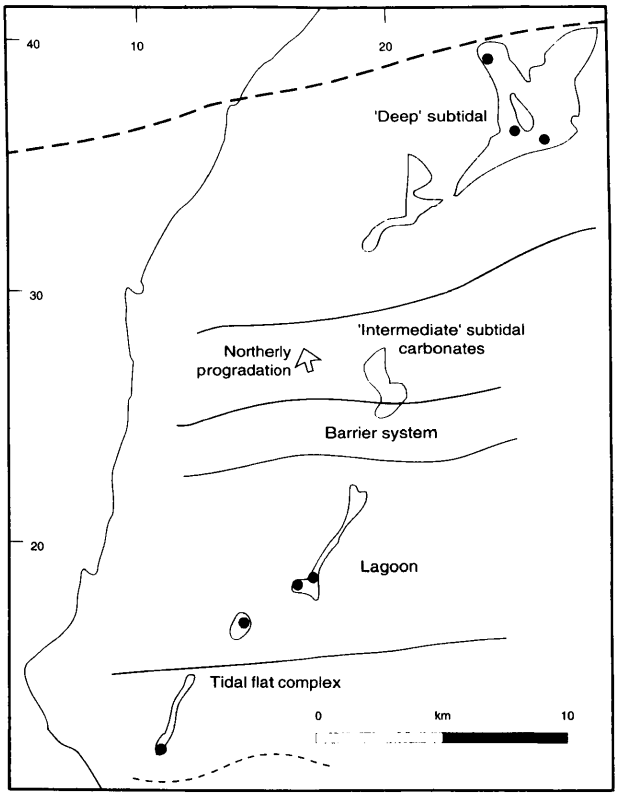


FIGURE 9. Schematic palaeoenvironmental reconstruction of the 'upper' White Limestone Member during periods of relatively high sea level.

of sedimentary cycles developed on other structural blocks of northern Britain during the Asbian (e.g. Derbyshire Platform, Walkden, 1974; North Wales Shelf, Somerville, 1979a, 1979b) suggests that a eustatic cause is likely to drive these cycles. Some tectonic influence may also contribute to cycle development: cycle W1 shows greater internal partitioning and thicker development near the platform margin compared with the platform interior, which may be due to either earlier transgression near the platform margin and non-sequence in the interior or increased tectonic subsidence at the margin together with minor footwall oscillations resulting in deepening events.

The 'megacycles' form the lowest frequency cycles of the White Limestone, and their order of magnitude and regional extent suggest an extrinsic control. The boundary between the two megacycles corresponds with a major deepening event near the platform margin which is not seen in the platform interior, but corresponds with a change in progradation direction, interpreted to have been brought about by a significant change in regional palaeoslope. These factors suggest a tectonic control of megacycle development with major movement along the warped platform margin (Maryport-Gilcrux Fault) resulting in an increase in the water depth and subsequent facies development behind the margin and tilting in the platform interior to produce an approximately north-facing ramp system during the early part of the second megacycle (upper White Limestone Member).

The tectonostratigraphic development of the region is summarised in Figure 10, which illustrates the bi-directional progradational nature of the depositional system during the lower White Limestone Member megacycle away from a central 'high' area. Onset of warped subsidence at the northern platform margin prior to deposition of the upper megacycle, caused tilting of the platform and resulted in the ramp-like geometry expressed in cycle W5 and the unidirectional (northward) progradational nature of the depositional system during the upper megacycle.

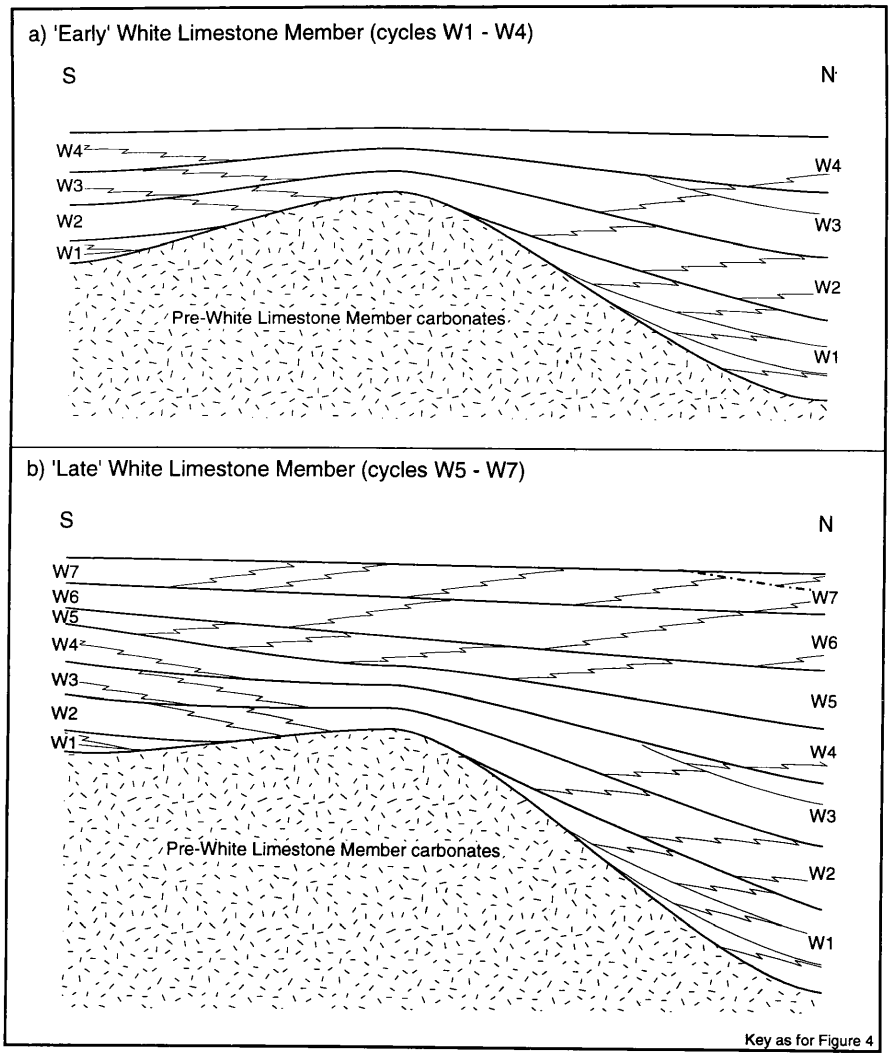


FIGURE 10. Cartoon tectonostratigraphic development of the White Limestone Member in northwest Cumbria. In the 'early' White Limestone (cycles W1 to W4), depositional systems prograded north and south away from a central 'high' area. Movement on the northerly margin fault system resulted in a major deepening event in the north and a change in the regional palaeoslope direction in the platform interior which resulted in a single northerly prograding depositional system in the 'upper' White Limestone (cycles W5 to W7).

Summary

The White Limestone Member of north-west Cumbria represents mixed carbonate-clastic deposition within a shallow-water platform setting. A prominent cyclicity is defined by laterally persistent clastic deposits which are generally deposited during times of subaerial exposure with altered volcanic airfall palaeosols, floodplain silts, channel sandbodies, coals and possible lake margin deltaics, but transgressive embayment muds are also recorded. Cycles are regionally correlatable and may be subdivided by both regional and local scale deepening events. The seven cycles stack to form two megacycles of tectonic origin.

Transgression and onlap of the pre-White Limestone depositional surface occurred from both the north and south with the establishment of sub-wavebase carbonate deposits in both platform interior and margin locations. Cycle W1 is thicker and consists of a greater number of internal flooding events near the platform margin and therefore may record slightly earlier transgression in this area compared to the platform interior, or alternatively may show an element of tectonic control upon cycle development in this area. Cycles W2 to W4 display increasingly shallower water deposits which prograded southwards in the platform interior and northwards (basinwards) near the margin, and indicate the generally progradational nature of this lower, ?post-rift megacycle.

Warped subsidence at the basin margin resulted in a dramatic localised deepening event which resulted in a return to argillaceous sub-wavebase carbonate deposition at the base of the upper megacycle near the platform margin. Tilting, caused by this tectonic event, altered the regional palaeoslope in the platform interior and resulted in a switch in progradation direction to northwards and led to the establishment of a ramp-like geometry to the depositional system during cycle W5. The two remaining cycles of this syn-rift megacycle display a return to shallower-water carbonate deposition across the platform with cycle top clastic deposits near the margin conspicuous by the occurrence of coal horizons.

CLASTIC FACIES			
FACIES GROUP	FACIES / FACIES ASSOCIATION	DESCRIPTION	ENVIRONMENTAL INTERPRETATION
Claystone	Claystone	Claystone with blocky fracture & polished slickensided fracture surfaces. Colour usually red or green. Occasional sinuous carbonised rootlets. Often overlie irregular, rubbly, tops of limestone beds. XRD analysis indicates mineralogy of illite, mixed illite-smectite and anatase with accessory kaolinite, quartz, calcite, apatite and pyrite. Expandable layer content between 15 and 22%.	Subaerial accumulation and pedogenic alteration of ?wind-derived volcanic material.
	Silty Claystone	Dull claystones with high silt & very fine sand content. Colour usually grey-green. Often overlie irregular limestone surfaces with nodular/laminar tops. Occasional rootlets. XRD analysis indicates mineralogy of illite, mixed illite-smectite, kaolinite, quartz and anatase with accessory gypsum, pyrite, calcite and apatite. Expandable layer content of 10-20%.	Floodplain palaeosol development with some component of wind-derived material.
	Laminated Claystone	Fissile grey-green claystone with intact delicate brachipod fauna. Contain angular clasts of reworked carbonate. XRD analysis indicates a mineralogy of illite, mixed illite-smectite and anatase. Expandable layer content between 10 and 15%.	Marine deposition of reworked palaeosol material in low energy setting - ?Marine embayment.
	Black Shale	Thin, fissile, black to charcoal grey shales with abundant marine fauna including Productid brachiopods. Often overlie palaeosol units prior to carbonate depostion.	Low energy marine: sub-wavebase. Offshore to 'middle shelf' prior to onset of carbonate production.
Sandstone	Coarsening-up Silty-Sandstone	Structureless thin deposit of grey clay-rich siltstone passing up into very fine-grained orange-coloured sandstone.	?Lake margin delta with sediment reworked from surrounding floodplain.
	Channel Sandstone	Fine to medium-grained well-sorted mature sandstone with epsilon cross-bedding defined by silty laminae. Thin deposit, laterally extensive at outcrop scale occurring within silty claystone facies.	Channel Sandstone. Epsilon cross-bedding dur to point bar migration in sinuous channel. Lateral thin shape may suggest braided system.
	Conglomerate	Granule-grade reworked marine and pedogenic carbonate clasts within a sparry calcite cement showing evidence of growth within the vadose zone.	Non-marine (?fluvial) redeposition of karstified and pedogenic carbonate.
	Coal	Low density with black shiny lustre and occasional partially preserved plant fragments. Overlie silty claystones, and in turn are overlain by thin black shales.	Floodplain marsh.

TABLE 1. Summary facies description and interpretation of clastic deposits within the White Limestone Member.

CARBONATE FACIES			
FACIES GROUP	FACIES / FACIES ASSOCIATION	DESCRIPTION	ENVIRONMENTAL INTERPRETATION
Argillaceous	Dark	Dark grey wackestones with planar to wavey argillaceous partings and subparallel alignment of platey bioclasts. Rich, low diversity faunal assemblage.	Clastic-influenced 'deep' marine carbonate environment, ?restricted.
	Homogeneous	Dark to medium grey argillaceous wacke/packstones with very rich, diverse faunal assemblage, especially corals. Absence of sedimentary structures.	Clastic-influenced 'deep' marine carbonate environment.
	Rubbly Stylonodular	Dark to medium grey wackestone to packstone with nodular appearance formed due to abundant pressure solution seams. Moderately diverse macrofaunal content.	Clastic-influenced 'deep' marine, may be shallowest deposit of Facies Gp.
Transitional	Porcellanous	Pale cream-coloured wackestones, porcellanous appearance & conchoidal fracture. Generally low macrofaunal content.	Lagoonal, and in lee of minor carbonate sand bodies.
	Crinoid-Rich Packstone	Generally medium grey packstone with a rich, diverse macrofauna, dominated by comminuted grey or brown crinoid fragments.	Marine deposition at or around wave base - 'intermediate' subtidal
	Burrow-Mottled	Medium grey wackestones to packstones with prominent darker grey burrow-fills of Thalassinoides displaying early cementation fabrics.	Omission colonisation of sub-wave base carbonates due to hiatus.
	Dark Porcellanous Wackestone	Dark grey wackestones, porcellanous lustre & conchoidal fracture. Fauna of molluscan fragments & dasycladacean algae	Back-barrier lagoon.
Grainstone	Macrofossil-Poor Grainstone	Massive pale grainstones, generally structureless, composed of abraded bioclasts, peloids and lithoclasts. Low diversity, scarce, macrofauna.	Subtidal carbonate sandbody formed above wave-base.
	Macrofossil-Rich Grainstone	Massive pale grainstones, generally structureless, composed of abraded bioclasts, peloids and lithoclasts. Rich, diverse macrofauna, includes in situ & reworked corals.	Carbonate sandbody formed above wave-base.
	Coated Grain Grainstone	Massive pale grainstones, generally structureless, composed of peloids & lithoclasts with abraded bioclasts and subordinate coated grains, low macrofaunal content.	Carbonate sandbody formed above wave-base. Most distal grainstone?
Mudstone	Grey Laminar Calcrete	Pale grey carbonate mudstone with sub-cm scale, sub-parallel, disrupted colour banding. Absence of fossils, occasional sparry fenestrae.	Soil hardpan - formed in areas of low rates of groundwater flow?
	Brown Laminar Calcrete	Pale brown carbonate mudstone with mm-scale crinkled colour bands. Occasional fenestrae, no macrofauna.	Soil hardpan - formed in areas of high rates of groundwater flow?
	Fenestral Carbonate Mudstone	Pale grey carbonate mudstone with abundant fenestrae and occasional sub-cm scale slightly crinkled sub-parallel colour banding.	Peritidal deposit - carbonate mudflat.
	Amalgamated Nodular Mudstone	Pale grey carbonate mudstone composed of mm to cm-scale coelesced nodules. Abundant sparry calcite-filled fenestrae, often with associated pyrite.	Nodular calcrete - formed within well-drained soil profile.
	Dolostone	Pale grey to rusty brown carbonate consisting of coarse dolomite crystals.	Diagenetic alteration of limestone.

TABLE 2. Summary facies description and interpretation of carbonate deposits within the White Limestone Member.

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Acknowledgements

This paper summarises a small portion of the research undertaken by the author into sedimentary style of the Carboniferous Limestone Group of north-west Cumbria, whilst at the University of Manchester. Dr. A. E. Adams is thanked for his supervision of this project, which was funded by a NERC studentship. I am grateful to all the various landowners for permission to visit sections, especially Hargreaves Quarries (Moota), Dave Hopkins of Bardon Roadstone for Clintz Quarries and boreholes and Martin Whitehead at Enterprise Oil for access to the composite log for Westnewton - 1. Eric Skipsey is also thanked for his comments on an earlier version of this manuscript.

Andrew Thurlow

[redacted]

CUMBRIA RIGS GROUP

Mervyn Dodd

Eric Skipsey spoke persuasively at our 1992 AGM of the need for a Cumbria RIGS group (RIGS is an acronym for Regionally Important Geological/Geomorphological sites, a proposed national network being developed by local voluntary organisations co-ordinated by English Nature). At the time Regionally Important Geological Sites which did not satisfy the research criteria for SSSI (Sites of Special Scientific Interest) status were not safeguarded in any way. This article is a progress report, written in late 1995 on what Cumbria RIGS has done, and outlining what may yet be done. Opinions expressed are my own.

Cumbria RIGS has been active since mid 1992. In the county its aims and methods have evolved to meet the local situation, varying significantly from the anticipated national pattern, seemingly more appropriate for Southern and Eastern England.

We have found fewer sites at risk of loss from commercial development, landfill etc., than expected, and have been able to find alternative sites to replace those at risk. A site alongside the Kidburngill Opencast site in West Cumbria is a good illustration. New developments can make additional sites available as at Banks Gate, near Stainmore on the A66. In this respect geologists have fewer problems than wildlife groups.

We started from the guidelines recommended for RIGS groups (Wilson, 1994) to assess our local geological heritage. These suggested groups of enthusiasts should accept responsibility for stocktaking, evaluating and recommending sites within 10km grid squares. This quickly proved unworkable within Cumbria, a large rural county with limited manpower.

The CGS was responsible for recommending sites in National Grid Squares NX & NY within Cumbria, an extensive area with a wide range of exposures of Palaeozoic and Mesozoic rocks and a great variety of landforms. Similarly the Westmorland Geological Society identified sites in the SD Grid Square in the south of the county. As Cumbria is an area of diffuse, often sparse, settlement with the main towns on the periphery we found ourselves relying on the enthusiasm of individuals:- members of local and national geological societies, professionals from the BGS and universities and interested country lovers. Rather than stocktaking and then recommending sites we found ourselves doing both at the same time!

'Quality control' therefore has proved essential. Any site proposals submitted have been assessed by a Site Selection Committee comprising volunteers from the local geological societies and professional officers from English Nature, Cumbria Wildlife Trust and Cumbria County Council. This committee has met 4 or 5 times a year. Sites approved are then registered with the planning authorities. In the past 3 years the RIGS group has been consulted on planning applications from Askam-in-Furness to Aspatria and from Parton to Stainmore, particularly where highways improvements, quarrying and mining extensions are being considered.

So far just over 200 sites have been proposed in Squares NX and NY. As co-ordinator for these squares I have enjoyed visiting proposed sites I might not have seen otherwise. Work on SD grid square was co-ordinated initially by Russell Smith and more recently by Jean Slee-Smith, both members of the WGS. To date they have investigated rather more than 100 proposed sites. Many of these sites in squares NX, NY and SD will be 'for the record', and are likely to be visited only occasionally, usually by professionals or research students.

Well over 200 sites in Cumbria have been approved and registered with the County Planning Authority to date. Recent excursions by geological societies, national and local, have generated a steady flow of possible new sites. I envisage a trickle of Site

Proposals in the future as we have probably selected almost all of the best sites, apart from landforms and several type sections in the Windermere Supergroup rocks south of Dunmail Raise. So far landforms have proved a problem. Few of us volunteers have sufficient expertise in this discipline and the large extent of these features causes problems of definition with resulting difficulties in the planning field. Some parts of Cumbria have been less thoroughly considered than they should , the Pennine fringe and the Furness area in particular.

As local "County Rigs groups" work independently there are no obligatory national or regional meetings to co-ordinate procedures and discuss progress. So we feel the time we volunteer is spent productively, rather than spent in large, unwieldy gatherings. However there is a downside to 'doing our own thing'. Individual RIGS groups have taken very different approaches, one concentrating to a considerable extent on conserving and interpreting a particularly important site, another preferring to designate a relatively small number of outstanding sites. As Cumbria RIGS manpower and financial resources are limited we have consciously decided not to involve ourselves in providing expensive interpretation boards and time consuming conservation measures, as we lack the relevant skills. Members of other RIGS groups have attended some of our meetings, providing stimulating, informal contacts. Regional evening meetings of RIGS groups' representatives (Carson, 1995) have taken place twice in Liverpool, not the most convenient venue for us. After being represented at the first meeting, we did not attend the second having weighed the costs of travel and overnight accommodation against the benefit.

You may say, all very well, but who knows about these sites and what about the attitudes of landowners and tenants. True, these are problems we are tackling, but so far we have met sympathy and appreciation, rather than hostility.

We appreciate we have a duty to contact the owners and tenants of all RIGS sites after they have been approved. This is proving to be a long, time-consuming and on-going job. As far as possible, individual volunteers provide such information about their local areas. We have discovered there are old mines and old quarries which make good RIGS sites, which nobody admits to owning! Easy access to the open fells is something we all appreciate, but this makes it difficult to find out who owns the land and which farmers have common grazing rights as tenants. A part time temporary appointment for one day a week for 6 months was made with one of the specific tasks to identify and contact landowners and tenants. Another such appointment was made late in 1995.

A previous survey of likely geological sites within the Lake District National Park was made in the early 1980's, but was never made easily accessible to those interested. We are making sure a similar situation will not recur. Copies of our Site Proposal Forms are held at Tullie House Museum, Carlisle, and at the Cumbria Wildlife Trust offices in Ambleside. Summaries are on disc at both centres. Tullie House will provide one sheet summaries for individual sites, free of charge for educational groups and at an agreed rate for commercial users. The question of which computer software format should be used has proved a problem as our supporting organisations use different systems appropriate for their specific needs.

A software system for the summaries was chosen at the November 1995 half yearly meeting of our overall Management Committee. This is a large group at which a wide range of interested organisations are represented, which gives it considerable authority and stature. These include the County Council Planning Department, local universities, the Lake District Special Planning Board, the National Trust, North West Water Authority, the Country Landowners' Association, the Institute of Quarrying, as well as organisations involved almost on a day to day basis. It oversees our progress. Eric Skipsey, as Chairman, and Toby Butler as Treasurer, report twice yearly on the Group's activities and financial situation. This Management Committee has been consistently supportive of our initiative. Audrey Brown of the WGS is the Secretary of both the

Cumbria RIGS committees. With clerical help from English Nature she sees our organisation runs smoothly and efficiently, a much appreciated achievement.

We are very aware of our need to make the general country loving public aware of their geological heritage. Most of you already have your own copy of Eric Skipsey's RIGS booklet 'Geological Excursions in the Eden Valley', and will appreciate how it arouses the interest of the lively, curious country lover. Less than 200 of the print run of 1000 have yet to be sold. A similar leaflet about the Keswick area written by Alan Smith is scheduled to be published in early summer 1996. Another leaflet is being prepared by Barrie Webb, formerly of the BGS, about the Alston area.

All these activities cost money. So far we have been fortunate in receiving contributions towards our running costs from Cumbria County Council, finance and clerical support from English Nature and support from other organisations for specific projects. Thus the Curry Fund, administered by the Geologist's Association and the East Cumbria Countryside Project, under the aegis of Eden District Council covered the cost of Eric Skipsey's booklet. We gratefully appreciate and acknowledge all such help, not all of which can be acknowledged in this short article. Consequently all the proceeds from the sales of Eric's booklet are available to finance further booklets. Other costs we have met include the financing (shared with Engiish Nature) of the part time appointments, of putting of site details on disc and our own expenditure on RIGS business. Fund raising has been an ongoing task for Eric Skipsey, who in particular has worked as a dedicated volunteer long and hard on RIGS business, a commitment all of us appreciate.

Where does Cumbria RIGS go from here? I envisage 3 continuing threads. Identification and notification of additional sites will be a minor aspect. Development and amplification of contacts with landowners and tenants quietly behind the scenes will be one major thread. Making local RIGS/SSSI geological site information available to responsible, interested groups and the general public will be the other main thread. There is much yet to be done.

Acknowledgements

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BOOK REVIEW

THE STRUCTURE AND EVOLUTION OF THE NORTHUMBERLAND-SOLWAY BASIN AND ADJACENT AREAS - A NEW BGS. MEMOIR

(ISBN 0 11 884501 2 by R. A. Chadwick, D. W. Holliday, S. Holloway and A. G. Hulbert. H.M.S.O., London 1995, price £30)

A review by E. Skipsey

Publication of the new BGS Memoir marks an important development in our understanding of the geology of Cumbria and surrounding districts. The surface and near-surface geology of the region has been described in many earlier BGS. 1:50,00 maps and memoirs. This account breaks new ground as it is essentially regional in approach, dealing with the deeper, concealed parts of the Carboniferous succession and basins and the associated structures which have not been considered previously. The book presents in an atlas format a concise review of the tectonic and sedimentary history of the Carboniferous rocks of the Northumberland Trough, the Solway Basin (largely beneath Permo-Triassic cover) and adjacent areas, including the Lake District and Alston Blocks, the Vale of Eden and the northern part of the Stainmore Trough.

Introduction

During the exploration of northern England for oil and gas in the 1980's, numerous seismic reflection surveys were carried out. The Memoir relies heavily on the interpretation of the seismic surveys and provides much new information released by oil companies that has not been available outside the technical press. In this account such data has been integrated with geological information to produce a series of structure-contour and preserved-thickness maps, at a scale of 1:625,000. The maps illustrate the evolution and present-day structure of the Northumberland-Solway Basin and adjacent areas and are accompanied by a short descriptive text and a set of

palaeogeographic maps, which together provide a review of basin evolution.

Good quality seismic data have been acquired in many parts where Carboniferous rocks are exposed at the surface or occur beneath a thin drift cover. In such areas the entire Upper Palaeozoic basin fill is generally imaged by seismic methods. However data commonly deteriorates in areas where Permo-Triassic rocks crop out and also in areas of thick drift. Stratigraphic calibration of the seismic data is provided by the scatter of deep boreholes over the region. These are augmented by surface exposures, except in the centre of the Solway Basin, which has an extensive cover of younger, Permo-Triassic rocks forming the Carlisle Basin. The very thick Early Carboniferous deposits which form the deeper part of the Lower Border Group in the Northumberland- Solway Basin and their equivalents in the Stainmore Trough are neither penetrated by boreholes nor are satisfactorily exposed at the surface, resulting in less reliable interpretations. One valuable item in the Memoir is the summary of Carboniferous stratigraphy of the region which draws together the differing correlations and terminology used previously for various districts in the region.

Outline of the geological history

The Memoir provides a useful account of current understanding of the evolution of the region and a synopsis is given here.

The Lower Palaeozoic and Early Devonian rocks of northern England and southern Scotland, which comprise the basement of the Carboniferous basins, provide evidence of the closure of a major ocean. The Iapetus Ocean closed as a result of subduction and the subsequent collision of the palaeo-North American (Laurentian) and palaeo-European (Avalonian) continents. This region of complex structure, termed the Iapetus Convergence Zone, formed during late Silurian and Early Devonian times, has been identified by deep seismic exploration to lie beneath the Northumberland-Solway Basin belt. Crustal thickening at this time led to a major phase of granite -

batholith intrusion that underlies the principal blocks of the region. Subsequently throughout much of Devonian times, the region formed part of the Old Red Sandstone continent and was dominantly an area of erosion.

A period of crustal extension became widespread in early Dinantian times. The Maryport-Stublick-Ninety Fathom fault system which forms the southern margin of the Northumberland-Solway Basin, is the main structure controlling sedimentation in the basin. This and other large synsedimentary faults appear to be inherited from reactivated, pre-existing basement structures with many orientated in a generally east-north-east direction. The areas forming structural highs during Early Carboniferous times - the Lake District, Alston and Cheviot blocks together with the Southern Uplands - contain large, rigid, low density granitic intrusions in the pre-Carboniferous basement.

Early synextensional ('rift') strata, of Courceyan to Chadian age, are largely restricted to the fault-bounded basinal areas with main depocentres adjacent to the Maryport-Stublick-Ninety Fathom and the Closehouse-Lunedale-Butterknowle fault systems. Adjacent block areas received little sedimentary cover during this time. Younger synextensional rocks, of Arundian to Holkerian age, gradually spread more widely as the extensional phase gave way in post-Holkerian times to a period of thermal relaxation subsidence and sedimentation which was characterised by limited normal faulting.

Crustal compression or dextral transpression during the Variscan Orogeny, led to uplift and basin inversion, which terminated sedimentation in Late Westphalian times, and the region once more became an area of widespread erosion. The maximum depositional thickness of strata in the basins is difficult to estimate because of the subsequent erosion of much of the Upper Carboniferous sequence. Up to about 5000m of Dinantian and 1000 - 2000m (compacted thicknesses) of Silesian strata are likely to have been deposited in the major depocentres.

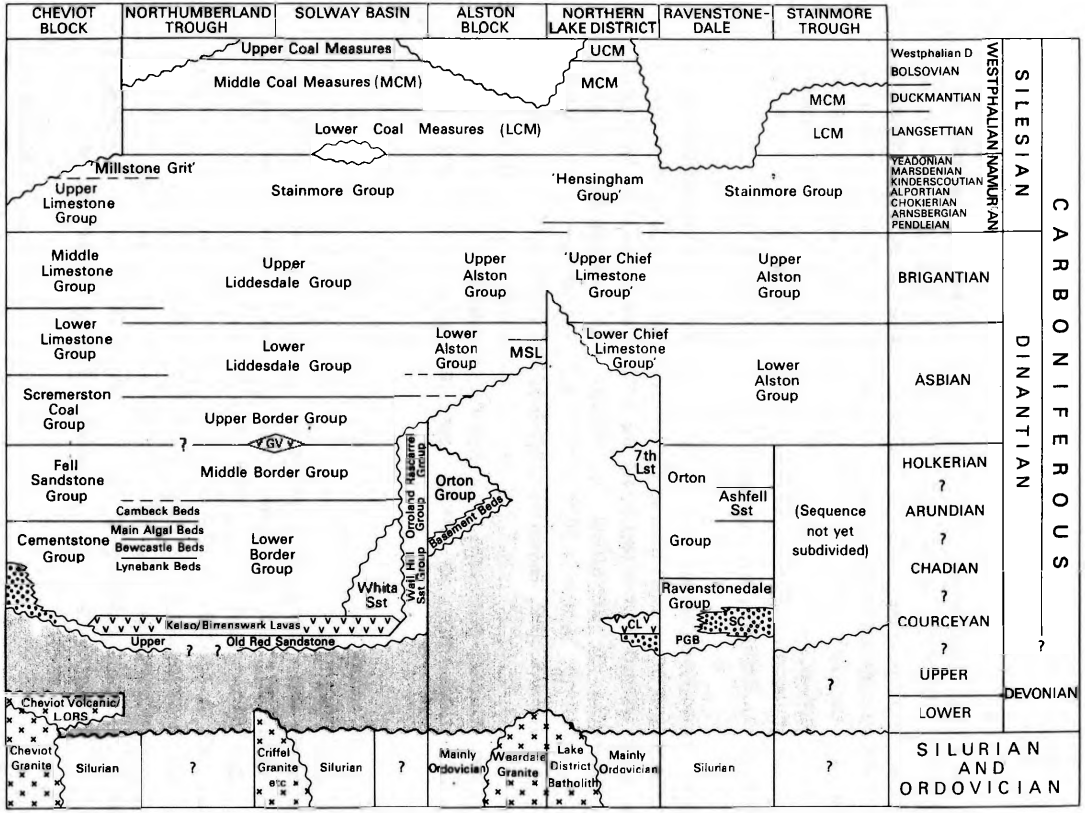


Figure 1. Summary of the Carboniferous Stratigraphy of the Region, (from Figure 5 of the Memoir)

(CL Cockermouth Lavas, GV Glencartholme Volcanics, MSL Melmerby Scar Limestone, PGB Pinskey Gill Beds, SC Shap Conglomerate)

Following the Variscan Orogeny, erosion stripped away much of the Silesian cover of the region. In Permian times, sedimentation re-commenced in the Vale of Eden and more locally in the Carlisle basin area. Sedimentation became more widespread in late Permian, Triassic and early Jurassic times and probably eventually covered the whole region. Later Mesozoic structural and sedimentary history is not clear. It is probable that a cover of Late Cretaceous Chalk may have existed but the former presence of other formations is uncertain. The region underwent widespread uplift and erosion in Cenozoic times, when most of the post-Carboniferous cover was removed and further erosion of Carboniferous rocks took place. Over a number of structural highs, including the Lake District, Southern Uplands and parts of the Alston Block, all Carboniferous rocks have been eroded away and basement rocks crop out at the surface.

Economic geology

The detailed structural examination of the Carboniferous basins is followed by a valuable chapter considering aspects of the economic geology of the region, particularly dealing with the different aspects of energy potentials. The structural interpretations described in the Memoir have significant implications for possible coal, hydrocarbon and geothermal energy resources while the possibilities of the new energy resource, coal-bed methane, are also considered.

Conclusions

Traditional methods of geological surveying are not always-reliable indicators of subsurface structures. Nor is any one deep borehole a good indicator at what might be found at depth at other nearby localities. Seismic reflection profiling has enhanced our knowledge of structural and geological evolution in basin analysis, as described in this Memoir. This collection of structure contour, preserved-thickness and subcrop maps and associated palaeogeographic maps has greatly extended our understanding of the structural and geological evolution of Cumbria and its surrounding districts.

The Carboniferous rocks of northern England have long had great economic importance although many of the deposits are now nearing exhaustion. More recently, the region has been investigated as possible sources of oil and gas and of geothermal energy. Although the immediate exploitation of any such resources seems unlikely, this book provides an up-to-date summary and appraisal of the information obtained in these geological investigations.

E. Skipsey



ALLUVIAL FANS IN THE BUTTERMERE - CRUMMOCK WATER VALLEY : CUMBRIA.

Dr. R. A. Smith

Introduction

The Buttermere - Crummock Water valley is one of the principal glaciated troughs of the Lake District massif. Its headstreams rise on the outcrop of the Borrowdale Volcanic Group at the head of the Honister Pass and beneath the major peaks of Grey Knotts (697m) and Brandreth (715m). Along a relatively short section of the valley on its western side the igneous intrusion of the Buttermere - Ennerdale Granophyre is exposed. For the most part, however, the valley is cut into rocks of the Skiddaw Group. This is the largest and best developed glaciated trough cut into these rocks in the Lake District.

Alluvial fans are significant landscape features along the length of the valley as far north as Lorton (a distance of approximately 16 km), as well as in the major left bank Loweswater tributary valley. High-gradient tributary streams have proved capable of transporting significant quantities of debris and depositing it into the floor of the low-gradient main valley. In places fans have been built into the lakes as arcuate deltas. At other points they extend into the floor of the main valley as low angled cones from the mouths of the tributary valleys. At Buttermere village Sail Beck has produced sufficient debris to build a fan completely across the valley from one side to the other.

It is reasonable to assume that the erosional landforms of the glaciated trough and the sediments (till, sands and gravels) within it are Devensian in age. The valley was probably ice free by 13,000 BP. Sissons (1980) has mapped Loch Lomond Stadial (11,000 - 10,000 BP) glaciers in eight of the tributary valley systems but none extended into the main valley trough. Fan development could therefore have begun immediately after the valley became ice free.

The present day hydrological regime is typical of upland Lake District situations. Rainfall on the highest parts of the catchment will exceed 4000mm per year. Available records at lower levels within the valley record slightly lower levels:

		Altitude	Annual Rainfall
Fleetwith	NY 209132	422m	3670mm
Bleaberry Tarn	NY 167154	506m	2908mm
Gasgale Gill	NY 187210	604m	2535mm

(Averages for 1916-1950 from 'British Rainfall 1968' - HMSO 1974)

Runoff is likely to exceed 70% of rainfall. Little of the catchment is wooded, peat is not extensive and the slopes that are vegetated are covered with short grass, bracken or upland heath. The amplitude of relief is high (780m for the basin as a whole). In short, the capacity of upland streams to transport debris is high, provided there is a supply.

The aim of this paper is to document and describe 23 fans in the valley (Figure 1 and Table 1). It is not possible however to subject all of them to the same level of analysis. Virtually all of these features are now wholly or partly enclosed as agricultural land. Consequently, accessing places is difficult, agricultural use has led to clearance of loose material (boulders etc.) from the surface and some stream courses have been controlled to prevent flooding. Sections in the fan materials are generally poorly exposed. Further slight complications have arisen from the modifications that took place to Crummock Water early this century when the lake level was artificially controlled by the building of a low retaining wall at the northern end and a small weir at the outlet. The effects of this are that the water level is now stabilised around 1.5m higher than the natural level. As a result the lake has encroached a little on to the Sail Beck fan (7) and wave action has caused some erosion of the fan at Lanthwaite Boat House (4).

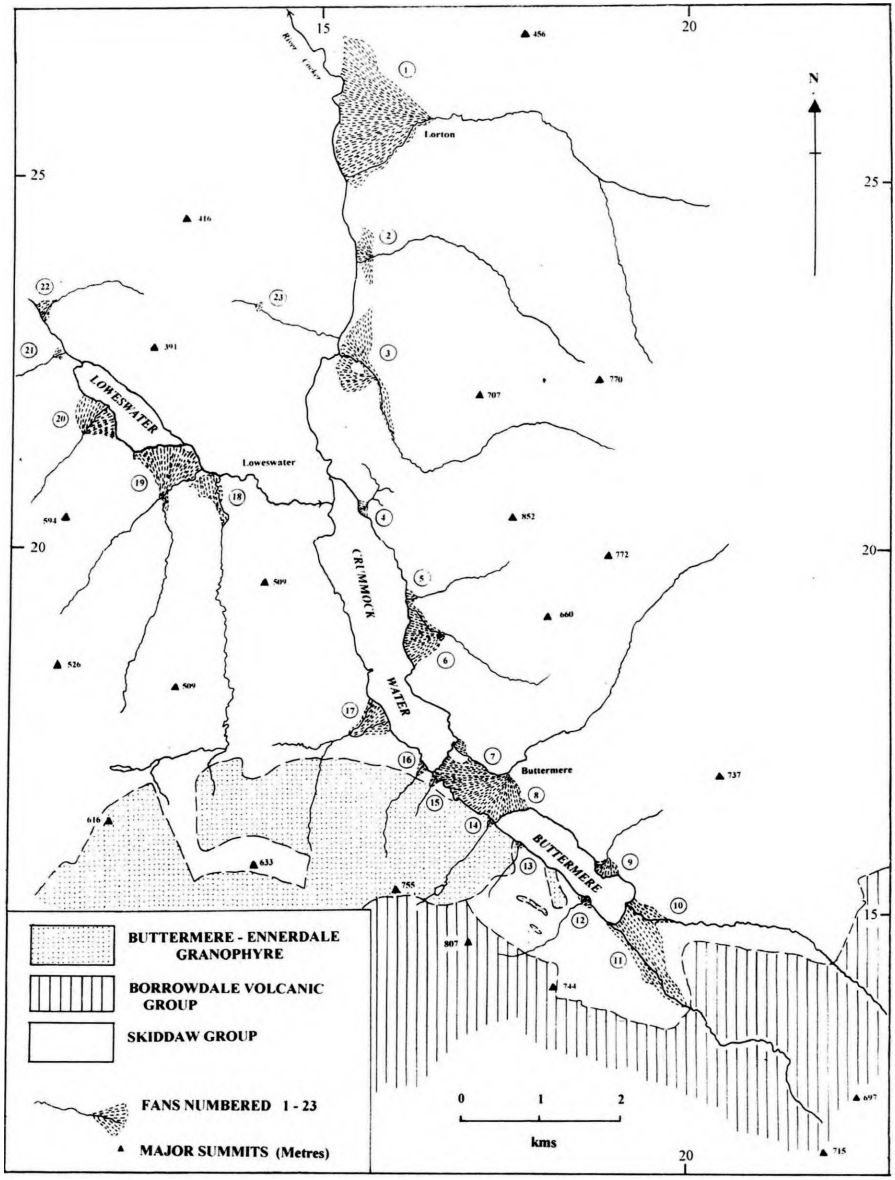

15
20
25
N
Lorton
LOWESWATER
Loweswater
CRUMMOCK
WATER
Buttermere
BUTTERMERE
456
416
391
770
707
852
772
660
594
509
526
737
616
633
755
807
744
697
715
BUTTERMERE - ENNERDALE GRANOPHYRE
BORROWDALE VOLCANIC GROUP
SKIDDAW GROUP
FANS NUMBERED 1 - 23
MAJOR SUMMITS (Metres)
0
1
2
kms

Figure 1

Fan	Grid Ref NY	Geology	Fan Area kms^2	Basin Area kms^2	M/S	M/B	A/G	MCG	AMP
1. Blaze Beck.	155255	SG-kst/Lwf/Hbf/In	1.24	15.2	1.5	-	0.12	0.079	720
2. Hope Beck	156237	SG-Hbf/Lwf	0.11	2.9	2.5	-	-	0.14	688
3. Liza Beck	155225	SG-Kst(M)/Kst/Lwf	0.30	6.2	2	-	0.22	0.14	763
4. Lanthwaite Boat Hse	156205	SG-Kst(M)	0.013	0.66	4	45.5	-	0.10	502
5. Cinderdale Beck	163193	SG-Kst(M)	0.022	0.98	2	-	-	0.24	754
6. Rannerdale Beck	164187	SG-Kst(M)	0.22	3.048	1.5	-	-	0.129	754
7 Sail Beck.	170168	SG-Buf	0.55	6.796	1	-	-	0.066	741
8. Bowder Beck	177165	SG-Buf	0.025	0.16	1	-	-	-	-
9. Hassness How Beck	187157	SG-Buf	0.042	0.96	2	34.4	-	0.29	636
10. Gatesgarthdale Beck	193152	BVG+SG-Buf	0.53	6.6	1	-	-	0.86	652
11. Warnscale Bottom	190148	BVG+SG-Buf		5.8	0.6	-	0.08	0.126	-
12. Comb Beck	185153	BVG+GR+SG(M)	0.013	1.076	4	28.2	0.42	0.26	706
13. Old Burtness	161176	BVG+GR+SG(M)	0.005	0.43	5	-	-	0.51	706
14. Sourmilk Gill	173163	GR+BVG	0.013	1.2	(15)	>100	0.31	0.327	706
15. Near Ruddy Beck	165168	GR+BVG	0.015	0.22	(15)	>75	0.38	0.387	657
16. Far Ruddy Beck	164168	GR+BVG	0.017	0.97	(15)	>75	-	0.286	657
17. Scale Beck	158177	GR+SG-Buf	0.125	2.7	3.5	-	-	0.161	535
18. Mosedale Beck	135207	SG-Kst/Kst(M)/Buf+GR	0.115	6.8	1.5	-	0.52	0.06	518
19. High Nook Beck	130210	SG-Kst/Kst(M)	0.26	5.8	1.5	-	0.46	0.073	448
20. Holme Beck	122216	SG-Lwf	0.19	1.484	4.5	43.0	-	0.18	449
21. Waterend Beck	116214	SG-Lwf	0.01	0.29	5	-	-	0.12	351
22. Whittern Gill	114230	SG-Lwf	0.05	0.5	4	-	-	0.092	261
23. Watching Gill	142231	SG-Lwf/Kst	0.01	0.11	11	-	-	0.39	225

Table 1. Analysis of alluvial fans.

Key to Table 1

Geology:	SG	Skiddaw Group
	Buf	Buttermere Formation
	Kst	Kirkstile Formation
	Lwf	Loweswater Formation
	Hbf	Hope Beck Formation
	(M)	Metamorphosed within the Crummock Water Aureole
	BVG	Borrowdale Volcanic Group
	GR	Buttermere/Ennerdale Granophyre
	In	Minor Intrusions

M/S Mean slope of the fan in degrees

M/B Mean size of the 30 largest boulders in the stream bed on the fan. (NB. Figures for fans 14/15/16 are approximations, these fans are difficult to define and the fan debris difficult to measure as discrete boulders. This parameter has not been measured on most fans as it becomes meaningless where the fan channels are controlled and periodically dredged of debris.)

A/G Percentage of the catchment glacerised in the Loch Lomond Stadial (Figures derived from Sissons 1980).

MCG Mean Channel Gradient m/m

AMP Amplitude of Relief in the catchment (Metres)

The fan area given for Gatesgarthdale Beck (0.53 km^2) is the combined area for the two fans of Gatesgarthdale Beck and Warnscale Bottom. It impossible to demarcate the two separately. Similarly the amplitude of relief is not recorded for each catchment separately.

A key problem posed by these fans relates to their age and the extent to which they are contemporary or relict features. Related to this is the possible role of periglacial processes in the Loch Lomond Stadial and also probably in the late Devensian.

Description of the Fans.

Blaze Beck, Lorton (1). This is the largest tributary catchment in the valley and the fan spread the largest in areal extent. It is a simple low angled cone that extends from the fan head at High Lorton into the valley floor where it merges imperceptibly into the flood plain of the River Cocker. The whole area is enclosed farmland and no useful sections exist. Blaze Beck is confined to the southern edge of the fan and shows some recent artificial control along its course.

Hopebeck (2). There are substantial volumes of weathered debris stored in the upper part of this system in the floor of upper Hope Gill and in small tributary valley fans. Downstream the stream trenches through glacial tills on the flanks of the main trough. A narrow , elongated fan has been built at the junction with the main stream but provides few distinguishing features or exposures.

Liza Beck (3), drains Gasgale Gill, one of the most entrenched valleys of the area and the tributary with the highest amplitude of relief of the whole catchment. It is cut along a zone of some complexity in Skiddaw Group materials of the Kirkstile Formation, with an important and complex thrust fault structure along the northern valley side. There is much bare rock exposed on both sides of the valley, considerable loose scree material and a very ready supply of slope debris being delivered into the stream bed for transport. The rocky valley mouth is unusual in that it deflects the stream northwards forcing it to carry its debris to the east of Brackenthwaite Hows. There is considerable valley infill in the section between Peel Place (NY 160 211) and Beck House (NY 158 220) but most of the fan debris has been carried out into the main valley floor building out both sides of the small rocky feature of Turner How (NY 155 223).

The relatively small fan at Lanthwaite Boat House (4) is a significant but puzzling site. It has been built as a delta into Crummock Water by an extremely small stream. Wave action, presumably enhanced by the new artificial height of the lake has led to the creation of a bluff varying between 1.5 and 2.5m high for approximately 200 metres along the southern edge of the fan. Analysis of the material exposed has revealed the following data:

- The material is clast supported angular cobbles and mixed gravels with sandy infill.

- There is no stratification. All the clasts are Skiddaw Group material, many heavily haematite stained. There are a few large clasts in excess of 50cms.

- Many of the 'flat' clasts lie horizontally.

Data from a random sample of 100 clasts (> 10mm):
Zingg Classification: %
Rods 23, Blades 37 Discs 36 Spheres 4
Krumbeins Sphericity Index 0.571
Powers Scale of Roundness:
VA 16, A 48 , SA 26 , SR 10.
Mean Powers Value 0.244 (angular)

The material is thus predominantly of an angular nature but with a few clasts showing edge rounding. The shape classification reflects the tendency for the Skiddaw rocks to produce 'flat' particles (high % of Discs and Blades). It would suggest the material has not travelled far.

Cinderdale Beck (5) is a short, steep stream which channels down the southern flank of Grassmoor and has built a proportionally small fan into the lake.

Rannerdale Beck (6) has infilled the angle between Hause Point and Cinderdale Common with a low angled spread of material. No useful sections have been located.

The fan produced by Sail Beck (7) forms the isthmus area between Crummock Water and Buttermere. A small side stream Bowder Beck (8), (NY 177 165) has added to the fan at the north east corner of Buttermere but is insignificant in the overall picture. From the fan head at Buttermere village there is a remarkably even and uniform slope of slightly less than 1 degree across the whole of this fan. The fact that it has been able to build right across the valley floor and pin the outlet stream from Buttermere into Crummock Water is a striking feature. The low angle of the fan and the evidence from a few, rather poor ditch and stream sections suggest the bulk of the material deposited here is of relatively small calibre. All the area is enclosed farmland. This fact has undoubtedly enhanced the impression of a smooth, debris free structure, but it is interesting to note that well over 90% of the field boundaries are fences and hedges and that there are only four short sections of stone walls. This would suggest there was little sizeable debris on the fan that needed clearing. Some control measures of the stream across the fan have been adopted. Embanking has confined the channel to the base of Long How (NY 171 172) and the exit to Crummock Water to the north of Nether How (NY 168 172) . The original course for this stream seems likely to have been to the south of Nether How. The First Edition 1:10560 scale Ordnance Survey map (Cumberland Sheet LXIX 1867) shows it in its present position, but earlier maps such as William Hutchinsons History and Antiquities of Cumbria 1794 appears to show it taking the more direct line to Crummock Water.

Hassness How (9) is the perfect arcuate delta built out into the upper end of Buttermere. Immediately opposite, on the other side of the lake, Comb Beck (12) has built a similar structure. A comparison of the two features is instructive. The two catchments are of a similar size, Comb Beck being marginally larger. The fans on the other hand are very different in size, the Hassness How Beck producing a fan around three times larger. Further, the slope of the Comb Beck fan (4°) is much steeper than that at Hassness (2°) . Both were built unhindered out into the lake which here is known to have a remarkably flat floor and be very symmetrical. When the first bathymetric survey of the lake was completed in October 1893 (Mill 1895) one of the sounding lines was across the lake at this point

between the two deltas (section A-B, Map IV). The description records a slope off Comb Beck delta with a 1 in 3 gradient for 270 feet and .....'the absolute flatness of the lake floor has no natural equivalent in sub-aerial scenery; a bowling green .....' (p 29). The differences between the two deltas must derive from the bedrock differences of the two catchments. Hassness Beck is entirely within the Skiddaw Group which here are the very heavily disturbed melange of the Buttermere Formation. Comb Beck on the other hand, has a catchment made up of Borrowdale Volcanics and Granophyre with some altered Skiddaw Group material on the lower slopes. These differences are confirmed by the following analysis of 50 random clasts taken from the material exposed at mid-beach on the shores of the two deltas:

	Mean Size	Zingg Classification				Krumbein
	mm	D	B	R	S	Sphericity Index
Hassness How	16.51	28	72	0	0	0.447
Comb Beck	25.60	9	14	48	20	0.665

Gatesgarthdale Beck and Warnscale Bottom (10-11), the two streams that feed into the head of Buttermere both have extensive alluvial accumulations at their mouths. Warnscale is far and away the largest. Both have low gradients. Comparisons with the other fans is difficult since they are essentially lake head infills.

The four streams that run down the Granophyre outcrop on the western side of the valley, Old Burtness (13), Sourmilk Gill (14) and Near and Far Ruddy Becks (15,16) are characterised by steep channel gradients and exceptionally small fans. It is difficult to define the margins of the fans as they are merely piles of loose, irregular blocks (some > than 1m in size). Scale Beck (17), which also drains part of the Granophyre has a totally different character. It has a rather varied basin topographically and enters the lake across a boggy fan.

The fans produced by Mosedale Beck (18) and High Nook Beck (19) effectively dam the Loweswater valley and contain the lake at its eastern end. Both streams have trenched through glacial sands

and gravels within the valley and spread their fans on to the lower ground beneath. The High Nook fan in particular has the low angle of many of the other fans flowing off Skiddaw Group rocks in the valley.

Holme Beck (20) which has built its fan out as an arcuate delta into Loweswater is reminiscent of Hassness How in Buttermere. Its overall angle of slope is higher but its profile is distinctly concave, with its lower portion meeting the lake at a low angle (approx. 1°). The catchment area is small.

There are two small fans in the upper part of the Loweswater valley at Waterend Beck (21) and Whittern Gill (22). Neither are particularly noteworthy. On the eastern slopes of Fellbarrow, 125m or so above the main valley floor, there is a fan built out from the bottom of Watching Gill (23), a short gully that notches Watching Crag. There is ample loose debris around which this small stream has been able to move, but lower down its gradient was checked at the foot of the slope.

Elsewhere in the valley and in several of the tributaries other small fans and chutes of material exist. Several of the streams running down the steep eastern face of Mellbreak have very small fan accumulations at the lake shore (NY 155 184, 155 186, 152 194). On the opposite lake shore there is a small amount of debris at the mouth of Red Beck (NY 161 196). Similarly on the NE shore of Loweswater (NY 130 216) there is a small delta built by Crabtree Beck. A particularly impressive chute of fan material has collected along a faulted and mineralised gully on the SE slope of Carling Knott above High Nook Beck (NY 124 202). None of these were thought significant enough to warrant inclusion in Table 1.

Discussion

The propensity of tributary streams draining catchments based on the Skiddaw Group rocks to produce extensive fan spreads has been amply demonstrated in this valley. By contrast, in the six basins on the Borrowdale Volcanics and Granophyre outcrops equivalent

volumes of transportable debris has not been generated. The implications of these differences for other Lake District locations is worth noting. The parallel between Derwentwater/Bassenthwaite and Crummock Water/Buttermere in so far as they both appear to owe their separation to delta building is frequently quoted in the literature. The parallel here is a good one as again it can be demonstrated that the supply of debris for the Derwentwater/Bassenthwaite isthmus land was derived primarily from the Skiddaw outcrop. Topographically similar situations on the Borrowdale Volcanic outcrop at Armboth on Thirlmere and Measand on Haweswater failed to generate sufficient debris to allow complete separation of the lake basins.

The data presented suggests that for a given geology the areas of the fans is broadly a function of drainage basin area. Two of the Skiddaw Group basins, Lanthwaite Boat House (4) and Holme Beck (20) do however stand out as particularly small catchments. A number of factors influence fan size. Debris supply is clearly very important. Catchment area which is reflected in discharge is fundamental but channel gradient must also have a bearing. Valley floor configuration will affect the pattern of deposition and may well determine whether all or only part of bedload is deposited. Coupled with this is the tantalisingly difficult problem of ascertaining the thickness of fan deposits, particularly where fan shape is irregular (eg. Liza Beck (3).

The Lanthwaite Boat House fan could possibly be explained by an unusually large supply of loose debris. The huge buttress of Grassmoor End at the head of the basin could be a possible source. It is a largely unvegetated series of crags and loose scree. Oxford (1985) mapped and described .."an extensive accumulation of talus which at its base has a series of gently arcuate bulges to the west, away from the free face " at the foot of this slope. He suggested it was a protalus rock glacier of Loch Lomond Stadial age. The weakness of his argument was the low elevation of the feature (200m) and its unfavourable aspect (bearing 275°, ie almost due west). Subsequently this interpretation as a protalus rock glacier has been described as 'dubious' by Ballentyne and Harris (1994). Regardless of the interpretation placed upon this feature, it cannot be denied that there

is a great quantity of weathered material lying along the part of this footslope described by Oxford, but not in the short section immediately to the north of the feature where the Lanthwaite Boat House basin headstreams have encroached to the base of the open scree. The nature of the material described in the shore section of this fan is not incompatible with protalus material that has subsequently been transported a short distance downslope.

The large fan created by Holme Beck presents a different situation. This is a perfect arcuate delta built out into Loweswater. It is likely the sharp change in channel gradient at the head of the delta at Holme Force, coupled with a shallow lake basin (< 5m of water on this shore) led to complete deposition of the stream bedload.

The success of Sail Beck (7) in building its fan right across the valley and forming the isthmus between the two lakes has already been referred to. The relative impotence of the Sourmilk Gill stream on the other side is striking. It is interesting to consider whether this examination of fans sheds any light on whether the isthmus is merely a thin deposit of debris over a rocky bar between separate rock basins, or whether there is sufficient debris here to have separated the two lakes entirely by an alluvial accumulation. Two points in favour of the former hypothesis can be made. There are undoubtedly substantial rocky outcrops in the middle of the trough at the head of Crummock Water in the form of Nether How and the Holme Islands, both of which are being built around by alluvial infill. Secondly an average thickness of at least 30m of material would have to have been supplied by Sail Beck to dam the trough completely (assuming there was no rock bar). This would represent in volume terms something approaching 0.0195 km^3. of debris. Extrapolation from other fans in the valley (e.g. Blake Beck) where the geometry is simpler to estimate volumes of material produced from the catchments, the likely volume of material generated by Sail Beck is under half that figure (0.009 km^3.).

Finally the age of these fans must be considered. None of them appear particularly active at present. Most are stabilised with vegetation and all the major low angled valley floor fans are

agricultural grassland or woodland. As many of the stream channels on the fans are controlled artificially and some periodically cleared, measuring boulder size in the present fan stream is not meaningful. Outbuilding of the lake deltas is still evident, particularly at Sail Beck, Holme Beck and Gatesgarthdale. There is, however, some potentially useful data available on sediment yields from one of the streams in the valley - Liza Beck. A sediment trap (now disused) was established on Liza Beck close to the mouth of Gasgale Gill (NY 160 212) by Clayton (1951) as part of a wider network in Cumbria. The data available from these traps has recently been analysed by Newsom and Leeks (1985). A 46-year bedload yield (up to 1983) has been calculated for Liza Beck and two other Cumbrian streams, together with some short term data covering only six years of operation of the traps. The data set is very small and must be interpreted with caution. Nevertheless it appears to produce some interesting conclusions. The medium term (46 year) estimate of bedload yield for Liza Beck is 29t/km^2 /yr. Unfortunately the Liza Beck fan (which is below the trap) is very irregular and one of the most difficult to measure and estimate its volume. A reasonable estimate based on careful measurement of its geometry is that there is approximately 0.003 km^3 of fan material. Assuming a volume to weight conversion of 1.8 for an unconsolidated sedimentary deposit the bedload yield figure would give a figure of around 46,000 years at that rate to accumulate that volume of material. Such a calculation contains some major assumptions and may well contain some gross errors of estimation but the time discrepancy between 46,000 years and the 13,000 years the glacial record suggests as the maximum time available for accumulation is so large that even given possible errors it should not be ignored. It suggests that current rates of deposition in the present hydrological regime are insufficient to account for these fans. This conclusion is reinforced by two other points regarding these figures. Compared with other catchment data available from other sites in upland Britain these yields are relatively high (Ballentyne and Harris, 1994, pp 254-5). Secondly, of all the basins in the study area, Liza Beck has the highest amplitude of relief and because of its unique geology untypically large areas of bare rock and unvegetated slopes.

The evidence suggests that for the most part these fans are relict features. Fans are products of fluvial processes, so an explanation of the features requires an enhanced sediment supply and/or enhanced fluvial activity at some stage(s) since the Devensian ice left the valley. Arguing by analogy with evidence elsewhere in the Lake District and from work in upland Britain, frost action could explain the enhanced supply of transportable debris and periglacial conditions the enhanced fluvial transport. Regrettably there is no evidence in the valley to make dating precise.

It can be demonstrated quite readily that the Skiddaw Group is a frost-sensitive rock type. Its fissile nature yields small platey clasts eminently transportable by even modest fluvial discharges. The difference in the size of the fans derived from the Group outcrop in this valley alone is testimony to this. Elsewhere in the Lake District Boardman (1977, 1978, 1985) and Oxford (1985) have elaborated this point with reference to periglacial scree deposits and landforms. Harvey (1974 and related work) has pointed to the seasonality of sediment yield from similar materials in the Howgill Fells where he demonstrated that on contemporary fans 73% of the yield was derived during the winter half of the year. The nature of the clasts seen in the fan deposits in the Buttermere-Crummock Water valley are wholly compatible with material that has been frost shattered.

Equally there is good evidence for enhanced fluvial transport under periglacial conditions during the Loch Lomond Stadial (11,000 - 10,000 BP). Comparison of cores taken from the floors of lakes with and without Loch Lomond Stadial glaciers demonstrates that under periglacial conditions fluvial transport is increased. Sediment supply would be increased by the break up of sparse vegetation cover, the absence of any peat cover and feeble soil development. Overland flow (particularly during summer melt) would be effective in moving debris on surfaces overlying permafrost. Whether the major phase of fan development under these conditions was confined to the 1000 years of the Stadial is arguable. Boardman (1985) demonstrated that the Sanbeds fan on the flanks of Skiddaw could have been produced within the 1000 years, but this implies high denudation rates that may have a local explanation. It remains open that fan deposition could

have occurred in the interval between ice sheet retreat and the culmination of the Loch Lomond Stadial involving paraglacial reworking of unstable sediments left on recently deglaciated terrain. A further dimension in the argument is raised by the recent description of a fan near Stockley Bridge in Upper Borrowdale by Boardman and Smith (1994) and the dating of buried organic deposits at the site by Parker et al (1994). Fan aggradation here is related to human induced vegetation changes involving forest clearance and the introduction of sheep grazing following 10th Century AD Viking settlement. The settlement history of the Buttermere-Crummock Water valley is similar. The magnitude of these changes however cannot be quantified. In the absence of datable deposits that can be related to these fans their precise history remains unresolved.

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R.A. Smith
[redacted]

EXCURSIONS

SEDIMENTARY VARIATION IN THE FIFTH TO WHITE LIMESTONES OF WEST CUMBRIA

Leader : Andrew Thurlow (Manchester University)

9 April 1994

Members met at Moota Quarry entrance (NY 150 360), where the leader explained the geological background to the four quarries to be visited.

Moota Quarry

The quarry is situated some 3 kilometres south of the Maryport - Gilcrux Fault System which acted as the northerly margin to the Lake District High during the Dinantian, and was thus periodically influenced by the dominantly clastic sedimentation occurring within the Solway Basin to the north of this fault line.

Fifth Limestone

Sparsely fossiliferous generally dark coloured fine-grained bioclastic carbonates of the Fifth Limestone occur at the base of the quarry.

Clastic sediments occur at distinct levels within the quarry and are marked by grass-covered ledges in the western face of the quarry. The lowest package, 18 metres above the base of the section is well exposed across a wide shelf in the northern part of the quarry. The measures rest upon a nodular carbonate mudstone developed on the top of the underlying limestone bed. They consist of pale clay-rich sandstones which fine upwards with abundant carbonate mudstone nodules and are capped locally by a thin micritic limestone with rip-up clasts. This limestone is overlain by a persistent green-grey claystone and 10 cm thick coal which is followed in places by a dirty calcareous

sandstone with *Zoophycus*, abundant wood fragments and a persistent limestone rich in productoid brachiopods. Overlying clay rich measures associated with micritic limestones, sandstones and coals are interpreted as deposits formed under subaerial conditions following a fall in relative sea-level and represent floodplain, palaeosol and calcrete formations.

Fourth Shale

This consists of a 1 metre palaeosol clay resting on a surface with minimal relief and overlain by a 5 cm sandy coal. A nodular calcrete horizon occurs beneath the clay, which contains sinuous black carbonised seams, interpreted as rootlets preserved within the fossil soil.

White Limestone

The lowest beds of the succeeding carbonate deposits are similar to the lower beds of the Fifth Limestone and are indicative of deposition below wave-base. These quickly pass up into much paler, coarser beds in the same style as the upper Fifth Limestone, with a variety of interbedded clastic measures. The highest beds exposed in the quarry are very pale coloured limestones, cut by abundant veins of orange coloured barite, with an 80 cm interbed of grey micaceous alluvial siltstone coarsening upwards to orange sandstone.

Kelton Quarry

This exposure (NY 057 184), situated some 24 km south of Moota is located in a platform interior setting.

Fourth Shale

Only 40 cm of the sandstone from these clastic measures are exposed at the base of the succession in Kelton quarry.

White Beds

The lower contact of the White Beds with the Fourth Shale is not exposed, but the lowest carbonate measures are represented by fairly thick-bedded, pale, coarse grained grainy limestones. Palaeosol clay formation is common throughout the succession. Karstified tops to the limestone beds beneath these palaeosol clays are commonly altered from the typical grainy rocks beneath into micritic carbonates due to the process of soil formation,

Rough Beds

The base of the Brigantian age Rough Beds is taken at the base of the thin fenestral carbonate mudstone overlying the palaeosol clay-filled palaeokarstic surface with a relief of 40 cm, seen part way up the eastern end of the north face of the quarry. This bed is overlain by a fairly thickly-bedded limestone with algal oncolites.

Yeathouse Quarry

This small exposure (NY 038 159) which lies some 3 km, WSW of Kelton, was visited in order to view parts of the late Asbian succession not exposed at Kelton.

Fifth Limestone

The base of this limestone is exposed at the mouth of the entrance cutting into the quarry where it overlies shoreface sandstones at the top of the Fifth Shale. The main quarry face shows a rather thin succession of Fifth Limestone, which passes up from highly fossiliferous medium-coloured bituminous limestone into much paler and coarser, grainy limestones.

Fourth Shale

This package of clastic measures is poorly accessible in the south-western corner of the quarry and was seen to consist of alternating beds of siltstone and medium-grained, purple sandstones.

White Beds

Only the lowest beds of these measures are now exposed due to the backfilling of the larger quarry to the south-west. The pale-coloured, coarse limestone rests with a sharp contact on the underlying siltstone.

Clints Quarry

Clints Quarry (NY 007 124) north of Egremont is the most proximal to the Manx-Cumbrian Ridge which probably acted as a source of clastic sediment intermittently throughout the Dinantian,

Fourth Shale

In the entrance cutting to the quarry, the clastic measures of the Fourth Shale are poorly exposed and were seen to consist of red and green siltstones overlain by silty nodular limestones.

White Beds

The base of the White Beds was seen overlying the Fourth Shale in the entrance cutting. The remainder of the White Beds were seen to the north and south of the entrance to the quarry, where they are pale, coarse grained rocks, typical of the platform interior White Beds succession.

Rough Bed

The base of the Rough Beds is taken at the base of the lowest dark limestone containing algal oncolites with a bioturbated ("suck-bed") base overlying a thin palaeosol clay.

The north face of the quarry exposes a succession higher In the Fourth Limestone : from the Junceum to the Spotted Beds. The palaeokarstic surface which marks the top of the Potholes Beds is somewhat peculiar for the west Cumbrian succession in that it

contains a sandstone fill. Undercutting of the underlying limestone is apparent and a thin sheath of red clay separates the sandstone fill from the karstified limestone below. This feature resembles the sandstone plugs described from the Brigantian succession in Anglesey, interpreted as forming through synchronous dissolution of limestone beneath a soil cover and fluvial sandstone deposition, rather than mechanical abrasion of the limestone to form the "pothole".

THE GRAPTOLITES OF DOBB'S LINN

Leaders : Dr Euan Clarkson and Cecilia Taylor (Edinburgh University)

24 April 1994 - Joint meeting with the Westmorland Geological Society

Dobb's Linn is a spectacular waterfall in a ravine some 15km north of Moffat and 1km north of the tourist-attracting Grey Mare's Tail off the A 708 road from Moffat to Selkirk. It occupies a gorge cut into Ordovician and Silurian greywackes and shales, and is noteworthy for exposing a near-continuous sequence through the Caradoc, Ashgill and Llandovery strata.

Its geological significance was first recognised towards the end of the 19th century by a local schoolteacher, Charles Lapworth. He explored the exposures systematically, and established correlation and succession by a pioneering use of palaeontological evidence. His findings and interpretations remain valid today, with only minor modifications.

Stratigraphic analysis here rests on fossil graptolite species, and is facilitated by the fact that many species were present or abundant through short periods of geological time. Dobb's Linn now provides the internationally recognised stratotype for the Ordovician/Silurian boundary.

There being little space opposite the mouth of the Dobb's Linn ravine, cars were left at the Grey Mare's Tail car park. The party entered the gorge for what was described as "less than 1km of walking"; it did not disclose that the "walking" involved several stream crossings and much scrambling up and down loose steep scree.

The leaders gave an introductory account of the main features of the area. Under the leader's guidance, stops were made at successive points in the succession, and the plentiful graptolite specimens were identified with the leaders' help. Because of scree slippage, by no means all of the finds were typical of the points reached in the succession, but the typical ones were generally found. No attempt is made here to list the species - anyone contemplating a visit to the site should arm themselves with one of the guides listed below.

A stiff climb at the junction with Long Burn led to a bluff from which an excellent view is to be had of the waterfall - the burn falling over near-vertical greywacke sheets. Higher up, a rich collecting-ground in loose scree gave way to grassy slopes, where some shelter was had from the chilly wind.

After a lunch break here, the party moved down to and along the stream valley, and was shown the Ordovician/Silurian boundary, defined as the horizon at which the graptolite *Akidograptus ascensus* is found here and at other points world-wide. Here also, as at other points in the area, bentonite strata occur, evidence of volcanic activity during this period. The leaders remarked that recent advances in geochemical analytical techniques now permit the use of these bands in confirmatory correlation.

Most of the party then climbed the moorland above the Linn for a comprehensive view of the area, including for good measure, the cottage where Lapworth stayed when making his pioneering observations. A steep descent brought the party back to the outward route and a return to the car park.

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THE SKIDDAW GROUP ABOVE LOWESWATER

Leader : Mervyn Dodd (CGS)

11 May 1994

Members and friends met at the telephone box at the northern end of Loweswater for an evening excursion to examine the Skiddaw Group on the fells to the east of Loweswater.

The rocks are part of the Loweswater slump which closes SSE, the recently published 1:25 000 BGS map showing the axis, the Loweswater anticline, where the beds overturn being some 1km to the east of the area to be visited. One km further east still a thrust (the Loweswater thrust) on Low Fell brings the older Kirkstile Slates over the Loweswater Flags. These slump folds are thought to be submarine slumps or slide masses directed towards the centre of the basin located roughly where the Causey Pike thrust lies.

The Loweswater Flags are turbidites, dominantly greywackes, with the finer sandstones being more obvious than the shale and mudstone units. Several partial Bouma Series appear to be present.

The party made its way up the fell to Aiskill Knott (NY 123 227). Here shales and sandstone bands are present. Several small slump

folds can be seen with marked differences in the competence of the beds. Massive graded sandstone beds up to 30cm thick are present and small short-lived Bouma sequences can be seen.

The second stop, lower down the road from Mosser (NY 126 222) was previously a quarry. The beds here are flat lying with much thicker sandstones than at Aiskill Knott.

The final stop (NY 127 221) is also an old quarry, probably a source of roofing slate. An easterly directed thrust fault cuts across the western wall at a low angle. Minor "folds" form on the eastern edge of the quarry with wide axes but steep limbs, especially on the western side. A little to the east are slightly larger minor "folds", very much like those on Goat Crags above Buttermere which are interpreted as slump generated.

AN INTRODUCTION TO THE SILURIAN AND CARBONIFEROUS ROCKS IN THE LANGHOLM AREA

Leader : Iver Gray (CGS)

15 May 1994

After meeting in the town of Langholm, Dumfriesshire, the party travelled to Peden's View Quarry (NY 862 345). The leader explained that although Silurian rocks occur from Kirkcudbright to St Abb's, this quarry is one of the few good exposures in the Langholm area. One metre thick beds of greywacke alternate with mudstones, and graptolites have indicated a Wenlock age. Sole structures indicate inversion and the sequence appears to be greatly affected by faulting with much slickensliding in evidence.

The second location visited was at the Skipper's Bridge over the River Esk south of Langholm (NY 835 372). Here the Birrenswark Lavas were examined in potholed river bed exposures. The lavas form the base of the Lower Carboniferous (similar to the Cockermouth Lavas) and are dominantly olivine basalts. On the west bank patches

of red sand were noted plus amygdales occurring in 30cm diameter patches close to the bridge abutment. The Birrenswark Lavas are about 60m thick and occur in six flows. They form part of a series of lavas stretching from Kirkbean south of Dumfries, north eastwards towards Birrenswark, and north of Newcastleton to Riccarton. A possible soil horizon was examined in the road cutting south of the bridge on the left bank of the river. In this locality the upper Old Red Sandstone is missing from the succession, cut out by the Whita Fault upstream from the bridge.

The party then moved on to the secluded Tarras Glen to examine the Lower Carboniferous exposures. At the bridge (NY 812 382) the top of the Whita Sandstone is exposed, this unit representing a 300m thick lens of Lower Tournaisian delta deposits. Further upstream the overlying cementstones (sandy, algal limestones) are interbedded with black mudstones representing sabkha deposits. The cementstones contain vugs of dolomite. In the river cliffs minor folding and coarse, Recent gravel deposits were observed. In the valley side on the left bank of the Tarras Burn a tufa deposit has been formed by a petrifying spring known as The Marl Well (NY 815 385). On the flood plain abandoned channels were noted. An erratic of Criffel Granite indicated the easterly nature of the Scottish Re-advance ice flow.

Lunch was taken at Armstrong's Pele Tower at Hollows (NY 786 382). The tower is built on a river terrace, from sandstone taken from the adjacent, underlying quarry and a limekiln dating from 1790 used rock from the lower part of the quarry. Folded Lower Carboniferous rocks are exposed in the bed of the River Esk close by the tower. A NNE plunging syncline is seen in the limestones just north of the tower and an anticline occurs further downstream.

The party walked 500m upstream to examine the Enthorn Dyke which is exposed in the river bed close to a fish weir (NY 790 378). Two sections of quartz dolerite dyke are exposed which have been recorded as 33m and 22m thick. They trend east-west and show spheroidal weathering. Returning to an area just downstream from Armstrong's Tower, the cyclical nature of the Lower Carboniferous

was observed. A limestone with Productids is overlain by a shale and then a sandy shale containing calcareous nodules and plant remains showing palaeocurrent orientation. This is succeeded by a flaggy sandstone, a massive sandstone with channels, a 10cm coal, a 30cm shale and then another massive sandstone exposed in a small cliff on the west bank.

Following a visit to Hollows Mill, the party examined the exposures in the bed and banks of the Esk at Gilknockie Bridge (NY 782 385). Immediately north of the bridge the Millstone Grit is faulted against the Lower Limestone Group by the Gilknockie Fault, the northern boundary fault of the Solway half graben. The Lower Limestone Group dips gently east while the Millstone Grit, south of the fault, dips steeply north-west, being greatly disturbed by the fault. Beneath the bridge abutment on the right bank the Millstone Grit is overlain unconformably by the flat lying Lower Coal Measures.

The final stop of the day was at Harelaw Quarry (NY 791 428) to examine the Harelaw Limestone. The large limekilns in the area worked until 1947 and the quarry is now used as a dump. The well-bedded limestone is overlain by a thick shale containing *Davidsonina septosa*. The very extensive quarries worked down the dip to the NNW on a pillar and stall system and the party entered the more accessible workings. Floor holes make the quarry dangerous. There was no evidence of the coal seam previously exposed at the base of the unit and worked for use in the adjoining kilns.

This excursion was a follow up to a lecture given by the leader at the 1994 AGM. The leader was warmly thanked for an excellent presentation of very varied geology in beautiful scenery.

THE UPPER CARBONIFEROUS OF THE COCKERMOUTH AREA

Leader : Dr Martin Boland (British Geological Survey)

19 June 1994

A group of members met in Branthwaite where the leader explained that much of the day's excursion would concentrate on areas covered by the joint Department of the Environment/BGS funded applied geological mapping programme between 1985 and 1991 and by the re-mapping of West Cumbria as part of the BGS core programme. The revision of the mapping of the Upper Carboniferous in West Cumbria faced the difficulty of lack of exposure, and map construction is largely based on borehole and mineplan data. The programme for the excursion focused on the Hensingham Group and the Whitehaven Sandstone series.

The first locality visited was Branthwaite Edge Quarry (NY 059 229). Approximately 4m of coarse grained to pebbly red sandstone outcrops in this quarry. The beds thin upwards from very thick to medium bedded. Towards the top of the sequence, thin conglomeratic layers with sub-rounded mudrock clasts up to 4cm in size are developed. The clasts are hematised and specular hematite is developed within the more porous sandstones. An open cast exploration borehole drilled 40m east of the quarry shows this sandstone unit to be at least 45m thick. Correlation with exploration boreholes for the Moorside Opencast Site, south of Branthwaite Edge, suggests that that this sandstone occurs above the Unnamed E seam and is thus equivalent to the Whitehaven Sandstone Series (WSS) seen in the Whitehaven area.

The WSS was extensively mapped on the Cockermouth sheet during the last survey, however it was subsequently realised that much of the sequence mapped as WSS was in fact reddened Coal Measures. A sedimentological change does occur towards the top of the Coal Measures in West Cumbria and it is sometimes difficult to separate reddened strata from true WSS. Criteria for identification of Whitehaven Sandstones include coarse grain size, presence of

sandstone blocks within channel sandbodies and multichannel and multilateral sandbodies.

The party then moved on to the quarries in Brigham (NY 083 301). These quarries expose up to 10m of Hensingham Grit, the basal member of the Namurian-age Hensingham Group. The medium to coarse grained, buff coloured sandstones occur in tabular sets which thin upwards. Crinoidal and productid material has been recorded from grits exposed to the south of these quarries. Local evidence of rooting has also been noted. The sequence may represent alternating marine and non-marine conditions. In the northern part of the quarry a shale was examined, along with a slickensided fault and coal fragments.

In the afternoon the party travelled by cars to Bothel then walked to Gilgooden Beck (NY 168 406) to examine a stream bed section recording the transition from Namurian age strata into the basal Westphalian A sequence. The section was followed downstream in the direction of younging. The Namurian is represented by a thin sequence of carbonate rich mudrocks with fossil fragments. Fauna from this locality has indicated that the beds lie within the Arnsbergian Stage of the Namurian. After a few metres of non exposure the overlying sequence passes from dark shales to a thick sandstone unit with an erosional base. The non-sequence may be a eustatic feature or a tectonic one as the locality lies close to the Gilcrux Fault. The sandbody becomes a gannister towards its top with evidence of rooting and preservation of some *Calamites* stems. The overlying shale is carbonaceous but an in situ coal cannot be seen. The shale passes up into approximately 6m of rippled siltstone to fine sandstone exposed in the river cliff.

This sequence can be correlated with the West Pastures borehole which was sunk 500m to the north-west. Two thin coals, which have been correlated with the Albrightons, were recorded in the borehole at about the level of the carbonaceous shale seen in the beck.

The final locality visited on the field trip was Pow Gill (NY 252 440) near Bolton New Houses. The gill section shows a northward transition from grey productive measures exposed in the stream at Powgill Cottage to the reddened measures seen north of the bridge which have previously been described as part of the WSS. At Powgill Cottage a 25cm thick coal can be seen in the stream bank. The coal is underlain by 60cm of grey palaeosol and is overlain by 30cm of black carbonaceous shale with much plant material and listric surfaces. Correlation with the workings at Bolton Colliery to the west suggests that this seam is the Crow, a leaf of the Main Band coal seen in the main coalfield. To the north of the bridge a thick, coarse grained, red sandstone occurs. This sandbody was previously interpreted as the base of the WSS but, unlike at Branthwaite Edge Quarry, no conglomeratic material occurs, and it could be interpreted as reddened Main Band rock. The mudstones and siltstones overlying this sandstone are pervasively reddened. Seatearths can be identified within the sequence, however any associated coals have been removed by oxidation.

NEW EXPOSURES IN THE LOWER CARBONIFEROUS ALONG THE DALTON-IN-FURNESS BY-PASS

Leader : Derek Leviston

3 July 1994 (am) - Joint meeting with the Furness Geological Group

The Dalton by-pass opened in September 1993, and two large cuttings between Elliscales roundabout and Thwaite Flat have exposed good sections in the Lower Carboniferous.

The visit began at the bend on the old road east of Thwaite Flat (SD 218 746) where a brecciated, dolomitic limestone was examined. This lies close to the boundary between the Dalton Beds and Park Limestone although the junction here may be faulted. Walking eastwards along the old road the southerly dipping Dalton Beds were seen to the north and the Park Limestone behind St Helens Farm to

the south. Crossing the valley of Hagg Gill at SD 222 747, the Dalton Beds and the overlying Park Limestone were seen in the prominent mound to the south of the road. The east side Hagg Gill is formed by a fault scarp.

The party walked around the outside of Elliscales Quarry to the roundabout on the Dalton by-pass. The quarry was not visited on this excursion but may contain the boundary between the Red Hill Oolite and the Dalton Beds (Rose and Dunham, 1977). The leader noted that recent work suggests that the boundary may be marked by a dark shale, and the whole quarry may lie within the Dalton Beds.

In the cutting on either side of the roundabout sandy, dolomitised, well-bedded limestone is exposed and a shale band on the north side of the road may indicate the base of the Dalton Beds. Two faults cut the section: a northerly trending fault with vertical displacement at the roundabout and a west north-west trending tear fault which can be traced on both sides of the road. The latter is indicated by brecciation, slickensiding and mineralisation by calcite, dolomite and hematite.

The party then walked westwards along the by-pass towards Thwaite Flat and examined the exposures in the second cutting. Here dark Dalton Beds limestones and shales show minor folding and an unusually steep dip to the south-west probably due to the proximity to the Park - Yarlside fault system which lies beyond the western end of the cutting. Large specimens of *Caninia* and *Delepinia carinata* indicate a position in the lower part of the Dalton Beds.

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THE ST BEES SANDSTONE AT HAWCOAT QUARRY

Leader : Brian Neil

3 July (pm) - Joint meeting with the Furness Geological Group

Following the morning visit to the Dalton by-pass the group moved on to this large quarry within the urban area of Barrow. The leader explained that this locality is one of the few exposures of Triassic rocks in South Cumbria. Infilling has reduced the thickness of rock exposed to about 30m; the floor of the quarry has been grassed over and is now used as an open recreational area.

The exposed rocks are entirely within the Triassic St Bees Sandstones, the local representative of the Sherwood Sandstone Group which underlies much of the coastal lowlands of south-west Cumbria. The quarry probably lies in the upper part of the formation. Originally 148 feet of sandstone was exposed in the quarry and a boring in the quarry floor proved 749 feet of sandstone without reaching the base. The Davy Street borehole showed 2,012 feet of red sandstone which, because of its position and the dip of the beds, would indicate a total thickness of 2,500 feet (760m). The dip of the rocks is about 10° with a strike of 290°. To the south-west the St Bees Sandstone dips beneath the younger Triassic salt and mudstone units which underlie Walney Channel and Walney Island. The St Bees Sandstone has long been believed to have acted as a reservoir of iron rich waters from which the Carboniferous Limestone was mineralised. This view has recently been challenged on age grounds because of the palaeomagnetic pole positions derived from the West Cumbrian hematites.

The rocks were examined beginning in the south-west part of the quarry close to Schneider Road, working towards the upper part of the quarry in the north-east and to progressively older rocks. The beds are interpreted as a series of river channel sediments deposited in a semi-arid environment. Flood events are indicated by sandstones deposited in channel bars and periods of lower flow by shales

deposited in lower energy conditions. There is no evidence of coarse high energy deposits.

At the south-west end of the quarry sandstones are interbedded with micaceous shales, indicating a subaqueous rather than aeolian environment. The sandstone is medium grained, sub-angular to sub-rounded, showing varying degrees of weathering. Alternate units show cross bedding and parallel lamination. The mineralogy and chemistry is similar to that of the St Bees Sandstone in the Vale of Eden and West Cumbria. Quartz is partly cemented with silica and red iron oxide is conspicuous between the grains. Variations in hematite content give rise to colour variations between beds and laminations.

A short distance along this face, there is a good example of convolute bedding caused by slumping, picked out in the laminated sandstones. Tabular cross beds appear to show a palaeocurrent direction towards the south-west.

At the south-east corner of the quarry the dip of the beds is picked out by a prominent, continuous shale horizon which may be a flood plain deposit. The average thickness of the beds is about 0.5m and this is taken to indicate relatively shallow water depths. The shales probably indicate phases of deposition by relatively gentle currents. A short scramble was needed to investigate part of the lower part of this face immediately above and below the prominent shale horizon. Trough cross-bedding in the sandstone is succeeded by trough cross-lamination and then the shale band. Above this, the start of the next flood event is marked by a conglomerate of rip-up, shale flake clasts and then by a thin sandstone. Above this a thin band rich in mica, probably deposited in a sheltered trough as the flood waters waned. This is succeeded by the next massive sandstone bed.

Towards the middle of the eastern wall of the quarry very flaggy beds are visible at the top of the face and the thick sandstone unit show wash-outs. Vegetation and soot staining make this face difficult to examine.

The upper part of the quarry where the oldest beds crop out shows some of the cleanest exposures. At the southern end of the face (above the bed of nettles) white beds indicate either low iron content or a wetter, less oxidising environment. At the foot of the face a parallel laminated unit is overlain by thin beds showing both tabular and trough cross-lamination. Cavities at this and other locations are taken to indicate the weathering out of shaley clasts.

Round the corner from this location there is a good example of a flame mark along with other dewatering features. A small scale channel has an erosional base and a fill of coarser sand and eroded shale flakes which grade upwards into finer sands. Several larger channels are exposed in this face; one of these cuts through at least seven older units. The lower part of the face shows both trough and tabular cross beds. In the middle part of the face is a shale band up to 0.5m thick. This is overlain by a continuous sandstone unit about 2m thick, which indicates deeper water conditions than the underlying beds. This unit can be traced southwards and with foresets facing consistently towards the south or south-west showing the direction of migration of a large sand bar.

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THE WINDERMERE GROUP BETWEEN TROUTBECK AND KENDAL

Leader: Andrew Bell (Open University)

8 October 1994

Members and friends assembled at Dubs Reservoir where the leader explained that the Windermere Group (WG) was deposited over a wide area of Cumbria and an area to the south, as the Avalonian continent underplated the Laurentian continent during the Silurian Period. This setting is reflected in changing sedimentary environments and tectonic features. The excursion would examine parts of the WG, working from the boundary with the underlying Borrowdale Volcanic Group (BVG) in the Troutbeck Valley to progressively younger rocks close to the top of the WG succession east of Kendal.

Walking northwards along the track from Dubs Reservoir the boundary between the WG and the underlying BVG could be picked out by a break of slope on the southern flanks of Wansfell. The WG is characterised by lower relief, grassy fields and relatively good agricultural land whist the BVG forms higher fells with rocky outcrops, thin soils and rough pasture. Rocks close to the boundary between the two groups were examined at NY 422 035. Down the slope to the north of the track the BVG rocks form rounded outcrops with no clear bedding. The grey/green, porcellanous, fragmental rock is interpreted as a pyroclast surge deposit. In the track itself, rocks of the Dent subgroup (Coniston Limestone) are exposed. Mudstones alternate with dark limestones, the latter forming beds, nodules and lenses. Beds dip at about 45° to the SSE and the mudstones show a strong cleavage dipping at about 80° to the NW. The subaerial volcanic activity of the BVG has therefore been followed by a period of deposition in shallow, marine conditions.

Part of the Brathay Formation was examined in a disused quarry close to a small wood south of the track at NY 423 034. Dark, laminated mudstones indicate a change to deep water, low energy,

anoxic conditions. A thin layer of bentonite has been dated at 425Ma old. The strong cleavage characteristic of the Brathay Formation has developed in rocks which are tilted in a monocline but not folded. The leader explained that it was possible for cleavage to develop in shear zones associated with the thrusts in the continental plate margin, as opposed to development during folding.

Rocks of the Coldwell Formation were examined in rocky outcrops on the fellside further south at approximately NY 422 028. These sediments are slightly coarser than the Brathay Formation, and contain a comparatively rich fauna. Bioturbation has destroyed any original lamination and organic matter has been consumed by scavengers to produce relatively light coloured sediment.

The final part of the excursion was to the Kendal subgroup rocks east of Kendal. The party ascended Benson Knott from Laverock Bridge on the A685 and at various points on the hillside excellent turbidite sections in the Bannisdale Formation were seen. The leader pointed out that these sediments accumulated at the rapid rate of 8000m in 5 million years. Close to the summit of Benson Knott, folding in the upper Silurian is demonstrated by dips to the north, in contrast to the uniform southerly dip seen earlier in the day in the lower Silurian rocks. The greater proximity to the subduction zone may account for the monoclinal structure of the lower Silurian compared with the folding in the upper Silurian rocks which were further away.

At the summit of Benson Knott 2m thick, sandy units alternate with finer beds. The sandstones show hummocky cross-stratification thought to be due to the effect of storm waves on a sea bed in water less than 50m deep. This illustrates that filling of the sedimentary basin had occurred by the end of the Silurian. De-watering features, possibly triggered by earthquakes, were identified.

The panoramic view of south Cumbria from the summit allowed the party to identify pick out the outcrops of the Windermere and Borrowdale Volcanic Groups and provided a fitting finale to the excursion.

GLACIAL SEDIMENTS AROUND ST BEES

Leader: Dr John Merritt (BGS)

23 April 1995 - Joint meeting with the Westmorland Geological Society

South of the promenade at St. Bees, there is a lengthy coastal exposure of glacial, fluvial, and glaciolacustrine sediments deposited during the final 20,000 years of the Devensian glaciation. The rocks are poorly cemented and their exposed position has ensured that they suffer a range of weathering, mass wasting and erosional effects, which in some places obscures the sequence. The entire cliff length is unstable, and visitors should take sensible precautions to ensure their safety.

Glacial rocks can, of course be observed in numerous localities around the world. The general absence of vegetation in such areas produces more or less complete exposure, in an unambiguous geographical setting. Deposits and landforms can therefore be related with a high degree of confidence to the processes that created them.

In deglaciated areas such as the British Isles however, interpretation is made difficult by almost complete vegetation cover and greatly changed geography. The latter point is a vital one, for not only have the glaciers melted away, but sea levels have changed dramatically, so that the present position of the coastline is an irrelevance. It is not surprising therefore, that there is no settled version of late glacial events around St. Bees., beyond the generally accepted picture of the deglaciation of 11,000 years ago being interrupted by a brief re-advance of the ice followed by its complete wasting away.

It is against this background that the party visited numerous exposures. When examining the deposits the uninitiated were shown

the value of a small garden spade as an aid to fieldwork. With sandy rocks in particular, rainwash and spray obscure the surface with a film of 'dirt'. When this is scraped off, the detail that is revealed is startling.

Only four of the sites visited are reported here, and have been chosen simply to identify the three main units and one of the minor ones. The main ones can be examined over large areas.

1. *The 'minor' rock* is an exposure of peat about 50 cm thick, high up on the cliff face. This lies on top of till, and is interpreted as and infilled kettle hole lake. Radiocarbon dating of pollen from the peat shows the lake to have existed during the Windermere interstadial, about 13,000 to 11,000 years ago. The pollen itself show a vertical sequence of herbaceous-arboreal-herbaceous types, suggesting climatic amelioration followed by deterioration. This is confirmed by the fossil beetles from the arboreal layer, which are species associated with warmer summers than those experienced now. Further support comes from the evidence of an Arctic flora contained in the sands directly overlying the peat, and from the cryogenic disturbance of both peat and sands caused by seasonal freezing and thawing of near-surface groundwater.

2. *Lowca Till* is the less abundant of the two tills exposed. It is a relatively well consolidated lodgement till, containing a range of locally derived clasts, predominantly St. Bees Sandstone, but also Carboniferous sandstones, shales, coals, Borrowdale Volcanics and Ennerdale Granophyre. Fabric analysis suggests ice movement from a northerly direction.

3. *St. Bees Gravels.* These vary in clast size, but range up to the spectacularly coarse, and are crudely bedded overall, with cross-bedding suggesting and approximately north-south flow of torrential force. The largest clasts are boulder sized chunks of local Triassic and Carboniferous rocks, and it is possible that the deposit represents a catastrophic flood event.

4. *St. Bees Till.* This contrasts sharply with the Lowca Till, being relatively pebble free and predominantly sand to silt grade. A marine fauna of foraminifera and dinoflagellates has been collected from this rock, suggesting an origin more complex than that of simple deposition from wasting ice.

The stratigraphic relationship between the tills and the gravels is:

St. Bees Till
St. Bees Gravels
Lowca Till

This is suggestive of two glacial advances separated by a warmer period of abundant meltwater. There are clear examples of folds consistent with the readvance of ice rucking up earlier deposits.

Within this broad picture there is an ongoing debate about the palaeogeographic detail responsible for the rocks we see today.

MINERAL DEPOSITS OF THE CONISTON COPPER MINES VALLEY

Leader: Brian Young (BGS)

6th May 1995 - Joint Meeting with the Open University (NW) G.S.

Members of both societies assembled upstream from Miners' Bridge in the Copper Mines Valley. Here it was possible to view from a distance the spoil heaps and sites of the former dressing floors and treatment works of the Bonser Mine. The spoil heaps of the Paddy End Mine were also visible, higher up the valley.

The leader explained that the purpose of the visit was to examine evidence of mineralisation in the context of the local area and the Lake District as a whole. All the fault-veins in the Copper Mines Valley are within the upper Borrowdale Volcanic Group. Mining pre-dated geological surveys and the deeper workings are now water filled. The

two main mineral suites in the Lake District are a predominately copper suite and a mainly lead/zinc suite. The copper suite is well developed in the Coniston area and although the geology and mineralogy of the area is well documented, comparatively little is known of the mineralisation processes. The current view is that the copper-dominated suite of minerals is of early Devonian age and is related to the Lake District batholith. Radiometric dates have been obtained from clay minerals in the hydrothermally altered wall rocks of the veins. The leader explained that there is some evidence that the mineralisation could be older than this and that the radiometric dates could relate to later events.

Further up the valley close to the Youth Hostel a block probably from the Bonser Vein was examined. This shows a banded vein about 30cm across in ignimbrite wall rock. Poorly developed, white, elongate quartz crystals occur normal to the vein. Other bands are of pyrite, chalcopyrite and magnetite. Dark green chlorite occurs in the magnetite along with pockets of calcite/dolomite. The black, brittle mica stilpnomelane is also present on the Bonser dumps and small specimens of bismuthinite, native bismuth and pyrrhotite may also be found.

It was pointed out that the amount of magnetite increased with depth in the Coniston area, although not at the expense of copper; the opposite is true at Long Crag in the Greenburn Valley. The abundance of magnetite at depth and the impossibility of separating it from chalcopyrite by gravity dressing contributed to the closure of the Coniston mines in the last century.

Some of the magnetite occurs as pseudomorphs of specular hematite. Quartz, hematite and magnetite appear to be the earliest minerals to form, at temperatures indicated by fluid inclusions in the quartz to be as high as 350°C. Very similar veins in Snowdonia have been related to caldera events. If the faults in the Coniston area are also synvolcanic events, it would cast doubt on the accuracy of a Devonian age for the Coniston veins. Veins in the area are only wide and well-mineralised in hard, brittle lithologies, in particular the Paddy End Rhyolite, but not in the highly cleaved, less competent, volcanic

sediments. It may be that all the volcanics were mechanically competent by the Devonian; this would also raise the possibility of a pre-Devonian age for the mineralisation.

Some time was spent examining the spoil behind the Youth Hostel. As the waste is from deep in the Bonser Mine, no brightly coloured, oxidation minerals of copper are present. Minerals noted during the visit included weathered, cellular quartz with pyrite removed; brown, iridescent sphalerite and galena from a second phase of mineralisation; radiating blades of chlorite occasionally forming botryoidal surfaces; a block of arsenopyrite weathered jet black and pieces of pure magnetite which deflected a suspended magnet.

The party then proceeded up the valley of Red Dell Beck, past the archway entrance to Bonser Deep Level to the wheel pit and old workings close to Red Dell Beck at SD 286 990. The outcrop of the Bonser Vein is exposed close to the break of slope. Fenced off open stopes worked from the surface and from below have most of the vein removed. The vein and its ignimbrite (Paddy End Rhyolite) wall rock are clearly offset by a fault. When the vein is traced towards the south, it passes into andesitic tuffs and changes to a crush zone a few centimetres wide showing rusty iron staining.

The next locality examined was the Glory Hole at the top of the tramway incline at SD 284 991. The Bonser Vein is exposed in a large excavation which is too dangerous to enter. The rusty weathered vein consists of quartz, chlorite, pyrite and chalcopyrite. The absence of supergene minerals may be because the oxidised zone has been stripped off by glaciation.

The group then visited Black Scar above the north west shore of Levers Water. Here a scree run and a gully, followed by another scree run, lie along a vein running up the slope. On the scree slope blocks of wall rock and massive quartz were examined. Specimens of pyrite, chalcopyrite, chalcocite and bornite were identified. The possibility of supergene enrichment here was discussed. Similar assemblages occur at Seathwaite in Dunnerdale, Birk Fell Hause and Dale Head.

Malachite and chrysocolla were abundant in the scree. Oxidised copper minerals including malachite and chysocolla are common at this locality. The site is also of interest for the common occurrence of the rare copper-secreting lichen *Lecidea inops*.

Time permitted only a brief visit to the open stopes of the Paddy End Vein, known as The Back Strings, at SD 283 997. Sub-parallel veins are visible in the ignimbrites of the Paddy End Rhyolite which has been altered to a soft clay-rich rock, possibly by hydrothermal processes associated with the vein filling.

GEOLOGY FROM THE CYCLEWAY

Leader: Mervyn Dodd (CGS)

24th May 1995

The Cycleway was opened with central government, European and local authority funding. It follows the line of the Whitehaven, Cleator and Egremont railway which reached Rowrah in 1856. Its purpose was to allow development of the iron ore resources in the Carboniferous Limestones. Although the mines in the Frizington area were closed in the 1920s, the railway stayed open until the 1970s.

A group of members met on a very wet evening which did not allow completion of the intended excursion. The leader explained that much of the area is heavily drift covered so exposures are confined to quarries and railway cuttings and there are no exposures of Upper Carboniferous rocks.

The visit was restricted to the Yeathouse area near Frizington and began at Winder Gate. In the gulley just below the houses there are exposures of St Bees Sandstone and just below this are the small tips of the very early Yeathouse Mine, with its many small pits. The leader pointed out the line of the NW - SE trending Yeathouse Fault, with its throw of about 300m to the north-east. Permo-Triassic rocks outcrop on the north-east side of the fault with Carboniferous rocks to

the south-west. The party continued south-eastwards, along the easterly of the two railway branches, to "The Boilers", a series of large, rusting, iron pipes, installed to prevent water from Windergill flooding the mine workings below.

Bad weather prevented examination of the tip material in this area from which small kidney ore, calcite and dolomite are recorded. This waste was from the large Margaret Mine operation. Above the tip are exposures of the Permo-Triassic Brockram. Several short lived cycles of graded bedding suggest short flood events, with Borrowdale Volcanic Group and limestone pebbles (often dolomitised) set in an incoherent matrix. The dip is unusually steep due to the proximity of the Yeathouse Fault. Beyond are the remains of the headgear of the Agnes Mine, used to pump water from the Margaret workings. A recent landslip has produced a prominent scar on the newly reclaimed slope.

The next stop was on the westerly branch of the railway which lies along the line of the Yeathouse Fault. Basal Carboniferous beds can be seen to the west of the track, marked by a massive dark layer with pale yellow sands, close to the unconformity below which is not exposed. These beds rise to the south-west above the track. Limestones are exposed to the west of the track, Skiddaw Group rocks to the east. The limestones are from the Asbian 7th, strongly reddened, and liable to failure along weak, clastic horizons. An open, abandoned mine trial occurs 200m below Yeathouse Station. Another 200m down the track above a red sandstone bridge are exposures of Skiddaw Group turbidites with thick sandstone beds and slump structures. Heavy rain prevented the party visiting these.

Deteriorating weather then forced the party to retreat along the cutting past the entrance to Yeathouse Quarry where the Asbian 7th and 6th Limestones are exposed with the Chonetes shale marker band between the 6th and 5th Limestones. This is very rich in brachiopod remains and contains a few trilobites. The large cliffs on the edge of the quarry infill are the Asbian 5th Limestone.

The leader was thanked for providing an interesting and varied visit in very difficult conditions.

GLACIAL LANDFORMS OF THE MALLERSTANG AREA OF THE WESTERN PENNINES

Leader: Dr Wishart Mitchell (Luton University)

18 June 1995 - Joint meeting with the Westmorland Geological Society

The party assembled at the Moorcock Inn, Garsdale Head (SD 797 926). The morning was spent looking at drumlin forms in the Grisedale area (SD 776 929) and the afternoon was spent ascending Wild Boar Fell (SD 758 988), with a return to the Moorcock in between.

The party parked along the minor road into Grisedale near Mouse Syke. The leader outlined the background to the area, mentioning it had been originally mapped for the railway and was thought to have nurtured its own small ice cap. The glacial debris does not contain any erratics from distant sources, so it was thought the ice mass was centred on Wild Boar Fell (Raistrick). To account for the apparent drumlin trends, Raistrick put forward the idea that the lower and upper ice moved independently. This is now thought to be physically impossible.

The party viewed the landscape from Mouse Syke and saw what appeared to be a 'text book' shaped drumlin with a west - east long axis suggesting ice travelling easterly off Baugh Fell. We then walked north along the road, taking the footpath north-west at Moor Rigg, to view the drumlin from other angles. The drumlin lost its distinctive outline and its directional suggestions were no longer clear. To add to the complexity of the problem, no internal fabric has been recognised in the till, so the long axes of the clasts give no further evidence as to the direction ice was flowing when it created this structure. From the path, the party forged over the rough ground

around the back of the forestry plantation to Butter Beck. Here, the bedrock could be seen to be part of the Dinantian cyclothems of rapidly alternating limestone, sandstone and shale. A few marine fossils were found in the shales but the main aim of the stop was to view the drumlin, which could now be seen obliquely from above. Could it be possible that this one drumlin was in fact three? The leader introduced the term 'Mega-drumlin' to describe such a feature. Early drumlins could have later features super-imposed on them, causing the ridges on the original drumlin. The conflicting evidence from the drumlins could suggest that rather than an isolated source for the ice (Wild Boar Fell), there was a major convergence of ice here to join the main Wensleydale flow. It was mentioned that about 1000 m head of ice would be needed to get movement as far as the North Sea.

After lunch the party set off from SD 774 968 to ascend Wild Boar Fell via the col between Wild Boar Fell and Swarth Fell. The leader climbed with the ease of one accustomed to the Himalaya and the party got rather smaller as many fell by the wayside! It was explained that small local glaciers were thought to be responsible for the minor moraines seen below the Mallerstang valley and that these had formed during the Loch Lomond readvance. There was, however, debate as to what part periglacial and landslip activity had played in influencing the features. From a point somewhere around SD 757 973 we had an excellent view of the rotational nature of the slippages on the east face of Wild Boar Fell. These resulted from the strong, high mass Namurian grits of the upper layers of the fell causing failure in the weaker mudstones below. Faults and prominent joints added to the instability.

The party reassembled by the roadside and the leader was thanked for an interesting day and for bringing to our attention that glacial land forms always repay a closer look.

THE LATTERBARROW SANDSTONE

Leader: David Kelly (CGS)

5th July 1995

For the second time in an otherwise dry summer, rain caused the curtailment of an evening excursion. A group of members met on the Cold Fell road at the entrance to Lowther Forest Park (NY 061119), with the intention of examining the Latterbarrow Sandstone and its field relationships with the underlying Skiddaw Group and overlying Borrowdale Volcanic Group rocks. Possible periglacial features of the Upper Calder Valley were also to be visited.

The age and correlation of the Latterbarrow Sandstone has long been the subject of debate. The Leader noted that many workers, including Hollingworth (in Eastwood et al. 1931), and Shackleton (1975), considered the boundary between the Latterbarrow Sandstone and the Skiddaw Group to be conformable. Jackson (1961) included the Latterbarrow Sandstone as the uppermost subdivision of the Skiddaw Group. However Simpson (1967) interpreted the Latterbarrow Sandstone as the basal formation of the Borrowdale Volcanic Group, resting unconformably on the Skiddaw Group. During the resurvey of the Lake District by the B.G.S., Molyneux and Rushton (1984) discovered fossil evidence which cast doubt on Jackson's interpretation and in a more recent paper on the relationships Allen and Cooper (1986) conclude that the Latterbarrow Formation rests unconformably on the Skiddaw Group and that it should be considered a basal formation of the Borrowdale Volcanic Group.

In an abridged excursion the members began by examining the Borrowdale Volcanic Group rocks in a small fellside exposure at NY 061 117. Here poorly sorted, pyroclastic material occurs with clasts up to 10cm in size, weathering more slowly than the matrix; these rocks are typical of the lower part of the Borrowdale Volcanic group in the Calder Valley.

On the slopes of Swarth Fell at NY 064 118, the Latterbarrow Sandstone was examined. The rock varies from a fine grained quartzite sandstone to a quartz conglomerate with well-rounded clasts up to 1cm in size. The colour here varies from grey to reddish-brown. No sedimentary structures were identified.

As the party made its way down to the River Calder, landforms on the slopes of Latterbarrow, east of the Calder provoked much discussion. It was suggested that these may be fossil stone stripes, occurring at unusually low altitudes (less than 350m). When the features are viewed from further north on the east bank of the Calder, they appear to run obliquely to the slope and it may be that they run parallel to the strike of the Latterbarrow Sandstone and are related to the weathering and erosion of beds of varying lithology.

The Calder Valley in this area is heavily choked with boulder clay containing Ennerdale Granophyre erratics. The river is incised into the valley fill with a flood plain up to 70m wide. The terrace on the east side has been dissected by small tributary streams and by spring sapping. The small spurs on the slope show terracette development on their north facing sides.

The Skiddaw Group rocks were then examined close to the pronounced bend in the River Calder at NY 068 117. This locality is described in Shackleton (1975) and is the site of a significant fossil assemblage described by Molyneux and Rushton (1984): trilobites and acritarchs of late Tremadoc age were found in the dark mudstones which appear to underlie the Latterbarrow Sandstone. Another exposure of the Skiddaw Group close to the Latterbarrow Sandstone outcrop at Beck Grains (NY 077 112), about 1km to the east, has yielded didymograptid stipes and *Caryocaris*, suggesting an Arenig age. A simple conformable relationship between the Latterbarrow Sandstone and the Skiddaw Group is therefore untenable.

The rocks at this locality are dark grey and show alternating mud and silt laminations along which the rock splits. The bedding is strongly contorted and a recumbent, an antiform is visible in the east

bank. Towards the southerly edge of the exposure, beds of sandstone become more common; the leader argued that these sandstones appear to be lithologically different from the sandstones of the Latterbarrow Formation. A small, dark coloured, fine-grained dyke crosses the stream a few metres south of the sharp bend in the river.

The party the forded the stream and ascended the lower slopes on the east bank. This is an interesting vantage point to view the possible stone stripes on Latterbarrow, referred to earlier. Upstream from this point the valley of the Calder is underlain by the Skiddaw Group and is more open with gentle sides. Downstream on the more resistant Latterbarrow Formation, the valley is narrower. The boundary between the two appears to form a V-shape in the valley.

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GEOLOGY IN THE VALE OF EDEN AND ADJACENT AREAS

Leaders: Eric Skipsey (CGS) and Dr Stuart Monro (BGS Edinburgh)

15 - 17 July 1995

This 3 day programme of excursions was arranged in conjunction with the Edinburgh Geological Society annual field weekend. Some 15 members from the EGS along with a similar number from the CGS and "erratic visitors" from societies in the south of England participated in the weekend. The first day concentrated on Carboniferous strata, the second on the Permo-Triassic, and the final day on visits to a working anhydrite mine and granite quarry.

15 July 1995

The party assembled in Brough village prior to moving on to the disused Helbeck Quarry (NY 800 158) which had worked the Robinson Limestone. Once assembled at the quarry the party set about producing a geological map of the quarry and the hillsides to the north above the quarry. Discussions and instruction took place on field measurements and mapping techniques with examination of various features (faults, folds and thrusts, bedding thickness, rock type and fauna) exposed in the quarry. Further observations were made as the party progressed to the top of the quarry. At the top of the hill above the quarry the presence of two valleys with outcrops of limestone between them and in the hillside above indicated a significant change in rock type. Lithological information from a rabbit hole (!) and recent excavations for 2 ponds indicated the presence of a mudstone/shale unit which formed the valleys. Examination of the limestone outcrop in the valley centre indicated a different coral fauna and rock type. Initial problems determining the bedding dip in the limestone were resolved by inspection of the outcrop at Horseshoe Scar (NY 797 162) where well developed bedding was observed dipping to the north. This limestone was identified as the Melmerby Scar Limestone (MSL). The large scarp face of limestone in the hill to the north was also identified as MSL thus inferring the presence of a fault along the base of the limestone slope. At this stage the results of

the mapping were discussed and placed in the regional context. It was agreed that the mapping indicated a significant fold plunging to the east, the folding being due to the proximity of the Pennine Fault and the compressive tectonic forces associated with Tertiary movements. Lunch was taken part way up the large scarp face of the MSL, allowing an overall view of the area mapped. A visit was made to a barytes/copper vein associated with the Pennine Orefield mineralisation - discussion took place on the nature and mode of the mineralisation - it was concluded that there was still a lot to be learnt!

The party then returned to their transport and passed eastward along the A66 to the Punchbowl Inn. East of the Inn adjacent to the new route of the A66 highly dipping fossiliferous Carboniferous limestones and shales indicated the eastward continuation of the structures seen at Helbeck. Further on at Banks Gate (NY 846 147) again adjacent to the A66 outcrops of flat lying Great Limestone were examined. Here the exposed vertical surfaces of the limestone had weathered to reveal fine examples of rugose corals and productid brachiopods.

The party then proceeded back along the A66 to Appleby and along the B6260 to a location (NY 632 108) on the west side of Asby Scar. From this point the party walked eastwards for approximately 1 km, passing a quarry in the "Asby Marble" (a crinoidal limestone) onto the Scar. The Scar is the type locality for the Asbian sequence of the British Carboniferous succession. It is also one of the most extensive and best preserved limestone pavements in Cumbria and is protected by a Limestone Pavement Order. Discussions took place on the origins of the "clints and grikes", the age of formation of the pavement and the special plant life present within this unique environment. The party then returned to the transport and then to Appleby.

16 July 1995

The party assembled at the side of the minor road from Appleby to Hilton (NY 714 192) and followed the footpath along the side of George Gill to the exposures of aeolian sandstones (NY 718 188). Here, large scale dune cross-bedding is exposed in the cliffs on

both sides of the valley. Recent erosive wind action has emphasised quartz veining in the sandstones - the veining was the subject of an animated discussion regarding the origin of the veins and the chemical conditions required for their formation. Fluvial incursions of Brockram material were also observed as well as pebble filled scour and fill channels and clay "rip up" clasts.

The next stop was at Church Brough where exposures on Church Lane (NY 793 139) were examined. This location provides the most southerly exposure of dune bedding in the Penrith Sandstone, with the dipping slopes of the cross-bedding being clearly visible, the softer stone being composed of well rounded sand grains so characteristic of desert dunes.

The party then proceeded to Belah Bridge where, leaving cars in the lay-by (the old road across the River Belah) they proceeded eastwards, along the southern side of the river to Belah Scar (NY 794 120). Here a classic section in the cliffs shows several sequences of sandstones with basal scours filled with gravel (brockrams) and which pass up through sands and silts into thin mud layers, representing repeated floods cutting down into sand deposits. Local thicker patches of red mudstone suggest that the flood waters were sometimes trapped in ephemeral ponds. Much of the sandstone is either structureless or horizontally bedded but occasional layers show steep cross-bedding with well rounded, well sorted sand grains in these bands suggesting they may represent temporary encroachment by dunes from the north.

The party then crossed to the northern side of the river and proceeded up stream to a point where a small cliff was exposed in the southern bank of the river. This is the type locality of the Belah Dolomite where some 5m of dolomite and dolomitic shales are exposed in the bed of the river and the cliff. The Belah Dolomite occurs within the Eden Shales, above the Hilton Plant Bed and provides the only indication of communication with the Zechstein sea in the north-east of England (fauna collected from this locality indicates an equivalence with the Z3 sequence in the north-east).

Returning to the cars the party then moved on to Kirkby Stephen and Stenkrith Park (NY 773 075). Here the River Eden has cut a spectacular deep gorge through a thick sequence of brockram known as the Stenkrith Brockram. At this locality the brockrams have completely replaced the Eden Shales. This indicates that almost all the desert sequences on the southern margin of the basin are made up of brockram beds derived from flood debris washed down from uplands to the south. Examination of the pebbles in the brockram indicated that they consisted almost exclusively of debris from Carboniferous limestones and sandstones.

The party then proceeded to Nateby and took the public footpath through the fields to the bridge over the Eden (NY 771 064). In this area the brockrams have replaced almost the whole of the Permian sequence with only a very thin band of shales separating the "Upper" and "Lower" brockrams. On the western side of the river and downstream of the bridge the oldest brockram beds were observed lying on the Carboniferous Limestone. Eric Skipsey ended the day by providing a brief review of what had been seen and describing the work that had been undertaken by the Cumbria RIGS Group. The party then dispersed.

17 July 1995

The field meeting reconvened the next morning at the British Gypsum mine at Newbiggin (NY 628 278) where they were met by the mine manager.

The party was escorted to the mine entrance where the manager provided a review of the geology and the nature of the operations undertaken. The mine is one of two in the Eden Shales that are currently operating the other being at Birks Mine at Milburn (gypsum - 'A' bed) - the gypsum mine at Kirkby Thore has recently been closed.

Initial work at Newbiggin in the early 1960's was by quarrying. The maximum extent of the quarry is now indicated by a face of anhydrite (the 'B' bed) overlain by shales into which the mine entrance

has been excavated. The mine is in the form of a drift which follows the anhydrite bed, reaching a maximum depth of 40m as it dips towards the fells and a maximum distance of some 220m from the entrance. The main use for the anhydrite from the mine is in the cement industry. Gypsum from Birks Mine is mainly used as a 'filler' in the food industry. Good specimens of anhydrite and gypsum were recovered from the area in the vicinity of the entrance - the overlying Eden Shales were examined for fossils previously found at this locality - in this instance without success.

The party then moved on to Penrith and then down the A6 to the Concrete Products works at Shap. From here the party was directed to the Shap 'Pink' Quarry (NY 557 084) to examine the Shap Granite. The large quarry faces provided excellent exposures and the pronounced jointing, with one horizontal and two vertical systems was noted. The quarry company had collected specimens of the main rocks types and minerals associated with the granite and these were examined and discussed. The presence of dark "enclaves" within the granite was noted and discussed. Evidence of mineralisation, including pyrite, chalcopyrite and molybdenite was noted, and the results of metamorphism of the Borrowdale Volcanic Group country rock including the presence of garnets and epidote were also noted. In worsening weather the party then proceeded to the Shap Wells Hotel to see the famous unconformity where basal Carboniferous sediments lie over Silurian Brathay Flags.

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SHALLOW WATER DEPOSITS, FLORA AND FAUNA IN THE LOWER CARBONIFEROUS OF ASHFELL AND ASBY FELL

Leader: Alan Day (WGS)

September 17th 1995

The excursion began beside the A685 at Ashfell Edge, (NY 736 047). The leader explained that the top of the Arundian Stage is marked in this area by a regressive sequence consisting of shales, massive sandstones and thin, shaley limestones known as the Ashfell Sandstone. The dip is to the northeast so that younger Carboniferous beds crop out in the Eden Valley around Kirkby Stephen, with older Silurian rocks forming the Howgill Fells to the southwest.

In the cutting on the northwest side of the road numerous specimens of the compound coral *Siphonodendron* were observed disaggregated in shales and the leader passed around a specimen of a complete colony. The corallites at the edges of the colonies have been crushed, with cavities between the broken septa being filled with calcite. This crushing was thought to be caused by the weight of the growing colony pressing down on the earlier corallites. Some colonies have been abruptly terminated at the top as they were inundated by incoming muddy sediment. The muddy environment, causing dilution of nutrients and reduction in light (for symbiotic algae), has stunted some of the corals so that they tend to form homeomorphs of later species such as *Siphonodendron irregulare* and *S. pauciradiale*. Examples of excessive lateral budding were observed in the homeomorphs, a development to perhaps give less resistance in rougher waters. Crinoids, spiriferids and trilobites also occur in the shales.

In the same cutting a sandstone with a sharp erosional base, cuts into the shales immediately below which contain plant fossils. Overturned corals occur in the limestone above. This is partly dolomitised and partly porcellanous, with abundant chert nodules.

In the field on the same side of the road in small quarries, the cross-bedded Ashfell Sandstone, forming an horizon below the shale is exposed. This represents storm events which carried clastic debris from a sediment source to the north. In dolomitised limestones above the sandstone, burrows are common.

In the field on the southeast side of the road the limestone above the upper sandstone is exposed in a small quarry. Fan-shaped sections of colonies of *S. sociale*, about 1.5m across, were observed. In the cutting on the same side of the road, the porcellanous limestones above the sandstones contain mineralised 3D specimens of the plant fossil *Archaeosigillaria kidstoni*.

The party then moved on to a large disused quarry on the northwest side of the road (NY 750 058), where the Holkerian Ashfell Limestone is well-exposed. The rock is partly dolomitised, well-bedded and was much sought after for lime burning. Specimens *of S. martini* and *Chaetetes* were abundant, although no Lithostrotions were found on this visit.

The afternoon part of the excursion began with an examination of the Holkerian Ashfell Limestone in a small quarry (NY 692 077), near Mazon Wath. The limestone is thinly bedded with numerous small joints and produces a ringing sound when struck. The discovery of *Lithostrotion vorticale* demonstrated a post-Arundian, i.e. Holkerian, age. Specimens of *Siphonodendron*, *Syringopora* and *Linoprotonia hemisphaerica* were also noted. The party then proceeded across the open fellside towards the east and the valley of Potts Beck, which formerly flowed into the River Lune. The leader explained that the folds clearly visible on the north side of the beck were caused by pressure against the Dent Fault.

The party then examined a section starting on the north side of the beck at NY 696 080 and progressing up the slope to examine the transition from the Holkerian to the Asbian Stage. The Holkerian rocks at the foot of the slope are fossiliferous and the party identified *S. martini*, *Syringopora*, *Chaetetes*, *Composita sp.*, *Davidsonina* and gastropods. Chert nodules are common at this locality.

In a gulley near the top of the steep slope the Asbian stratotype was examined; the beds have been labelled and the bottom of the Asbian occurs at the top of bed d. The rocks are spectacularly fossiliferous with very large *Chaetetes*, *S. martini*, *Syringopora* and the Asbian indicator brachiopod *Gigantoproductus maximus*. The lower Asbian in this area is represented by the Potts Beck Limestone which was examined on Asby Scar. The scenery of the Potts Beck Limestone is distinctive, with limestone scars separated by grassy slacks which develop on the inter-bedded sandstones. Specimens of *S. junceum*, *Palaeosmilia murchisoni* and *Dibunophyllum bourtonense* were noted.

The excursion ended by examining small exposures below the main Asbian Knipe Scar Limestone (NY 682 088). The limestone scars of the Potts Beck Limestone form a steep syncline. The locality also provided an excellent vantage point to demonstrate the difference in scenery between the Potts Beck Limestone and the overlying Knipe Scar Limestone which lacks the grassy slacks.

The leader was warmly thanked for providing a detailed, instructive and interesting presentation of an area of spectacular geology and scenery.

Other Excursions

The following excursions were also held during 1994 and 1995.

8 June 1994	Basic igneous rocks of Carrock End Leader: Tom Shipp (CGS)
7 September 1994	The Geological Collection at Keswick Museum
24 September 1994	The Skiddaw Granite Leader: Norma Rothwell (joint meeting with the Manchester Geological Association).

14 June 1995	The Eycott Volcanics and the Skiddaw Slates in the Overwater area. Leader: Angela Marchant (CGS)
25 June 1995	The geology of the area around Bewcastle. Leader: Phil Kingham (CGS)

LECTURES

THE GEOLOGY AND SCENERY OF NORTH-WEST SCOTLAND

A lecture by Joe Crossley of Liverpool John Moores University, on 21 September 1994 at Castlegate School, Cockermouth

Mr Crossley started his talk by describing possible routes from England to the north-west of Scotland. One of these was over the Forth Road Bridge, past Stirling Castle and the "upside down" rocks of the Tay Nappe, another was over the lavas of the Central Valley of Scotland and past Loch Lomond. Other alternatives were by train to Fort William or by road along the A9 via Cairngorm or Glencoe and the Great Glen. The best time visit NW Scotland is in April or May, after that the Highland summer gets wetter.

Mr Crossley presented and overview of the geology of Scotland. Lewisian gneiss outcrops on the NW fringe of the mainland and on some Hebridean islands and underlies the remainder of northern Scotland. These are Pre-Cambrian rocks with ages between 3000 - 1800my (Archaean - Aphebian) which originally formed part of the Canadian (Laurentian) Shield. Sedimentary rocks of the Torridonian overlie the Lewisian. These have been divided into 2 distinctive groups. The Stoer Group lies to the west of the Lewisian outcrop and has a significant dip, the Torridon Group lies to the east of the Lewisian outcrop and is horizontal. There is a large time gap between the deposition of the Stoer Group (1000my) and the Torridon Group (740my).

The Lewisian is very strongly banded, the light coloured bands of quartz and feldspar contrasting with the dark amphibole / pyroxene / mica bands. Layered igneous intrusions are found, with strongly jointed ultrabasic/basic pyroxene bands and lighter calcic plagioclase bands which have been metamorphosed to mica. Granites are also present in the Lewisian occuring as a pink occasionally pegmatitic rock in the basic gneiss.

Structural deformation within the Lewisian is very varied and allows identification of a number of phases of folding - refolded and isoclinal folds are common. As a general rule of thumb the more nearly parallel the limbs of folds are the earlier the fold is, as the rocks cooled and became less ductile brittle fractures begin to predominate. The presence of the later brittle folds deforming the earlier recumbent folds confirms this hypothesis.

The Lewisian is cut by a swarm of dykes first described by Teal in 1885 and known collectively as the Scourie dykes. These are basic dykes with very fine grained dolerite margins and gabbro centres which were intruded when the gneiss was cool. The dykes are generally steeply dipping and occasionally contain very large quartz veins. They have been dated at 2400 my and allow the relative ages of the deformation to be determined. Dykes are seen to either cut across folds or to be deformed. This relationship has allowed the identification of 2 complexes within the Lewisian - the Scourian, deformed before the intrusion of the dyke swarm, and the Laxfordian, deformed following the dykes. The dykes exhibit variations in grain size due to rapid cooling at the margins and this has resulted in the centre of the dykes being more resistant to erosion (coarser grained, fewer joints) and forming a prominent topographic feature whilst depressions associated with the more easily weathered margins occur on either side.

The scenery in the areas of Lewisian outcrops is very characteristic. In the area of the relatively undisturbed Laxfordian complex layered gneiss produces gently dipping dip and scarp slopes with a cliff and bench type topography. In the Scourian the landscape is very steep and craggy with no dip or scarp slopes and long thin lochs resulting from the highly folded nature of the rocks. The contrast in the nature of the terrain between the 2 complexes is readily observed on aerial photographs. It was note that Rip Tinto Zinc had been prospecting for gold in the southern area of the Lewisian but had not found enough to justify exploitation.

The unconformity between the Torridon Group and the Lewisian is not flat, but has hills and valleys in it. Boulder beaches are also

seen, with boulders up to 1m across at the base of Lewisian palaeo-cliffs with a reduction in the size of Lewisian clasts away from the cliff. The unconformity within the Torridonian, between the flat lying Torridon Group and the underlying dipping Stoer Group shows large boulders of Stoer Group and of Lewisian in the Torridon Group basal conglomerate and at one location the presence of limestones at the top of the Stoer Group, these are the oldest limestones in Britain.

Large scale cross bedding is present in the Stoer Group sandstones but it was noted that sandstone is not the only lithology developed in this group. Volcanic mudstones are also present along with channel sandstones, pebbly and laminated sandstones, ripple bedded units, mudcracks which point to a seasonal climate (considered to be tropical from palaeo-latitude considerations) with flash floods.

The Stoer Group has an estimated thickness of c.6km and the Torridon Group c.9km. They are believed to have accumulated in a rift system which preceded the opening of the Iaepetus Ocean. Evidence for this comes from sedimentological data indicating sediment being fed from both sides of a rift and the relatively long outcrop compared to the thickness.

The dipping Cambrian sequence lies unconformably on flat lying Torridon Group and in some cases on the Lewisian. The Cambrian sandstones are derived from the Torridonian by are generally quarzitic with very little feldspar. The sandstones were deposited in a shallow water tidal environment, the cross-bedded units having vertical worm burrows typical of such an environment. At the top of the Cambrian is the fossiliferous Durness Limestone which extends in age into the Ordovician. Overlying the Durness Limestone is a quartz mica schist, the surface between the two is the Moine Thrust.

Finally Mr Crossley reviewed the recent geological history of north-west Scotland, providing slides showing examples of corries, hanging valleys, roche moutonee, perched blocks, raised beaches and debris slides.

GEOLOGICAL ASPECTS OF THE A66 TRUNK ROAD IMPROVEMENT FROM STAINMORE TO BANKS GATE

A lecture by David O'Farrell from the Civil Engineering Laboratory of Cumbria County Council's Department of Construction Services West Cumbria College, Whitehaven on 12 October 1994.

The initial part of the presentation was a review of the methods of obtaining and studying geological and other geotechnical information employed inroad scheme design and construction. Explanations were given of the desk top studies carried out using existing data which lead to the design of the main ground investigation. The techniques used for investigation include drilling (both soft ground and rock) trial pitting, geophysical surveying and field mapping of exposures. The field work is followed by the laboratory testing of samples and interpretation of these results and other information to give recommendations to the scheme designers. The interpretation should give guidance on a number of aspects including foundation strengths, slope stability, potential methods of rock excavation and the suitability of all excavated material for re-use within the works. The interpretative report also suggests methods of treating problem areas such as those underlain by mine workings or other cavities, those places with very deep soft deposits or locations where contaminated materials may be present. In general terms the design should ensure that the majority of excavated materials can be used for filling thus reducing the demand for imported material and space required for tipping unsuitable materials.

A detailed description was then given of the Stainmore improvement which comprises 5.9 km length of dual carriageway from the eastern end of the Brough bypass to Palliard Bridge. The route traverses a series of rocks of Carboniferous age (Dinantian and Namurian) consisting of limestones, sandstones, mudstones, siltstones and occasional coal seams. These sequences are known as the Alston and Stainmore Groups. The geological structure is modified by significant faulting and folding, part of the sequence being repeated along the route where the coal seam beneath the Four

Fathom Limestone is shown to occur at three separate locations. The coal seam is most probably the Borrowdale Coal which is known to have been extensively worked to the north of Stainmore at the Borrowdale Colliery. The major faults trend generally in a north-west direction downthrowing to the south-west and near the Punchbowl Hotel, the Augill fault is shown to have a displacement of some 200 metres resulting in steeply dipping near vertical strata. Elsewhere the strata dips at varying degrees generally to the north-east. The rocks are generally obscured at the ground surface by superficial deposits consisting of glacial till (Boulder Clay). To the east of Banks Gate the Great Limestone is near to the surface and a typical limestone pavement is close to the route at its highest elevation near the Stainmore Café. A number of swallow hole features were also identified in the limestone part of the succession close to the road.

Three particular areas with potential construction problems were identified from the ground investigation process and these were identified in more detail.

- Firstly the geological structure encountered in the ravine on the south side of the existing road at Augill Beck posed difficulties in designing the headwall for the culvert carrying the Beck beneath the extended embankment. Difficulties were also encountered by the Contractor during the construction phase. An explanation of the interpretation of the geological structure was given together with its effect on the design.

- The second geological feature described was the occurrence of shallow coal workings both in the form of bell pits and adits. These occurred in four separate locations and were thoroughly investigated by drilling. In addition to this the adits were inspected to assess their extent by the use of a specialist team of cavers who entered the network and carried out a survey. The areas where workings were considered to be within 10 metres of the ground level were treated by drilling a grid of holes at 6 metre centres and injecting a cement based grout prior to the main construction contract.

The final feature described was the location and treatment in the area of a natural cave system near Slapestones Bridge. The system had been mapped by local caving enthusiasts and this information was used as a basis for further work. The exact location of the cave system was marked at ground level using an Ultrasonic system. Again a caving team was used to enter the system carrying a transmitter which was tracked by a receiver at the ground surface directly above. The caver also confirmed the details and cave dimensions published on the original plan. The cave was found to be very close to the rockhead level and the superficial deposits were very thin - mostly topsoil. Consequently it was decided to construct a concrete slab at existing ground level over the area underlain by the cave upon which an embankment would be built to carry the new road.

The presentation concluded with a selection of colour slides illustrating the substantially complete project which was opened to traffic in December 1994.

THE RECENT GEOLOGICAL INVESTIGATIONS AROUND THE SELLAFIELD AREA

A lecture by Dr Bob Chaplow, Manager for Site Characterisation, UK Nirex Ltd, at West Cumbria College, Whitehaven
9 November 1994

UK Government policy and that of numerous overseas governments is that the long term disposal of radioactive waste should be in a deep underground repository. Nirex are tasked with developing such a facility for low and intermediate level radioactive wastes in the UK.

The approach that Nirex are taking encompasses the following requirements:

1) Future generations should be afforded the same level of protection as the present day.

2) The disposal system should not rely on intervention or monitoring.

3) Deep geological disposal should be utilised to provide multi-barrier containment.

Since 1991 Nirex has focused its attention on Sellafield. The investigations are targeted at evaluating the 4 main pathways for migration of radioactivity back to surface. These are via groundwater movement, gas migration, human intrusion and earthquakes. The most important of these is considered to be the groundwater pathway and Nirex is undertaking an extensive geological and hydrogeological study to characterise the groundwater chemistry and movement in the vicinity of the potential repository location.

Dr Chaplow described the scope of the work. Surveys have been undertaken on a regional, district and site scale with seismic, airborne geophysics, geological mapping, hydrogeological and hydrological surveys being conducted. In addition investigative boreholes have been drilled to obtain detailed information on the subsurface geology and hydrogeology. The investigation work is now being concentrated on the potential repository zone and the site of the Rock Characterisation Facility (RCF) at Longlands Farm near Gosforth. To date some 1950 km of seismic data and 8500km of airborne geophysical data have been acquired and 20 deep boreholes drilled.

Activities undertaken during and following drilling were briefly described. Long term monitoring of boreholes is undertaken using "Westbay" multipacker test strings to establish baseline groundwater system data and to monitor changes due to natural and induced effects.

Dr Chaplow placed the geology of the Sellafield area in its regional context, indicating that it was on the edge of the East Irish Sea Basin, which had been a major influence on the evolution of the Sellafield site. An east-west geological section was presented showing the Borrowdale Volcanic Group (BVG) outcropping in the

east but overlain by up to 1800m of sediments at the coast. In the vicinity of the proposed RCF the BVG is overlain by rocks of the Sherwood Sandstone Group (Calder and St Bees Sandstones) and the Brockram.

One of the major objectives of the investigation is to establish the location and nature of faults - in order to achieve this a 3 dimensional geological model of the area is being built up. A map showing the depth to the top of the BVG was presented which clearly showed the location and orientation of faults and fault scarps. Faults with throws >30m can be recognised using seismic data, smaller faults and fracture zones situated between boreholes can be identified using crosshole geophysical techniques.

Hydrogeological studies have been directed at improving knowledge of groundwater pressures, hydraulic conductivities, fracture studies, groundwater geochemistry and numerical modelling of groundwater flows. A wide range of tests are proposed to examine the fracture system at scales ranging from 1m to 1km. Although only a limited number of such tests can be undertaken in any one borehole the RCF will provide the opportunity to conduct tests over all of these ranges.

Hydraulic conductivity data from the BVG indicates that faults are not necessarily associated with flowing zones, on average there is 1 flowing fracture every 50m and the larger faults do not appear to be zones of enhanced permeability. - there does however appear to be a good correlation between the age of fractures, their mineralogy and flow characteristics.

Dr Chaplow explained that geochemical data had proved significant variations in salinity with fresh water in the sandstones at the RCF location and salinity values of up to 6 times that of seawater in the BVG at the coast. Four zones of differing groundwater chemistry have been identified, those being the coastal, intermediate and repository zone boreholes and lake sediment porewater and springs. The mixing of two groundwater types originating from the

BVG/granites and the dissolution of halites in the EISB is also apparent.

Preliminary groundwater age data shows lighter oxygen/hydrogen (cooler temperatures) isotopes in deep groundwater samples that may be indicative of recharge in the Late Pleistocene. C^{14} values $\geq$ 30 000 years have also been determined.

Dr Chaplow then turned to the programme for the Rock Characterisation Facility (RCF) emphasising that it was intended purely as an experimental facility with its development envisaged in 3 main phases:

1) Sink 2 shafts to 700m, linking the shafts to obtain data during sinking (estimated duration 3.5 years).

2) Drive out galleries at the level considered most suitable for the repository, conduct experiments and drill exploratory holes (horizontal and inclined). (estimate - 2 years)

3) Undertake extensions to the galleries parallel to the direction of minimum ground stress (estimate - 4 years).

It was noted that following the submission of a planning application for a repository a period of 10 years of further work was anticipated before the final approval of the safety case - if planning permission for the RCF were granted in 1995 it would not be until 2005 that construction of a repository would commence.

(Editors note - a detailed review of the geological aspects of the investigation work to date is presented in Volume 50, Part 1 (1994) of the Proceeding of the Yorkshire Geological Society).

CURRENT THOUGHTS ON THE DEVELOPMENT OF THE COAL MEASURES IN CUMBRIA

A lecture by Dennis Dickins of Cumbria Environmental and Geological Services, on 18 January 1995 at Castlegate School , Cockermouth

Mr Dickins indicated that the lecture was a review of research and exploration since 1970, recent work on the Maryport/Stublick/90 Fathom Fault and its relationship to coal deposition, and various features of geological interest which he had noted during his time with British Coal. It was emphasised that with regard to the coalfield it was mainly the interpretation of data which had changed rather than much new data becoming available.

A geological map and geological succession were presented which drew on the results of British Coal Open Cast (BCOC) exploration since 1970. The major problem that was encountered by the BCOC geologists was that there had been no satisfactory correlation of seams across the coal field - the deep mines had only worked the thick seams and the thinner seams (those as thin as 10cm were worked by BCOC) were not considered in the correlations. The situation was further complicated by the use of local names for seams and the structural complexity of the area.

One significant aid in resolving the stratigraphy of the coalfield came in the form of the BGS when they commenced the remapping of the area in the 1980's. This was as a result of both BCOC work and promised oil exploration in the Solway. The other significant development was the use of geophysical logs (natural gamma and density) in exploration boreholes which permitted rapid identification of lithologies and bed thicknesses and detailed correlation between boreholes on the basis of differing responses from coal, sandstone, mudstones and marine bands. The geological succession presented incorporated data from all of these areas and was considered to be the most accurate and up to date on the basis of the information available.

Mr Dickins then turned his attention to recent research on the Solway Basin and the role of the Maryport Fault. Structural events in the area have been the prime influence on the sedimentary history. The Caledonian Orogeny at the end of the Devonian and the post-Carboniferous Hercynian movements were the dominant phases with Tertiary events having a much lesser impact.

The history of the Solway Basin commenced at the end of the Devonian with the final closure of the Iaepetus Ocean. Recent geophysical work by Chadwick and others on the Solway Basin has indicated that the subduction zone probably dipped at 25° and lay beneath what is now the Southern Uplands. Listric faulting along the margins of the basin commenced in the early Carboniferous times and ceased in the Namurian. From then on there were pulses of movement associated with the Hercynian Orogeny and Variscan uplift. There was subsequent reverse movement along the fault followed by crustal sag which ultimately led to basin inversion.

Recent geophysical evidence points to the Maryport fault being a growth fault during the Carboniferous (i.e. the fault was moving during deposition) - if this is the case it is likely that there was up to 1000m of Westphalian (Coal Measures) strata deposited in the Basin with no more than 500m deposited to the south of the Maryport Fault (all of the thicknesses quoted are prior to end and post-Carboniferous erosion). It is likely that the (onshore) Canonbie coalfield is a relic of deposition which extended over the Solway area.

Mr Dickins then described some of his experiences and observations during his time with BCOC. The West Cumbria coalfield was deposited on a fluvio-deltaic plain - Mr Dickins provided an explanation of the evolution of such a system, indicating the development of coals and other facies and likely rates of deposition. The different varieties of coal were identified and described - Fusain (carbonised wood), Vitrain (shiny coal), Durain (dull coal), Clarain (a combination of bright and dull bands) and Cannel (a coal produced from algal matter). Coal from the West Cumbria coalfield can be high in volatiles and inherent sulphur with a tendency to slag - this is one of

the reasons for the closure of the opencast activities in the area. Mr Dickins showed indications of volcanic activity during Coal Measures deposition, evidenced by small brown flecks which occurred near the top of mudstone units. Tonsteins (clays of volcanic origin) were well known in the Durham and Northumberland coalfields and these "fragmented clay rocks" in the West Cumbria Coalfield were considered to be the lateral equivalent, indicating that the coalfields in the north-east were closer to the volcanic source.

Mr Dickins closed his talk with a series of slides providing examples of some of the features he had noted during his work with BCOC including glacial disturbance of measures, washout channels within the measures, sandstone dykes, structural disturbances and faults. The final set of slides provided a view of the Keekle opencast site where all of the features found in the coalfield had been observed - of note was the junction of the Whitehaven Sandstone and the Coal Measures (now preserved as a RIGS site) and the unconformity between the Permo-Triassic and the Carboniferous.

PLATE TECTONICS, VOLCANIC ISLANDS & PYGMY ELEPHANTS: THE SICILIAN CONNECTION

A lecture by Dr Martyn Pedley of the University of Hull,
on 22 February 1995
at Tullie House Museum & Art Gallery, Carlisle

Sicily sits at the centre of a number of major geological features of the Mediterranean. It lies at the divide between the Eastern and Western Mediterranean basins and the mountainous north of the island represents the continuation of the Alpine fold belt which runs down the centre of Italy into North Africa (the Maghrebian chain). The south-eastern area is characterised by rolling hills with canyons and gorges of Miocene to Oligocene limestones with Quaternary limestones on the periphery. This large limestone massif, the Hyblean Mountains is part of the African Plate, the Alpine fold belt to the north is part of the European Plate which has been thrust on top of the

African plate - the most southerly allocthonous unit of the European Plate is the Gela nappe.

The main phase of volcanic activity in the area was during the Pliocene and the Quaternary although the Central Mediterranean Graben is still an area of active volcanoes (e.g. Pantellaria, Linosa). The most famous of the volcanoes in the area is Etna which is located above the subduction zone where Africa was plunging under Europe. Activity on Etna commenced in the Late Pliocene, today the majority of the activity is restricted to eruptions via satellite cones on the slopes of the mountain. Pillow lavas (submarine) are present at the base of the succession (dated as Late Pliocene to Pleistocene) which give way to subaerial lavas. The volcanic pile now occupies a very large area and the height of Etna has resulted in every climatic zone in Europe, from Mediterranean to Arctic tundra being visible on the mountain. Dr Pedley showed a superb photograph of an exposed lava flow feeder dyke and of the flanks and summit of Etna. It was noted that access to Etna is restricted due to the potential for violent eruptions of volcanic bombs which have accounted for a number of fatalities in the past. A recent example of human intervention to redirect a lava flow from the volcano was noted. The inhabitants of the town of Nicolosi hired bulldozers and successfully diverted a lava flow away from the town, only for it to wipe out a small village!

The Quaternary succession of SE Sicily indicates a progressive decrease in water depth. The base of the succession comprises deep water clays deposited in the foredeep above the subduction zone in water depths of 300m or more. This facies is characterised by planktonic foraminifera and a pelagic fauna. Occasional erosion surfaces with overlying shelly facies represent material from further up the slope resedimented by storms or earthquake activity. This sequence is overlain by clays & sands deposited marginal to the massif, the thinly bedded sands with occasional limestones contain a shallow water fauna. These clays and sands are followed by shallow water limestones which onlap onto the Tertiary Hyblean region. The limestone contains coralline algae which have volcanic clasts as their initial nucleus. By the end of the Early Pleistocene significant changes had occurred with these sediments giving way to marly clays and

sands, then brackish and freshwater facies with freshwater tuffaceous limestones giving way to true tufas.

Thick palaeosols are present directly above deepwater clays indicating that large areas of land became emergent. The lower surface of these palaesols is very flat - due to the withdrawal of the sea without the erosion of sediments. The margins to the emergent Hyblean island contain a series of blind caves which may extend for up to 50m and then stop dead. These caves are now at an elevation of 3 - 400m above sea level but are in fact sea caves - evidenced by the presence of shallow marine bivalves. Remains of elephants were also discovered in the caves. A complete skeleton indicated a height of ~1m at the shoulder, these are *Elephas falconeri* a dwarf species derived from *Elephas antiquus* the European elephant. These dwarf species are peculiar to the Middle Pleistocene of Sicily and Malta and were subsequently succeeded by normal sized elephants. Pygmy hippopotami and dormice the size of cats have also been recorded.

This change of base level could have been caused by eustatic events or by tectonism. There is evidence for eustatic events from the influx of normal sized African elephants but there are also significant structural features that need to be considered. The Sicili line, a series of en-echelon fractures and associated horst and graben features in a dextral shear setting started to develop in the Miocene - variations in sequence thickness follow the lines of the faults with horsts carrying limestones and the grabens thick evaporite deposits. The limestones on the horsts show evidence of synsedimentary deformation, dykes and basalts occur along the fault lines.

The Sicili line penetrates through crust of the African plate and is caused by the pushing of Africa under Europe. The entire floor of the Tethys ocean was consumed by the subduction process and by the Miocene the continental crust of Africa was being pushed against Europe. Africa started to stress and crack under the compressive forces associated with subduction of continental crust. However, true subduction did not occur due to the buoyancy of the African crust.

Early Pleistocene terraces in the Hyblean massif have been mapped at a variety of heights from 25 - 600m above current sea level, they are at their highest close to the Sicili line (a dextral shear complex lying close to the western side of the Hyblean massif). Clays on these highest terraces were deposited in 300m of water indicating uplift of the order of 1,000m in as little as 100, 000 years. Much of the sea level change is therefore tectonic - the frontal margin of the buoyant African plate could not subduct below Europe - areas to the west and east in the Caltanisetta and Ionian basins were trying to subduct but the Hyblean element was locked in place, consequently tears developed along the present lines of the Sicili and Malta scarp structures.

At the same time the Gela Nappe was emplaced from the north, depressing the leading edge of Africa even further. During the early Pleistocene tholeiitic lavas began migrating up fractures associated with the Sicili, Malta scarp, and north-east/south-west tensional faults resulting from marginal loading by the Gela Nappe. It is these active systems that rapidly became the vehicle for active uplift along the northern margins of the Hyblean massif.

As uplift occurred the SE area of Sicily became a large island which probably extended south as far as Malta and *Elephas antiquus* entered. A subsequent, probably eustatic, rise in sea level dramatically reduced the land areas. Two features have been noted regarding animal populations in island environments, either they become extinct because of competition for food and space or natural selection operates in favour of smaller individuals in order to maintain a viable gene pool. This provides an explanation for the diminutive elephants and hippopotami but fails to address the dormice! Regional uplift occurred in the Late Pleistocene and large elephants returned.

Dr Pedley concluded by stating that tectonic activity is still ongoing, with faulting visible in walls and roads, there are numerous effects in response to the isostatic disequilibrium and vulcanicity is still a hazard for residents of parts of the island.

QUATERNARY LANDFORMS OF UPPER EDENSIDE

A lecture by Dr Wishart Mitchell of Luton University
on 29 March 1995
at The Sixth Form Centre,
Queen Elizabeth's Grammar School, Penrith

Establishing a chronology of glaciation in the Yorkshire Dales and the Southern part of the Lakes is difficult due to the fact that the most of the work was undertaken by Victorian geologists with the most recent work being that of Raistrick in the 1930s and 1940s. The two most recent events, the Late Devensian Stadial and the Loch Lomond Stadial are the only periods of glaciation in these areas for which detailed evidence exists.

Although in the late 19th century Dakyns and other workers recognised the impact that glaciation had on the area through their work in the Yorkshire Dales, relatively little is known about the extent of the Late Devensian Ice Sheet - this is based essentially on Victorian mapping. The Victorian concept of glaciation was of ice flowing down the major valleys, with the Western Pennines being capped by ice constrained by ice from the North (Scotland) and the west (Lake District). In the early part of the 20th century workers such as Trotter and Hollingworth determined drumlin patterns and invoked the concept of basal ice divides to explain complex patterns where flow of ice was proposed up, as well as down the Eden Valley. The current view is that the chronology is complex and that various drumlin fields may be of different ages but this is impossible to unravel due to the absence of dates from the north of England. The Devensian ice sheet in Britain was very small compared with the Laurentide or European sheets - the current view is that the British ice sheet was separate from that of Europe.

Dr Mitchell addressed some of the problems surrounding drumlins - they are not just lowland features having been noted at elevations of up to 600m AOD. They do however appear to be associated with subglacial ice sheet processes. The possibility of them being of glaciofluvial origin has been raised in other areas,

particularly Ireland, but this does not seem possible in this area given their presence on high plateau areas - other causes, either erosional or glaciotectonic deformation of soft sediments beds were also possibilities - it was concluded that the mode of formation of drumlins was not readily understood.

Detailed field mapping of the drumlins had identified three main groups; the Wensleydale drumlin group with indicated flows to the east, the Deepdale/Dentdale/Ribblesdale group which indicate southerly flow, and the Rawthay group flowing west-southwest and joining with the Lune ice to flow onto the Lancaster lowlands. Plots of measured drumlin length indicate that the longest are in the Rawthay and central parts of the Wensleydale groups. Mapping has also indicated the former presence of a linear ice divide stretching from Wild Boar Fell across Garsdale and Dentdale towards Great Coum. This data has been used to establish models of ice streams by employing techniques, used in Canada and Greenland. There is evidence that ice has moved in different directions at different times - for example an inferred ice divide on Baugh Fell migrated to Wild Boar Fell with time and similar evidence is available from other areas.

Erratics of the Bluecaster dolerite on the eastern flanks of the Howgills Fells, transported by glaciers and subsequently incorporated in drystone walls have also been used to map the flow direction of glaciers. This northern movement of the ice divide explains the presence of Bluecaster dolerite erratics both in the Kirkby Stephen area and to the south - it appears that the ice divide has been wobbling about around topographic high points with time. Following the disappearance of the ice sheets there is very little data on post deglaciation times.

The last phase of glacial activity in Britain, the Loch Lomond Stadial, is represented by numerous glacial moraines in the Lake District. Only 5 small glaciers have been identified in Wensleydale, now represented as corries at Cautley Spout, Swarth Fell, Combe Scar, Whernside and Great Coum. Of note are features such as terminal moraines at the bottom of corries and debris flows resulting from landslides in the top of the moraines. Features mapped in the

Eden Valley by Rowell and Turner in 1952, and interpreted as glaciers, occur on both sides of valleys (which would not be expected) and are in fact deep seated rotational failures which produced landslides which are probably the same age as the glaciers.

Reconstruction of the palaeoclimatology of the glaciers allows an estimate of the equilibrium line to be produced. These indicate values ranging from 312m at Combe Scar to 618m at Whernside - these values are very low when compared with what would be expected on the basis of other information on the Loch Lomond Stadial. A rise in equilibrium line is noted going from the west, going both eastwards and northwards. The preferred explanation is that this is probably due to local environmental factors such as wind direction and snowblow - where snow is blown into the corries from the plateau areas above. This serves to indicate the effect that local factors can have on a palaeoclimate interpretation.

THE GLACIATION OF THE NORTHERN PENNINES

A lecture by Dr Angus Lunn of the University of Newcastle upon Tyne
on 27 September 1994
at Cockermouth School, Cockermouth

Dr Lunn began his talk by identifying his definition of the Northern Pennines as the area bounded by the Tyne gap and Stainmore (i.e. by the A66 and the A69 roads). The whole of this area is an Area of Outstanding Natural Beauty. In geological terms this is the Alston Block and the northern part of the North Pennine Orefield. From a geomorphological point of view the extensive lead mining features can be confused as natural features. The area is very accessible due to the number of roads built by miners and royalty owners. Most of the roads run from one valley to the next.

The solid geology of the area is very well known, the glacial geology is less well known, the North Pennines are not obviously glacially produced but are in fact highly modified.

The structure of the North Pennines is that of an uplifted fault block defined by the Stublick, Pennine and Lunedale Faults and tilted but not fault bounded to the east. This block consists almost entirely of Carboniferous rocks of Dinantian to Westphalian age which are underlain by an early Devonian granite batholith. During the Late Carboniferous to Early Permian the Whin Sill was intruded and today this forms the spectacular outcrops such as High Force in Teesdale and High Cup Nick in the Western Pennines. The topography is that of a table land dissected by dales. The dales appear as half radiating from a centre at Cross Fell. The dales are characterised by benched valley sides resulting from the erosion of alternating hard and soft rock types in the Yoredale sequences.

Very little modern work has been undertaken on the superficial deposits and landforms of the Northern Pennines, the 1:25 000 Middleton-in-Teesdale sheets and part of the Penrith 1:50 000 sheet are the only post war publications. Three PhDs have been undertaken in the past 10 years.

The environmental history of the quaternary is of a long sequence of cold and temperate climatic episodes in these latitudes - in many of the cold episodes Northern England must have been glaciated but nearly all previous glaciations have been removed by the most recent. Each glacial erosion event will have enhanced features left by previous events. All deposits date from the last glaciation or subsequent events.

The Lake District is a classic example of valley and corrie glaciation, in contrast although the Northern Pennines may have experienced valley glaciation, ice sheet glaciation predominated with ice moving across the valleys.

As elsewhere the direction of ice flow has been determined by the distribution of erratics. The most significant are Lake District rocks and the Vale of Eden sandstones. The distribution of the erratics indicates that the North Pennines were overridden by ice from the north and west. However, in the area of Cold Fell, south of Brampton, there is an erratic shadow - Cold Fell was sufficiently high to prevent

Lake District erratics from being deposited there. No erratics from the west have been recorded from the area to the south of Hartside indicating the southern limit of Lake District ice overriding the Pennine escarpment. In the South Tyne Valley erratics indicate ice flow from west to east but rock striae and stone orientation in boulder clay indicate that the final ice flow direction was from south to north. In Allendale the stone orientation is to the southeast indicating ice having veered round to this direction after having got into the Tyne Gap. Weardale, Teesdale and Upper South Tynedale were also glaciated by local ice, this area being another sanctuary from the invasive ice sheet carrying the Lake District erratics.

In 1916 J W Heslop-Harrison put forward the idea, based on the presence of a number of species of alpine plants in Upper Teesdale, that certain areas stood above the ice as nunataks and that the plants survived the last glaciation on these nunataks. The idea was taken up by Raistrick who produced a map showing the distribution of nunataks. The evidence was the absence of till above 2000 feet and the extensive and abundant evidence of periglacial activity. After the second world war pollen analysis of material deposited after the last glaciation indicated that alpine plants were abundant throughout Great Britain. Glaciologists also felt that the North Pennines were entirely buried by ice. The evidence for this was the radial flow of ice indicated by the orientation of the valleys and the requirement for ice on Cross Fell to explain the direction of ice flow observed to the north (flow towards the northeast) and to the south (southeast). Added to this was evidence of glacial erosion of sandstones and of glacial meltwater channels flowing uphill which can only occur under ice. More recent computer models are equivocal.

The consequences of glaciation on the landscape are seen in four types of erosion:

1.Landscapes of aereal scour

2.Selective linear erosion

3. The landscape has been glaciated but there is little evidence of it (there has been no erosion).

4. Local mountain glaciation (?corries and valleys similar to the Lake District).

The style of the aereal scour depends on the rock types and the structure. In limestone areas aereal scouring gives limestone pavements but in the North Pennines glacial material overlies these pavements.

In the Northern Pennines there is a continuum of forms from asymmetric valleys to "stoss and lee hills". The asymmetry of the valleys is due to the ice flowing across the valleys. The side of the valley that is in the lee of the ice flow is smooth and tapered, the side facing into the ice is steeper and rougher. The main exception to this is Weardale„ but since this trends west to east the ice would be flowing along the valley, the northsouth trending tributaries are however asymmetric. The mechanism for the formation of these asymmetric features is not understood. Ice moulding of ridges of rock also occurred (all trending eastwest) along with local roche moutonée associated exclusively with the Whin Sill.

A series of giant erratics known as the Bulman Hills, the best examples in the North of England occur a mile north-east of the summit of Cross Fell. These erratics are 100 - 200m in diameter and 12 - 15m high. They comprise a sequence of Great Limestone strata rafted from an outcrop about 1 mile away. There are many more erratics further to the east but these are largely buried by glacial drift. Several have been proved by opencast boreholes in the coalfield. At Broom Hill near Tow Law an opencast coal site worked an erratic and encountered glacial till beneath the coal bearing strata.

In a tributary valley of Weardale (Swinhope Burn, near Stanhope) a ridge has been mapped running across the valley, which, if encountered in the Lake District would probably be described as a terminal moraine. It consists of a series of masses of solid strata metres thick tipped in lots of different ways. This is known as the

Creerly Hills moraine and was pushed into place by ice having been removed from faulted strata on top of the hill.

The mechanisms for the generation and emplacement of these giant erratics are believed to be associated with movement at the permafrost / wet rock interface along a dislocation plane within a weak rock such as a seatearth or shale.

Less is known of the glacial deposits but they are also asymmetric in distribution. Boulder clays occur on the lee side of the valleys. Very locally the tills may get moulded into drumlins. Where tills lie on limestone shake holes are produced - these are even observed on the erratics of the Bulman Hills.

When deglaciation of the area commenced major meltwater channels developed which cut across the watershed between dales. These are thought to be subglacial, flowing beneath, and in the same direction as, the ice. As the ice became thinner these became chutes, where the water reached the base of the ice and ran along the valley floor. Marginal meltwater channels are also observed where ice is still present in the valleys but not on the hills. Here the water runs off the hills until it reaches the edge of the ice and then follows the edge until it reaches a chute. Very little deposition from meltwaters is recognised - the bulk of it is assumed to be in river gravels and other alluvium.

It is not clear if the Loch Lomond Interstadial reached the Northern Pennines. There is good evidence for a periglacial / tundra environment, this still occurs on Cross Fell today. Indicators such as soil blisters (caused by freezing in winter), stone polygons, stone stripes, ploughing blocks, block scree, block fields and frost riven boulders all appear in the Cross Fell area.

HOLES IN THE GROUND

A lecture given by Mr I. A. Williamson, Consultant Geologist, at Queen Elizabeth School, Penrith, on 26 October 1995

Mr Williamson, formerly Head of Mining Geology at Wigan College, has spent the last 20 years as a consultant , particularly on matters relating to mining activity in Carboniferous strata. The focus of the lecture was on the effects of coal mining, especially in urban areas, and the speaker drew on his first hand experience of many local problems in the north-west of England.

First the basic techniques of underground mining were explained from the earliest times starting with the extraction of black nodules of flint from the chalk at Grimes Graves in East Anglia by late Neolithic and Early Bronze Age man. Primitive 'pillar and stall' working enabling up to 70% extraction levels was illustrated. The regular pattern of coal working at Hapton Colliery, near Burnley around 1800 and at Wigan Nine Feet by similar methods, was also illustrated. Early circular 'bell pits' in coal field areas were described and explained. Subsidence of the surface into workings of these kinds were shown to be a major problem of old abandoned coalfields to the present day.

The complexity of building and present day development in old coalfield areas like South Lancashire were highlighted. It was pointed out that the Carboniferous sequences in these areas were exploited not just for their coal but that fireclay, thin ironstones, shales for brick making and even flagstones for roofing were all extracted by underground mining. Limestones were also mined under Ardwick in central Manchester and in areas in Scotland where good limestone in the Dinantian is scarce. The lack of mine plans for early workings is a difficult problem facing the Consultant Geologist today when asked to advise on surface conditions. The speaker illustrated difficulties in interpreting borehole data in areas previously worked underground and the difficulties encountered in locating old shafts and tunnels.

The speaker illustrated the variety of different types of failure associated with ground in mining areas, stressing that such failures may be long lasting and occur up to 100 years after mining has ceased. The effects vary from simple collapses into workings leaving depressions in the surface, to complex migration of voids upwards into the overlying strata that takes time to close. The effects associated with fault structures were shown to be particular sources of problems. Some excellent slides illustrated some of the problems in the Burnley and Wigan areas where the effects on buildings, roads, motorway sites, the Leeds-Liverpool Canal and old industrial sites were striking.

The material was put into the historical context with contrasts between the early primitive mining activity and the more modern techniques. The way the diameter of mine shafts grew in size from around 4m in the 1800's to over 10m today was illustrated, and the way early Bell Pits were only able to penetrate down to 20m, whereas with modern pumping equipment deeper mines became possible.

Finally, Mr Williamson illustrated some of his recent work where problems relating to the build-up of methane gas in tunnels and old workings was explained. The well known disaster at the Abbeystead Pumping Station was discussed.

An audience of over 20 members produced an interesting set of questions for the speaker who was thanked not only for and interesting and informative lecture but one delivered with some fascinating and at times humorous examples.

GEOLOGICAL MAPPING AND PROSPECTING FROM SPACE

A lecture by Mr J. McM. Moore, Head of the Geological Remote Sensing Group, Imperial College, University of London on 8 November 1995 at West Cumbria College, Workington

Mr Moore indicated that his talk would cover two topics, Remote Sensing (Space and Aircraft imaging) and Image Processing (the enhancement of digital data displayed in image forms).

Remote sensing uses the ultra-violet to microwave area of the electromagnetic spectrum, predominantly in the 0.4 - 2.5 μm (the visible and short infra-red) but with some use of the thermal region of the spectrum (8-11μm wavelength).

The best known of the remote sensing satellites for geological applications is LANDSAT 5. This orbits the earth in such a way that the entire surface (with the exception of the near polar regions) is covered every 16 days. Images are gathered at 9.30 - 10.00 am, the time of day when statistically the cloud cover is least. The satellites have 2 sensors and orbit at heights of 700 - 900km. The multi-spectral scanner, using filters for green and red visible light and 2 differing parts of the near infra-red, collects 4 different images. The data is acquired by a scanning mirror which constructs images in a 185km wide swath. Individual picture elements (pixels) vary between 79 and 30 m square depending on the version of the sensor - i.e. of the order of the size of a football field. There is therefore a limit to the scale at which the image can be used.

An example of an image of the Lake District showed water as black - infra-red (IR) is absorbed by water. Differing types of vegetation are easily discerned - the IR detectors are very sensitive to the amount of chlorophyll and geological features (e.g. the Pennine Fault) are defined indirectly by changes in vegetation. Trees reflect 15% of visible light (green) but 40% of IR, IR thus gives better results and images for identifying vegetation types and is very good at identifying different types of land use. If 3 separate images are combined false colour composite images can be produced. Several examples of these false colour images were shown including one of the Ngorongoro crater in the African Rift Valley, where faults and salt lakes were clearly visible. The crater itself appeared as an island of vegetation surrounded by desert. An image of Cyprus allowed easy identification of an ophiolite sequence on the basis of the differing vegetation types.

There are four types of resolution in space imagery:

1. Spatial
2. Spectral (sensor wavelength, range)
3. Temporal (16-18 days)
4. Radiometric (detector sensitivity)

The example of two images of Mt. St. Helens, one taken in 1975 and one taken following the eruption in 1980 were used to indicate the concept of temporal resolution and to highlight the potential of the tool to monitor geological change. A further example was that of an image obtained at 0930 on a winter day over SW Scotland. The low elevation of the sun produced marked shadowing resulting in an extremely clear definition of the Southern Uplands fault which had been eroded out to form a series of scarps and discontinuous valleys in this area.

During the mid 1980's the introduction of the LANDSAT TM (Thematic Mapper) satellites resulted in an improvement in resolution from about 80m to 30m. The image is still subject to degradation (blurring) when it is enlarged with mixed pixels producing a "salt and pepper" effect due to mixed samples of terrain.

The newest LANDSAT TM satellites employs sensors which monitor the band 5 and 7 spectral regions where rocks are brightest. In Band 7, rocks containing water show a reduction in brightness - this opened up the opportunity to identify hydrated minerals like clays and gypsum. The increased resolution also allows topographic mapping down to a scale of 1:50 000. Use of multiple separate measurements permits the identification of rock types from space. Thermal imaging - mapping the distribution of soil moisture - can identify concealed features such as old river systems infilled by farming activity and wet mine workings.

In the late 1980's a French satellite (SPOT) was launched which produced 20m pixels but only recorded 3 bands producing standard false colour images. The improved resolution allowed the

production of maps at a scale of 1:25 000. Images of the town of Ermononville to the north of Paris were shown on both false colour (20m pixels) and in black and white (10m pixels). It was noted that the Russians had the capability to resolve to 5m but this was only available for limited areas of the world.

An example SPOT image of the Lake District picked out geomorphological features very well - Coniston and Levers Waters and the screes and dumps from quarries were clearly visible. However, because SPOT only records the standard 3 bands of false colour it is not possible to separate rock types - this could be done using LANDSAT. Other SPOT images were shown of Keswick, dominated by vegetation and geomorphologic features, and of Wasdale, with the Sellafield and Drigg sites being clearly visible.

An example of the way in which remote sensing data can be processed to produce a different presentation was provided using the gravity map of the Lake District contoured in the conventional way. The data was converted to a digital form, highs represented as bright areas, lows as dark, and then colour was added, providing a novel representation of the major subsurface geological units in the region.

The use of geochemical data as images in mineral prospecting was also demonstrated. Processing of the images allowed the recognition of a number of differing types of mineralisation in the Lake District based on a display of stream sediment geochemical data. The Borrowdale Volcanic Group of the Central Lakes, is characterised by high zinc trace element levels while high lead and barium coincide with the Alston area. High lead/zinc/barium occurs at Carrock Fell and high arsenic/bismuth/antimony (often a good indicator of gold!) define the Carrock and Coniston old mining areas. High values of arsenic were noted at Shap, Coniston and Carrock. Nickel/copper/chromium and antimony were indicated at Drigg. Uranium was indicated on the MOD firing range above the Appleby to Brough road and was also present at Drigg.

The lecturer concluded by stating that the LANDSAT and SPOT imaging is on open file but is expensive to obtain in digital form

at about $5,000 per image. However, data is very cheap in hard copy as photographic prints.

PROBLEMS IN THE RECONSTRUCTION OF PAST CLIMATES

A lecture by Mrs M. Fox of the Cumberland Geological Society on 6 December 1995 at Whitehaven College.

Geologists recognise large scale climate changes which are indicated by such features as roches moutonées, hanging valleys, desert sandstones and subtropical forests. More recently work on identifying and predicting global climate change with resolutions of tens of years has become very important following the advent of concerns relating to global warming and other inter-governmental issues.

The lecturer indicated that she would concentrate on problems associated with the reconstruction of climatic variation over the last 500 years. One of the main sources for climate data, instrumental climate records, generally only extend back about 150 years. A review of temperature and pressure data on grid point coverage shows that even now there are some holes in the data set. Due to the inadequacy of the instrumental data other 'proxy' data is used. 'Proxy' data is obtained by identifying a parameter which varies systematically with climate. In order to calibrate these data a reliable present day instrumental record is required. This is not as easy as it may at first appear since the design of instrumentation, the locations in which instruments are sited and the way in which the data is measured may have changed. Station locations may also have changed (or the surrounding environment may have), observation times and interpolation methods could also have changed. Where inhomogeneities are recognised these can be corrected.

Examples of proxy data include tree cores, ice core data, coral geochemistry, oxygen isotopes in tufa cores (although there may be problems with oxygen isotope ratios interpretation) and varves (these can be resolved into annual events in some cases).

Documentary records of direct observations can also provide valuable information. Information such as the severity of frosts, hot days, droughts, floods, freezing of lakes, flowering of shrubs, harvests in government, estate records and maritime records or personal diaries are examples of such sources. There are however significant problems associated with accurate recording and subsequent interpretation. For example the often used phrase "in living memory" can be fraught with problems. Other difficulties such as changes in calendar conventions and copying errors (notably when using Roman numerals) only add to the problems. It is very rare to get a continuous set of records, however, examples are available from Northern Canada (The Hudson's Bay Co. where records extend back to 1760) and Iceland.

Ice cores provide high resolution (frequently annual) data for approximately 1000 years. Accurate dating of samples is achieved by the use of number of tools such as isotope ratios, electrical conductivity, particulate content and by re-freezing episodes (in Eurasian glaciers).

The ratio of the two isotopes of oxygen O_{16} and O_{18} reflects previous climatic conditions. The lighter isotope (O_{16}) is preferentially evaporated from water and the heavier one (O_{18}) preferentially condensed. There are however a number of problems which may provide anomalous results. Melting of the ice may result in the seasonal layers being destroyed and there is the potential for alteration by diffusion. Fine tuning of these records include the use of acidity peaks (from volcanic eruptions), β - radiation from atomic weapons testing and radio-carbon dating. Ideally a combination of these methods would be used. However it has to be recognised that there are a lot of factors influencing these parameters, e.g. the source and composition of the water, the weather, topography etc. so interpretation of the ratios is subject to uncertainty.

Dendroclimatology (the use of growth rings on trees for determining climate information) is the most accurate in terms of dating. It can provide an absolute indication of age and therefore has

great potential. However, the trees must respond to climatic change and therefore need to be on the limit of their ecological range in order for their growth to reflect best the climatic variations that are occurring. In high latitudes the ecological range is likely to be limited by temperature, at low latitudes by precipitation. Both climate related factors (e.g. sun, rain) and non-climate related factors (e.g. insects, competition, nutrients) affect growth and this needs to be considered when interpreting these data.

One annual growth ring comprises both early and late wood. The ring width is determined by the amount of growth and therefore the climatic conditions - radial growth is required so trees such as palms are not suitable for this type of study. Problems occur when double rings are formed, when rings are missing, and when rings do not extend around the entire circumference of the tree (the latter can be compensated for by the use of right angled sampling). Older trees put on thinner rings for the same amount of growth as a younger tree, so correction for age is needed for the ring width measurements.

Information from a number of sites is combined to provide a regional chronology. The longest continuous chronology using overlapping samples goes back to 1 AD, but wood up to 11,000 years old is available in S. America. One major, apparently world-wide, gap occurs at c 1200 BC, this may reflect some major volcanic event. Instrumental data is used to calibrate the ring width against temperature and then growth rings can be used to reconstruct past temperatures in the non-instrumented period. The ring width correlates best with June/July temperatures in the northern hemisphere - i.e. the period of maximum sunshine and therefore growth. Maximum 'late wood' density can also be used since this reflects growth over the entire growing period (6 months). It is unfortunate that although most of the data available using this technique reflects summer conditions - computer models indicate that any global warming is most likely to show in winter temperatures.

Principal Components Analysis which looks at spatial and temporal patterns in data has been used to investigate whether

results from one area can be used to reconstruct climate in another. An example for Principal Component 4 was shown for North America over the period 1947 - 1991. Over this period when the Great Lakes area was colder than normal, the Alaska/Bering Strait area was warmer and vice versa. This is attributed to the North Pacific Oscillation. The data analysed appears to correlate with the dendrochronology, but this is only a localised effect and is of no widespread relevance. A Principal Component 2 winter plot showed the effect of the North Atlantic oscillation, where differences in temperature between West Greenland and Scandinavia (one being cooler when the other was warmer) were apparent, but none of the proxy data correlated with this pattern.

Results of correlations across areas for the last 500 years have produced some interesting results. Ice cores from Antarctica show no apparent correlation across the continent. Temperature anomalies from the UK, Central Europe and Scandinavia show a good correlation between the 3 areas for the periods 1819-1828, 1868-1875 (both warm) 1810-1817 and 1832-1838 (both cold) - the eruption of Tambora in 1815 had a drastic effect on the climate, and is referred to as the year without a summer. At other times, one of these regions often fails to correlate with the others.

Sweden had several warm periods in the 10th, 11th and 14th centuries and 1570-1730 was the coldest period recorded whereas the coldest period in the Northern Urals was from 1530-1650 and the 20th century was the warmest. An examination of overall results for the northern hemisphere is inconclusive in indicating any trends - they could be interpreted as indicating either a fluctuation with a period of about 1000 years or as a lower mean with a significant warming in the last 60 years. If this warming continues this could result in a 2.5 ° C increase in average temperatures and a 50 cm increase in sea level by the year 2100.

Mrs Fox concluded by stating that results should not be taken from one part of the world and applied to other areas. Often quoted examples such as the 'Little Ice Age' of the middle ages may have

only occurred in the northern hemisphere - there was little data available from other areas of the world at that time.

PALAEOKARSTS, PITS AND PROBLEMS

A lecture by Dr Peter Vincent of the Geography Department, Lancaster University on 24 January 1996 at Castlegate School, Cockermouth

Dr Vincent introduced his talk by indicating that he would be exploring some new and provocative ideas to explain features observed in the Carboniferous Limestone.

Dr Vincent's work has been concentrated on Asby Scar, where the original intent of his research was to establish if there was a relationship between the petrology of the limestones and the form of the pavements. However, whilst conducting field work some very unusual surface features - mammilated limestone with lots of large circular holes were observed which were independent of any joint sets - these had never been recorded before. Augering the sediments infilling these holes revealed loess (wind borne dust) overlying ochre coloured clays - the latter classically interpreted as the residue from the weathering of limestones. In view of the accepted mode of formation of the limestone pavements it was expected that these clays were of glacial origin, however the nature of these clays did not suggest this. Further investigation required the digging of pits up to 4 ft deep (very hard work), this revealed a thick sequence of the red ochreous clay beneath the loess.

There is no evidence to suggest that there was Upper Carboniferous, Permo-Triassic or Upper Cretaceous deposition in this area. If the loess is of Permo-Triassic age the presence of pits, which appear to have survived glaciation, is difficult to explain unless the pits were in fact formed during the Carboniferous and what is observed now is in fact a Carboniferous karst sequence the top of which has been removed by ice action.

In order to assess this explanation the nature of Dinantian sedimentation needs to be understood. The shallow 'shelf' sea deposits were periodically exposed by tectonic and eustatic movements and there was also periodic volcanic activity which, when associated with subaerial exposure of the marine deposits resulted in the exposed pavements being covered by large amounts of volcanic dust. This dust weathered and decomposed to form soils which supported luxuriant vegetation.

The development of vegetation on a limestone substrate can result in significant amounts of CO_2 being generated by roots and soil micro-organisms. On hot damp days this can reach levels of 1% pCO_2 (pCO_2 is the partial pressure of the gas), more than enough to initiate karst development. The period of emergence would normally be followed by a sea level rise and development of shales which, when followed by a further rises would result in further limestone formation. Walkden has indicated that the duration of these cycles is of the order of 30,000 to 40,000 years - in a tropical environment this time period is probably long enough to generate the pits observed on Asby Scar.

During the formation of karsts the underlying limestones undergo a reorganisation with the production of calcretes. Calcretes generally show a lower joint system density compared with that of underlying, unaffected, limestones and hence have a greater resistance to erosion.

Consideration of these pits as solution features provides some important pointers as to their true nature. Examples were provided of these pits in coastal sections, along with examples in adjacent cliff sections, where the same features were observed in the cliff face as were seen in the shore sections - thus indicating that they were not the result of marine erosion. In these cases the 'wayboard' clays were observed above the palaeokarsts. These are non-fossilferous montmorillonitic clays related to the volcanic dust deposits.

Examples of these wayboard clays from various locations indicated the striking similarities with the clays found in the pits.

Comparison with the Devensian sections at Mosedale highlighted the very different nature of the two deposits - the Mosedale sequence was very poor in clay, being a typical gravelly glacial till, whereas the limestone pit clays contained virtually no stones and boulders.

The proposed model is that during initial glaciation at Asby the wayboard clays were pushed off the tops of the palaeokarsts and into the pits - if this is so then the pits must have preceded the glaciation episode. Further evidence for this is that a small number of pebbles have been found in the clays in the pits. Under an electron microscope these show both glacial fractures and chemical etching pits on their surfaces. The maximum size of the pits is 20 - 30 feet across but at Asby, since these represent the base of the pits, the original tops of the pits could have been much bigger.

PROGRESS OF SURVEY MAPPING IN WEST CUMBRIA: LOWLAND GLACIATION AND OPENCASTS.

A lecture by Mike McCormac of the British Geological Survey, Edinburgh 13 March 1996 at Tullie House, Carlisle

The lecturer indicated that his current task was to produce a complete revision of the BGS Whitehaven Sheet (Sheet 28) which was last remapped in the 1920s. Numerous sources of new data were now available, the most significant being deep and opencast coal mines which have been worked since that date. Now abandoned collieries such as Oatlands, Walkmill, Harrington and Lowca along with the more recent (but now restored) Keekle and Potato Pot opencasts were the main sources of data along with more minor opencast working and numerous coal exploration boreholes. Ongoing private enterprise opencasts were also a source of data.

Examination of these data indicated that the main structural features are dominantly NW - SE. The nature of these features indicated both extensional and compressional elements of a strike slip tectonic regime. The compressional aspects of this are well illustrated

production of maps at a scale of 1:25 000. Images of the town of Ermononville to the north of Paris were shown on both false colour (20m pixels) and in black and white (10m pixels). It was noted that the Russians had the capability to resolve to 5m but this was only available for limited areas of the world.

An example SPOT image of the Lake District picked out geomorphological features very well - Coniston and Levers Waters and the screes and dumps from quarries were clearly visible. However, because SPOT only records the standard 3 bands of false colour it is not possible to separate rock types - this could be done using LANDSAT. Other SPOT images were shown of Keswick, dominated by vegetation and geomorphologic features, and of Wasdale, with the Sellafield and Drigg sites being clearly visible.

An example of the way in which remote sensing data can be processed to produce a different presentation was provided using the gravity map of the Lake District contoured in the conventional way. The data was converted to a digital form, highs represented as bright areas, lows as dark, and then colour was added, providing a novel representation of the major subsurface geological units in the region.

The use of geochemical data as images in mineral prospecting was also demonstrated. Processing of the images allowed the recognition of a number of differing types of mineralisation in the Lake District based on a display of stream sediment geochemical data. The Borrowdale Volcanic Group of the Central Lakes, is characterised by high zinc trace element levels while high lead and barium coincide with the Alston area. High lead/zinc/barium occurs at Carrock Fell and high arsenic/bismuth/antimony (often a good indicator of gold!) define the Carrock and Coniston old mining areas. High values of arsenic were noted at Shap, Coniston and Carrock. Nickel/copper/chromium and antimony were indicated at Drigg. Uranium was indicated on the MOD firing range above the Appleby to Brough road and was also present at Drigg.

The lecturer concluded by stating that the LANDSAT and SPOT imaging is on open file but is expensive to obtain in digital form

at about $5,000 per image. However, data is very cheap in hard copy as photographic prints.

PROBLEMS IN THE RECONSTRUCTION OF PAST CLIMATES

A lecture by Mrs M. Fox of the Cumberland Geological Society on 6 December 1995 at Whitehaven College.

Geologists recognise large scale climate changes which are indicated by such features as roches moutonées, hanging valleys, desert sandstones and subtropical forests. More recently work on identifying and predicting global climate change with resolutions of tens of years has become very important following the advent of concerns relating to global warming and other inter-governmental issues.

The lecturer indicated that she would concentrate on problems associated with the reconstruction of climatic variation over the last 500 years. One of the main sources for climate data, instrumental climate records, generally only extend back about 150 years. A review of temperature and pressure data on grid point coverage shows that even now there are some holes in the data set. Due to the inadequacy of the instrumental data other 'proxy' data is used. 'Proxy' data is obtained by identifying a parameter which varies systematically with climate. In order to calibrate these data a reliable present day instrumental record is required. This is not as easy as it may at first appear since the design of instrumentation, the locations in which instruments are sited and the way in which the data is measured may have changed. Station locations may also have changed (or the surrounding environment may have), observation times and interpolation methods could also have changed. Where inhomogeneities are recognised these can be corrected.

Examples of proxy data include tree cores, ice core data, coral geochemistry, oxygen isotopes in tufa cores (although there may be problems with oxygen isotope ratios interpretation) and varves (these can be resolved into annual events in some cases).

ANNUAL GENERAL MEETINGS

The 34th ANNUAL GENERAL MEETING of the Society was held at West Cumbria College, Workington on Wednesday 8 February 1995 with the President, Mr F. T. Lawton in the Chair and 23 members present. Another successful year for the Society was reported. A larger lecture programme and more field excursions had been held in the current year. A particularly active year for the Riggs Co-ordinator had resulted in 68 new sites being accepted. The new display stand purchased by the Norma Gianini bequest was exhibited at the meeting.

Following the formal business of the evening Mr Eric Skipsey gave an illustrated talk on "Volcanoes around the Mediterranean".

The 35th ANNUAL GENERAL MEETING of the Society was held at West Cumbria College Workington on Wednesday 28 February 1996. The President, Mr F. T. Lawton was in the Chair and 22 members were present. Reports of a successful year were read from officers. Good attendances at lectures and field meetings were reported. 1996 would see the publication of Volume 6 Part 1 of the Proceedings. An improvement in the sales of publications had also been achieved with steady sales of the Guide 'Lakeland Rocks and Landscapes' continuing.

An interesting discussion took place on the challenge issued by the Geologists' Association President on the 'Pattern of English Building'. Council are examining ways of meeting the challenge in 1996.

Following the business meeting Mrs Sylvia Woodhead gave an illustrated talk on "Looking at geology in the Isle of Man".

ANNUAL DINNERS - 1994 and 1995

The 1994 Annual Dinner was held at the Hundith Hill Hotel, Lorton, near Cockermouth on 26 March. 34 members and friends enjoyed the evening and the address given by our guest speaker Mr George

Bott of Keswick. Speaking on 'Humour' Mr Bott entertained members with an interesting and, as to be expected, amusing talk.

The 1995 Annual Dinner was also held at the Hundith Hill Hotel, on Saturday 8 April. 37 members and guests were present. The Society presented the Charles Edmonds Award to Mervyn Dodd for his contribution to the Society and to Geology in Cumbria over many years. The guest speaker was Dr Stuart Monro from the British Geological Survey in Edinburgh. He gave a lively and amusing address on 'Geological Characters from Scotland and the North of England'.

OBITUARIES

H. Eccles

Harold was a Lancashire man from Accrington. As a teenager he was a very active potholer, cycling to the Craven District every weekend. In the 1930's, like many others he became out of work and switched to the Lake District where he joined Jerry Wright's group of Lake District Mountain Guides, walking and climbing.

His family moved to London and he worked as a shop-fitter taking teams of men around the country and abroad. He also changed his immediate allegiance and between the wars had regular seasons in the Alps.

About 1970 he and his sister, both unmarried, retired to Kendal. He found an interest in Geology and was a founder member of the Westmorland Geological Society. For a time he was their Excursion Secretary and later Vice-President.

His sister Edith died in 1987 and Harold lost much of his zest for life. As he got older he faded physically and was unable to join excursions and his heart failed in May 1995 at the age of 89.

He was a member of the Society for some years and being a very friendly and cheerful man he is much missed.

P. Wormell

Phil Wormell lived for many years at Welton, near Carlisle and both she and her late husband were teachers in the area. She was a member of the Society for many years, geology being just one of her varied interests. In recent years she was unable to take part in many Society activities but she retained her interest in geology and followed the Society's events at a distance. Her death early in 1995 robs the society of one of its long-standing members.

J. A. G. Thomas

The Society is sorry to record the death of Jack Thomas in 1994. He took a B.Sc. in geology at Kings College, London before joining Shell in the Hague as one of their first micropalaeontologists. He returned to Britain before the outbreak of the second world war.

After the war he returned to education teaching geography in Walsall, then moving to Breconshire and then to his old school in Pembroke to teach Maths. Geology was not on the curriculum so he taught it during the lunch hour and later helped those unable to get tuition in his spare time. In 1959 he moved to Verdin Grammar School at Winsford as Head of Geography and Geology, where he remained until his retirement in 1979..

Jack was the President of the Association of Teachers of Geology (now ESTA) in its early years and boasted 50 years uninterrupted membership of the Geologists Association. He also had wide experience of examination work, was one of the chief examiners for the London University 'O' level syllabus and chaired several examination board panels..

In addition to his teaching work Jack undertook the revision of Trueman's *Introduction to Geology*, authored *An Introduction to Geological Maps* and edited the *Rocks & Fossils Geological Field Guides* series which included Snowdonia, The Peak District and the Lake District.

SOCIETY BEQUESTS

During 1994 - 95 the Society has been fortunate in receiving two bequests.

The Sanderson Bequest

Mr Rowland Sanderson retired to Lakeland Park, Keswick after a career in local government in Keighley. He was a member of the Society for many years and a keen amateur petrologist. Following his death in 1994 his widow kindly donated his microscopes, thin section slides and a large collection of geological books and journals to the Society. The microscopes and slides are now in the Keswick Museum. The books and journals have been incorporated into the Society library.

The Colin Rose Bequest

Through the good offices of Sir Kingsley Dunham the Society has acquired a collection of books, journals and geological field guides belonging to the late W. C. C. Rose. Colin Rose was a founder member of the Society and worked for the British Geological Survey in west and south-West Cumbria. He did pioneering work (with Sir Kingsley Dunham) on the iron-ore field and on the Permo-Trias of South West Cumbria, contributed to the Cockermouth Memoir and published material on the Skiddaw Group. Colin Rose spent most of his life outside geology working for the Ministry of Power in London, most of his work in Cumbria being done as part of the emergency work during the Second World War or following his retirement.

The Society is indebted to his son Mr Andrew Rose for donating the material.

OFFICERS AND COUNCIL

Officers and Council elected for 1995 and 1996 are given below.

OFFICERS ELECTED FOR:	1995	1996
President	F. T. B. Lawton	F. T. B. Lawton
Senior Vice-President	K. W. Bond	K. W. Bond
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	Mrs M. Fox	Mrs M. Fox
Editor	C. J. Thompson	C. J. Thompson
Publications Secretary	G. Pinches	G. Pinches
Librarian	M. Burton	M. Burton
R.I.G.S. Co-ordinator	M. Dodd	M. Dodd
Council Members	E. Curzon	D. Dickens
	S. Hewitt	S. Hewitt
	E. Skipsey	E. Skipsey
	Mrs L. Wornham	Mrs L. Wornham
Honorary Auditor	Dr T. Dias	Dr T. Dias
Editorial Board Members	E. Skipsey &	E. Skipsey &
	Dr. R. Clark	Dr R. Clark

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

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