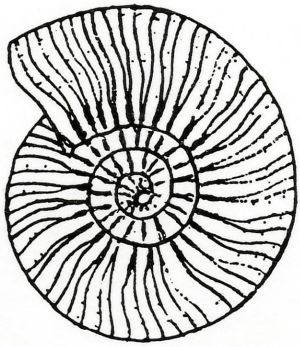
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CONTENTS

EDITOR'S NOTES 404

ORIGINAL ARTICLES

Origin of limestone pavements 405
I. C. Burgess and M. Mitchell

The conservation of limestone pavements 413
E. Skipsey

Conflicting interpretations of glacial sediments and landforms in Cumbria 419
Dr. D. Huddart & Dr. R. Clark

The Skiddaw Massif problem 437
Dr. R. Clark

The last 200 million years in Cumbria 449
E. Skipsey

Geology in the churchyard 457
(Adapted from the Geologists Association leaflet)

EXCURSION NOTES

The Vale of Chipping and Trough of Bowland - Dr. N. Aitkenhead 463
The Borrowdale Volcanic Group in the upper Calder Valley - D. Kelly 467
Westphalian sedimentology of the Whitehaven/Lowca area - Dr. N. S. Jones & Dr. P. D. Guion 469
Upper Teesdale - E. Skipsey 473
Controversial Irish Sea glacial models - Dr. D. Huddart 476
Kinniside Lead Mine - M. Dodd 481
The Permo-Triassic rocks of the Eden valley - Dr. L. Macchi 483
Mineralisation in the Caldbeck Fells - B. Young 486
The Seventh Limestone at Frizington Park Quarry - A. Thurlow 490
B.V.G. rocks in Lingmoor area of Langdale - Dr. F. Moseley 493
Civil engineering geology along A66 trunk road - J. Cockersole 496
Other excursions held during 1992 & 1993 499

CONTENTS

LECTURE NOTES

North Sea hydrocarbon plays 501
Dr. S. Brown
The challenge of the Lake District's big landforms 502
Dr. R. Clark
Lake District Vulcanism: caldera cycles & crustal extension 505
Dr. D.Millward
Gypsum caves and subsidence 507
Dr. A. H. Cooper
Mineral heritage of the north 509
B. Young
Volcanoes ancient & modern 511
Dr. R. J. Suthren
Hot dry rock geothermal energy research 514
Dr. H. G. Richards
Rise & fall of Ordovician Volcanic island arc 515
Dr. E. W. Johnson
The Building stones of Cartmel Priory 518
M. Mitchell
Geological mapping & photogeology in the Lake District 520
Dr. F. Moseley
Modern desert sedimentary environments 523
Dr L. Macchi
Other talks 525

ANNUAL GENERAL MEETINGS - 1993 &1994 526

ANNUAL DINNERS - 1992 & 1993 526

OBITUARIES 527

LIST OF SOCIETY OFFICERS AND COUNCIL - 1993 & 1994 527

EDITOR'S NOTES

This edition, Part 4, completes Volume 5 of the Society's Proceedings. It marks the radical changes in the preparation of the Proceedings that have occurred during the production of this volume. Part 1, published in June 1988, was prepared with great expenditure of time and effort by typing and re-typing, with the page arrangements involving cut and paste methods. In contrast, Part 4 has been entirely prepared using word processor and desktop publishing facilities with the authors' texts on disk being directly incorporated into the final version. In this connection I would like to thank Chris Thompson who has undertaken the formatting of the texts into the final pages after the completion of editorial work. I would also like to thank all who have contributed articles and provided lecture and excursion notes, thus enabling the Proceedings to provide a full record of the Society's activities and interests.

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.

Eric Skipsey, Editor.

Published by the Cumberland Geological Society, May 1994.

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

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ORIGINAL ARTICLES

ORIGIN OF LIMESTONE PAVEMENTS

I.C. Burgess and M. Mitchell

Introduction

The conservation of limestone pavements is an important aspect of the preservation of the Natural History of the Lake District and surrounding areas of outstanding natural beauty. The opportunity is here taken to review the current knowledge about the formation and geological history of these fascinating and beautiful features.

Small areas of limestone pavement may occur in any thickly bedded carbonate sequence particularly where dips are low and the beds have been eroded to form a 'scarp and dip-slope' topography. The karstic pavements form when the dip-slope surface is etched and sculptured, over a long period, by acid groundwaters percolating down joints and eventually producing the classic fluted 'clint and grike' morphology which is exposed by later erosion.

Around the margins of the Lake District and in the neighbouring Yorkshire Dales National Park, extensive limestone pavements of Lower Carboniferous (Dinantian) age are a characteristic feature of the landscape. These large areas of pavements however, do not form at random throughout the Dinantian sequence, but are confined almost exclusively to rocks of the Asbian and early Brigantian stages. These rocks show a marked small-scale rhythmic cyclicity, a feature absent from the underlying Holkerian and earlier strata, and the nature and origin of this cyclicity are a major influence on the pavement development.

Asbian Cyclicity

Carboniferous limestones display a variety of lithologies and textures and these are an expression of the different depths of water and

the energies of the environments in which they were laid down. Dixon (1912, p.532, Fig.8) was the first worker to discuss the importance of varying water depth in the formation of different limestone lithologies, but his interpretations were not followed up for many years.

That Brigantian and later strata in northern England were laid down in a repeating rhythmic sequence has been recognised since the early nineteenth century (Forster 1809; Phillips 1836). This concept was developed later by Dunham (1950), the alternations of limestones with clastic sequences (including coals) being accepted as demonstrating a rhythmic alternation of high and low sea levels.

Schwarzacher (1958) applied these concepts to a limestone sequence. Examining the Asbian rocks of the Settle area, he showed that several prominent bedding planes which featured widespread limestone pavements and were called 'master bedding planes', could be traced over considerable distances. These planes were used to divide the massive upper part of the Great Scar Limestone into a series of laterally persistent lithological cycles. Subsequently Doughty (1968) demonstrated that the same units could be recognised by the rhythmic fluctuations in joint density, the joints being at lowest density in the more massive limestones that immediately underlie the 'master bedding planes'. He attempted to relate the joint density to changing environmental conditions and consequent lithological variations during the deposition of the 'cycles'. He also noted (p.505) that it was possible that "some diagenesis preceded regional compression so that physical characteristics of the limestones were different from those of the original sediments".

The presence of an early period of diagenesis and induration was explained by the work of Walkden (1974) on the Asbian and early Brigantian rocks of the Derbyshire Dome. These limestones showed similar cyclicity to the Asbian rocks of the Settle area though limestone pavements are not widely developed. His work demonstrated conclusively that the 'major bedding planes' in Derbyshire were produced by contemporaneous Carboniferous subaerial weathering of the limestones with the formation of karstic surfaces (palaeokarsts). Walkden's important conclusions can be summarised as follows.

The palaeokarst surfaces underlie thick clay wayboards or beds of shale which are interpreted as subaerial accumulations of volcanic dust (Walkden 1972). These mudstones, within which soils and vegetation developed, were formed over a long period when the limestone was standing above sea-level. Relatively acid meteoric waters eroded the surface of the limestone by solution, and altered the top of the partly lithified limestone to produce a hardened rolling subshale karst surface. These erosion surfaces can be shown to have formed before the deposition of the next limestone because the lower surface of the overlying limestone is always sub-horizontal and does not follow the irregular surface at the base of the shale. The palaeokarsts therefore are contemporary Carboniferous erosion features formed by subaerial solution beneath a soil cover, a process which took place after the deposition of the shale layer and before the next limestone was laid down.

The ancient palaeokarsts which Walkden recognised in Derbyshire are also present in the Asbian rocks of other British shelf limestone areas. They have been described in North Wales (Somerville 1979a, b, c), Anglesey (Walkden and Davies 1983; Davies 1991), the southern parts of the Askrigg Block (Arthurton et al., 1988) and the southern Lake District (Horbury 1987, 1989). In all these areas they are responsible for the formation of major limestone pavements.

Observations about palaeokarst horizons by Horbury (1987) are important in our understanding of the development of limestone pavements. When a clean surface of a palaeokarst can be studied - they are often obscured by a cover of lichen - it can be seen to be mottled with dark-grey roughly circular markings surrounded by pale-grey matrix. The darker patches are interpreted by Horbury as diagenetic alteration of the limestone caused by organic acids associated with rootlets from the overlying shale. In addition many karst surfaces have crusts of dark-grey laminar calcrete. This early diagenesis results in the limestone below the karst surface being significantly more indurated than the adjacent underlying limestones. This in turn has a great effect on the development of joints which are poorly developed immediately below palaeokarsts. The fact that the palaeokarstic surfaces generally overlie more massive limestones which have been resistant to erosion over the millions of years

of their existence, is the main reason why they now form many large areas of splendid limestone pavements.

Pavement development

The main requirement for the development of a limestone pavement is the existence in a cyclic sequence of a palaeokarst horizon with early lithification producing a tough, thickly bedded limestone with widely spaced joints. However not all palaeokarsts produce pavements and there are areas of typically cyclic Asbian limestones such as Derbyshire, Bristol, the Mendip Hills and South Wales where pavements are not widely developed.

Two factors appear to control the distribution of pavements. The first relates to the rock sequence (and the topography). If the palaeokarst occurs in a generally more massive limestone sequence, subsequent weathering does not pick-out the karst horizon. Again if several closely spaced palaeokarst horizons occur without thick beds of hardened limestone being present between them, weathering is not able to accentuate the karst horizon.

The second controlling factor appears to be the glacial history of each area. In areas which were covered by the late Devensian ice (the last glacial phase of the Quaternary), such as the Lake District, North Wales and the Yorkshire Dales, limestone pavements are extensive. Presumably the shale partings were planes of weakness which were eroded easily by ice moving across the limestone and the underlying more toughened palaeokarst surfaces were resistant to abrasion. Isolated erratic blocks are seen resting on many pavements and are a clear indicator to the passage of ice across them.

Those areas not covered by late Devensian ice, such as Derbyshire, the Mendip Hills and South Wales, are blanketed with thick deposits of earlier Devensian glacial debris and loess derived soils, effectively preventing the erosion and development of limestone pavements.

The stepped topography of the cyclic Asbian limestones is particularly well seen in north-west England with many fine series of

scarps and ledges. The characteristics of the limestones in these stepped features reflect the changing depths of water at the time of deposition. The palaeokarsts occur on the ledges at the top of the scarps and are overlain by the mudstones which are the subaerial part of the cycle. The mudstones are rarely seen at surface outcrop because they are weathered away, but sometimes form damp grassy banks at the foot of the screes below the scarps. However they can be seen in quarry sections where they show up as darker bands.

The contemporaneous palaeokarstic surface has a low, hummocky relief, with pot-holes of varying depths at intervals. Superimposed on the palaeokarstic surface is the classic fluted 'clint and grike' morphology which formed much later at the present land surface, for the grikes follow the trends of the widely spaced joints or other planes of weakness in the limestone, and they do not extend beneath a rock cover, as can be seen where the beds have been quarried. Rainwater contains small amounts of carbonic acid, but not sufficient to cause adequate dissolution. It seems more probable that the grikes formed, beneath a thin cover of shale or glacial deposits, as a result of etching and dissolution by percolating acid soil waters. The residual soil cover was subsequently washed away down open joints, leaving the isolated glacial erratics perched on the exposed pavement, thus producing the features we see today.

Although bare pavements are common at present, their preservation in this form requires active management. The grikes commonly support coarse, tussocky grasses. In areas where grazing animals, particularly sheep, are excluded, such as at the northern end of Hampsfell, Grange-over-Sands, the pavements rapidly become overgrown, first by grass, then as a soil cover is established, by other vegetation, so that over a period of as little as 30 years, the pavements (though indeed, fully preserved!) cease to be a feature of the limestone landscape.

Conclusions

Extensive bare limestone pavements are formed as a result of a combination of circumstances.

1. The existence of a palaeokarst formed in Carboniferous times, now with widely spaced joints, the surface of which underwent early (contemporaneous) lithification to become resistant to erosion.

2. The presence of a mudstone overlying the palaeokarst, that allows clean removal of overlying strata.

3. The presence below the palaeokarst of a sufficient thickness of limestone to permit adequate drainage.

4. Recent glaciation, providing an effective mechanism for removal of overlying strata, exposing large surfaces.

5. A long period of subsoil weathering to allow etching of joints by percolating humic acids.

6. Intensive grazing, particularly by sheep, to expose the pavement and prevent it becoming overgrown and eventually obscured by vegetation and soil cover.

Acknowledgements

Dr Gordon Walkden and Dr Mark Lawrence kindly read an early draft and made helpful comments which have been incorporated.

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M. Mitchell & I.C. Burgess

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THE CONSERVATION OF LIMESTONE PAVEMENTS

E. Skipsey

The importance of limestone pavements

Limestone pavements are one of the outstanding landscape features and habitats of northern England and occur in areas where thick sequences of Carboniferous Limestone outcrop, as described by Burgess and Mitchell [See the preceding article in this volume - Ed.]. They can give rise in upland areas to great barren tracts of limestone country, furrowed by deep crevices and devoid of vegetation except such as have been able to secure a foothold in the crevices. They are present in lowland areas also but here they are often moss-covered and wooded. Their importance was recognised in a conference on limestone pavements organised by Cumbria Wildlife Trust in 1993, the report of which provides a wide assessment of this specialist environment, and the measures needed to protect it.

Ward and Evans (1976) published the results of a botanical survey and conservation assessment of limestone pavements in Cumbria which is the definitive study of the subject. The botanical survey was restricted, on grounds of feasibility, to those grikes which are more than twice as deep as wide. Here the flora was characterised by herbs and ferns of rocky places and woodlands not accessible to sheep. A system of floristic indices was devised and used to classify the pavements on the basis of deep grike species. The best pavements for flora were; Gaitbarrows, Hutton Roof Crags, Scar Close/Southern Scars of Ingleborough, Lancelot Clark Storth, Wakebarrow/Whitbarrow, Underlaid Wood and Hale Fell.

Limestone pavements are a rather hostile environment and do not, at first sight, offer much cover for invertebrates, especially insects. However they do provide an environment for specialist species which are adapted for limestones.

The protection of limestone pavements

English Nature is the government body responsible for conservation and its brief includes the establishment of nature reserves, designation of sites of special scientific interest (S.S.S.I.s) and provision of advice to local conservation bodies. One important action has been to locate areas of limestone pavements; a total area of 2500 hectares have now been identified in northern England. The map (Figure 1) shows the locations of the main limestone pavement areas in Cumbria and the borders of Lancashire. Only 350 hectares of intact limestone pavements remain in Cumbria out of a total area of 595 hectares and thus 40% of pavements in the county have already been removed or badly damaged.

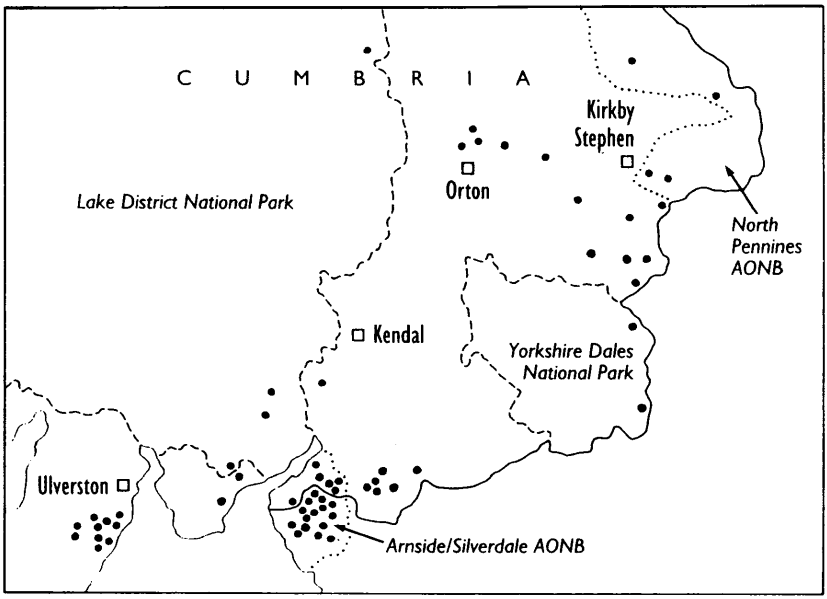


Figure 1. Main locations of Limestone Pavements in Cumbria and the borders of Lancashire



Plate 1. "An irreplaceable landscape", Great Asby Scar, near Orton.
(photograph courtesy of English Nature)

What are the reasons for this damage? In by-gone eras, surface sources of limestone were used for agriculture and drystone walling. Clints were used for decorative walls and gate posts in Victorian times and from then to the present day, for rockery stone. The use of crow-bars to extract the clints was followed later by pneumatic drills, hydraulic shovels and explosives, methods which continue even today even though planning permission is required for removal.

It was recognised in the 1970's that the systematic pillaging of pavements was rapidly damaging large areas. Attempts by some local authorities, notably Westmorland County Council, only met with limited success in stemming the pillage. This high level of destruction of an irreplaceable landscape feature led to the inclusion of powers in the Wildlife and Countryside Act of 1981 enabling local authorities to provide statutory protection. Under Section 34 of the Wildlife and Countryside Act 1981. "*where the Nature Conservancy Council* (now English Nature) *and the Countryside Commission are of the opinion that any land in the countryside which comprises a limestone pavement is of special interest*" they must notify the Local Planning or National Park Authority. If the Authority considers the character and appearance of this land would be adversely affected by the removal or disturbance of limestone, it can make a Limestone Pavement Order (L.P.O.) to protect it.

An Order prohibits anyone from removing or disturbing limestone on or within the area designated. Once the Authority has decided to make an Order over a piece of land, any person with an interest in that land will be served with a notice. The Order will also be advertised in a local newspaper and in the London Gazette. The Order comes into effect immediately but must be confirmed by the Secretary of State for the Environment within 9 months of being made permanent.

Both Cumbria County Council and the Lake District National Park give very high priority to the protection of limestone pavement and the use of Limestone Pavement Orders to prevent their removal. Each notification from English Nature and the Countryside Commission is assessed before making an order. It is important that all local residents as well as owners and occupiers appreciate the need to care for these exceptional features

and co-operate in protecting them. Conserving limestone pavements is an important activity with which everyone can help.

Acknowledgements

This article seeks to provide some information about the importance of limestone pavements and the ways in which they can be conserved. Much of the material has been taken from a leaflet 'Protecting Cumbria's Limestone Pavements', published by Cumbria County Council Planning Department, County Offices, Kendal. Other information is derived from the Cumbria Wildlife Trust conference report in 'Cumbrian Wildlife', No. 37, August 1993, which is obtainable from: Cumbria Wildlife Trust, Church Street, Ambleside, Cumbria, LA22 0BU. These sources are gratefully acknowledged.

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E. Skipsey
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CONFLICTING INTERPRETATIONS OF GLACIAL SEDIMENTS AND LANDFORMS IN CUMBRIA

Dr D. Huddart & Dr R. Clark

Introduction

There is a current controversy about how glacial landforms and sediments in lowland Cumbria from Morecambe Bay to near Carlisle should be explained. It is part of a wider general discussion regarding the manner of deglaciation in the Irish Sea basin. The established interpretation of the Cumbrian features has considered local ice cover to have been land-based. The opposed view is that during the waning stages of glaciation, when deposition of sediment and production of landforms were very active, sea-levels were relatively high and ice margins reached the sea extensively, including at localities now onshore. It asserts that in Cumbria the sea extended inland to places now as much as 140m above present sea level. This paper outlines the nature of the controversy and appraises the validity of the opposed views for Cumbria.

The glaciation in question is the most recent to have produced widespread ice cover in Britain. This is the Dimlington Stadial glacial of the Late Devensian Stage that concluded the Pleistocene. Its onset was about 26000 BP and maximum ice extent is generally taken to have been attained about 18000 BP or earlier. In this glaciation ice extended from the Irish Sea basin south by St. George's Channel to the Celtic Sea. Not all ice entering and generated within the basin could flow south due to the ensuing congestion. At the height of glaciation some ice was forced east into the Tyne and Tees catchments and south-east through the gap between the Pennines and the North Wales hills to the vicinity of Wolverhampton. Much of Cumbria had become ice-free by about 14500 BP (Pennington 1978). The following discussion is about processes and events in the period of ice loss, i.e. between about 18000BP and 14500BP.

Glaciomarine interpretation of glacial sediments and landforms.

In the first part of the nineteenth century the glacial theory prevailed over propositions that marine submergence and deposition from floating icebergs could explain widespread covers of 'drift', including those around the Irish Sea. There, the presence of marine shells in 'shelly drift' on the Pennine flanks and in North Wales had given support to a notion of marine incursion up to 400m above present sea level. Also in the first part of that century it was realised that growth and decline of regional icesheets directly affected global sea levels and also caused more localised depression and rebound of the earth's crust. As sea level and crustal movements occur at different rates and may be out of phase they introduce considerable complexity to analysis of events and environments in coastal localities in and near formerly ice-covered areas.

Explanations of sediments and landforms which depend on evidence, or assumptions, that the features were produced in marine environments with contemporary adjacent land-ice and in some instances with local ice shelves, are termed 'glaciomarine'. Recently there has been a revival of interest in glaciomarine environments and processes. Features around the coast of the Irish Sea have been described and accounted for in glaciomarine terms (e.g. Eyles and Eyles 1984, Eyles and McCabe 1991, Huddart 1977a, McCabe, Dardis and Hanvey 1987, Thomas 1985, Dackombe and Thomas 1991).

Late Devensian deglaciation of the entire Irish Sea basin has been explained in this manner (Eyles and McCabe 1989), but this approach has been questioned and explanations in terms of land-based ice have been reasserted for some localities around the basin (Wingfield 1992, Harris and McCarroll 1990, McCarroll and Harris 1992, Austin and McCarroll 1992). Many Cumbrian localities were among those cited by Eyles and McCabe (1989) in support of the glaciomarine explanation (Fig. 1) though little new evidence was introduced. Sediments and landforms at these places had earlier been explained in terms of land-based ice.

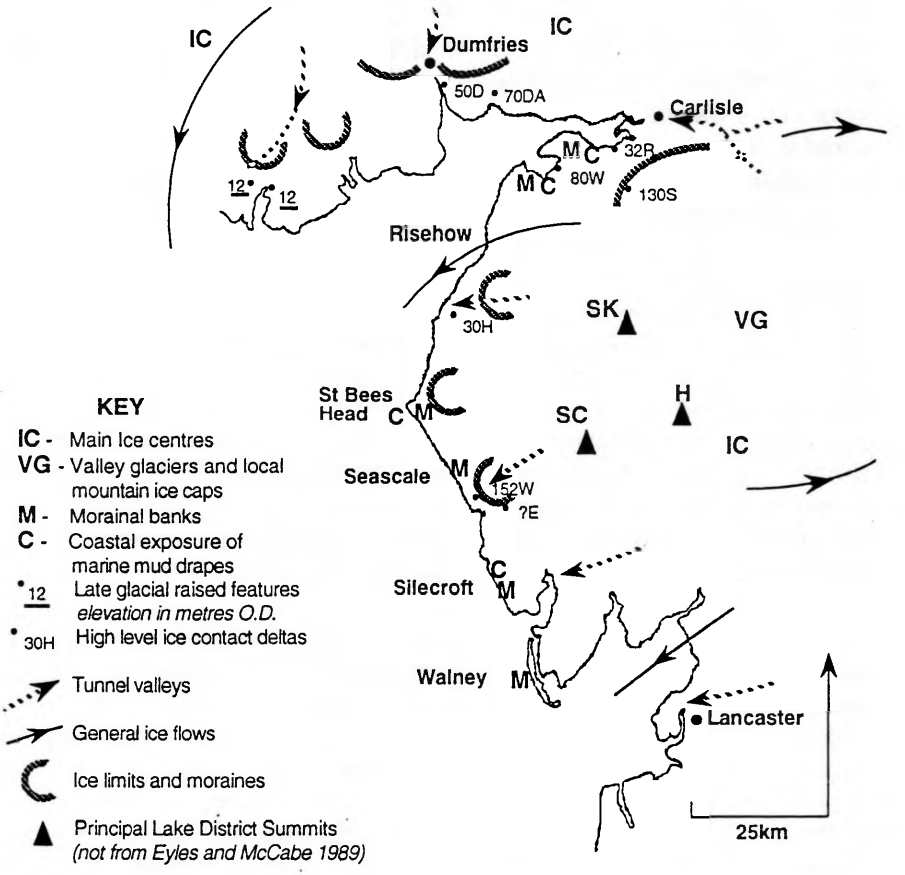


Figure 1 Locations of Late Devensian features in the Cumbria-Solway area (from Eyles and McCabe 1989). Location of high-level ice-contact deltas are shown by number (metres above present sea level) and letter (denoting place as specified in text).

The glaciomarine account of Irish Sea basin deglaciation begins with a rise of global sea levels associated with the start of a phase of world-wide ice loss. Rising seas increasingly impinged on the southern front of the Irish Sea basin ice sheet. Ice there floated and was disrupted. Embayments in the front of the ice shelf focused active iceberg calving and concentrated the rapid southward movement of ice from the main ice mass in the basin. As sea levels rose still further the marine ice margin retreated north, stabilising temporarily at grounding lines. The waning land-based ice round the basin produced abundant meltwater, much of it flowing at the base of land ice so easing ice movement and reinforcing the draw-down effect of iceberg calving at the ice front. Drumlin swarms were produced under streams of fast-moving land-ice with some reworking of glacial sediments and incorporation of material that meltwater had carried beneath the ice. Subglacial tunnel valleys were incised, particularly along the main valleys. Thick beds of marine sediment were laid down in areas where tidewater ice margins were stationary for sufficiently long intervals and morainal banks were built up from debris released at the ice front. Certain submarine ridges have been identified as marking former ice margins. Some inland ridges and tracts of hummocky ground are also considered to mark the former positions of tidewater ice margins, their present positions being due to subsequent crustal rebound.

Many flat upper surfaces of sand-gravel deposits now well above sea level have been interpreted as the surfaces of deltas formed where major meltwater channels from ice fronts reached the sea. The present heights of raised deltas are taken to indicate the amount of crustal uplift since the deltas accumulated at sea level. Thin covers of fine reddish clays, 'mud drapes', reported from a wide variety of deposits and landforms in lowlands around the Irish Sea were ascribed by Eyles and McCabe to settlement of fine glacial debris from suspension in the sea. Thus distribution of mud drapes was seen to provide evidence for the previous extent of the sea. At some sites around the Irish Sea basin marine fossils in situ rather than derived and redeposited, have been recorded and demonstrate the enclosing sediment to be glaciomarine. Eyles and McCabe did not report such fossil assemblages from Cumbrian sites.

At last, as it is supposed, the retreating ice margins and the advancing seas reached the coastlands of Cumbria, the Solway Firth and Galloway, still incompletely recovered from crustal depression imposed by the mass of ice they had carried.

Cumbrian sites noted and mapped by Eyles and McCabe represent almost the complete range of glaciomarine sediments and landforms. Drumlin swarms were shown schematically in Low Furness, although not the extensive drumlin field north from Lancaster to beyond Kendal. The Eden valley - Solway plain drumlin tracts were not mapped south of Risehow, and north of Carlisle were shown to merge with the drumlin areas north of the Solway. The mapping of tunnel valleys may be intended to be representative rather than comprehensive. The lower Eden and Irthing east of Carlisle, the lower Derwent or Ellen in West Cumbria, the Irt in Wasdale, a course in Furness and, in the south, the lower Lune were shown. Morainal banks, implying positions of glaciomarine ice margins, were mapped at St Bees, Seascale, Silecroft and Walney. Along the Solway coastline morainal banks were shown at Risehow and at two unnamed sites further to the northeast.

Positions of inland ice fronts were shown across the lower Eden valley south of Carlisle and, in the west, across the Derwent valley west of Cockermouth, near Egremont and across lower Wasdale. These positions were presumably determined from identification of features such as raised deltas. Raised delta sites were shown in Eskdale, with uncertain present top surface altitude (?E in Fig.1), and at Wasdale with top surface now at 152m O.D. This implies recognition of a local glacier terminus in lower Wasdale contemporary with a sea level 152m higher than at present. Four north Cumbrian raised delta sites were named and are shown in Fig. 1 as placed by Eyles and McCabe. They are, with top surface altitude in metres in parentheses, Harrington (30 H), Wigton (80 W), Sebergham (130 S) and Rosehill (32 R). Raised deltas north of the Solway are shown at Dumfries (50 D) and at Dalton (70 DA). The overall range of delta heights (120m) and the height differences between adjacent sites suggests these deltas were considered to be diachronous with no systematic relationships between ages and locations of deltas and height of contemporary sea levels: Eyles and McCabe (1989) did not discuss these relationships.

Five coastal sites with exposures of mud drapes were mapped, one near Risehow but unnamed, two near Carlisle, one at St. Bees and another at Gutterby. Marine mud drapes were believed to have much wider extent reaching some 140m above present sea level.

The established interpretation of glacial features in Cumbria and the proposition of late movement into Cumbria of land ice from the Irish Sea basin.

A 'land-based' ice interpretation has been applied to glacial sediments and landforms of Cumbria for over a hundred years (Goodchild 1875, Trotter 1929, Hollingworth 1931, Huddart 1991). Glaciomarine interpretations were not invoked. Trotter (1922, 1929) thought that clasts of Scottish provenance in uppermost tills in the Solway lowland of Cumbria were evidence of a movement (late in the Late Devensian glaciation) of land-based ice from the west and north-west. Marr (1916) writing of marine shells in glacial drift near Gutterby noted 'the boulders give proof of the encroachment of ice from over the Solway and the shells have no doubt been carried by the ice from the old sea floor'.

Evidence of such a readvance has been re-evaluated using stratigraphic, sedimentological and geomorphological methods by Huddart (1970, 1971 b, 1973, 1977 b, 1991), and Huddart, Tooley and Carter (1977) who concluded that the readvance was less extensive in north Cumbria than Trotter had supposed, though ice in a late incursion reached the coastlands south from St. Bees Head to Low Furness (Fig. 2). Despite the range of evidence for a late movement of ice, Pennington (1978) did not accept its occurrence, seemingly in consequence of somewhat ambiguous and unelaborated comments by Evans and Arthurton (1973). Others, including Sissons (1974) and Thomas (1985) have questioned though not rebutted the reality of the readvance, yet Clark (1992) gave some support to the likelihood of a late movement of ice from Scotland into Cumbria.

In general discussion of mud drapes, Eyles and McCabe noted the "thin reddish till-like stony clay [which] swathes pre-existing drumlins and outwash deposits" (Taylor et al 1971) in northern Cumbria. Trotter (1922, 1929) regarded this cover as contributory evidence for a Scottish

readvance, though Taylor et al were uncertain about its age and origin. It was reported as extending up to c. 140m O.D. in the area north of Cockermouth by Eastwood et al (1968). That altitude and those of the highest features they identified as raised glaciomarine deltas (Sebergham 130m, Wasdale 152m) were taken by Eyles and McCabe to show the extent of marine incursion into Cumbria.

The glaciomarine explanation of deglaciation in lowland Cumbria requires land-based ice moving generally westward to marine termini in the vicinity of the present coast and marine incursions to the degree noted above. It considers the glaciomarine features to be contemporary or near contemporary with drumlin formation under mobile land ice. It proposes that the Cumbrian land-based drumlin-forming ice streams terminated at marine margins now onshore, for example in Low Furness and north of Maryport, as evidenced by morainal banks and raised deltas. Several of the features regarded as glaciomarine by Eyles and McCabe are among those Huddart regarded as evidence for readvance of ice from the west and north-west. The readvance proposition requires the presence of active land-based ice where the glaciomarine one requires sea, the readvance to have been later than the formation of drumlins by mobile ice moving from inland Cumbria towards the coast and, in general, later than stagnation of land-based ice that had been involved in the formation of drumlins.

Thus there are two controversial and interlinked problems: whether the glaciomarine model can be applied to any of the sediment sequences in the Cumbrian lowlands, and the status of the so-called Scottish Readvance. These problems are now addressed.

1. Holme St. Cuthbert fluvioglacial complex

The location of this complex is shown in Fig. 2. It is the central of three supposed morainal bank sites marked by Eyles and McCabe (1989) in the Risehow-Carlisle area. Other Cumbrian morainal bank sites are not considered here: alternatives to their glaciomarine interpretation are presented in e.g. Huddart (1970, 1971a), Huddart and Tooley (1972) and Huddart, Tooley and Carter (1977). Eyles and McCabe presented no data for the sedimentology of this deposit, nor were relationships in Cumbria

between morainal banks, ice streams and drumlin formation discussed. It should be noted that on the coast south from Mawbray and on the Furness coast, drumlins have been eroded by the sea partially and wholly, so indicating the former greater extent of drumlin formation and demonstrating that the contemporary margins of land-based ice were seaward and not landward of the present coastline.

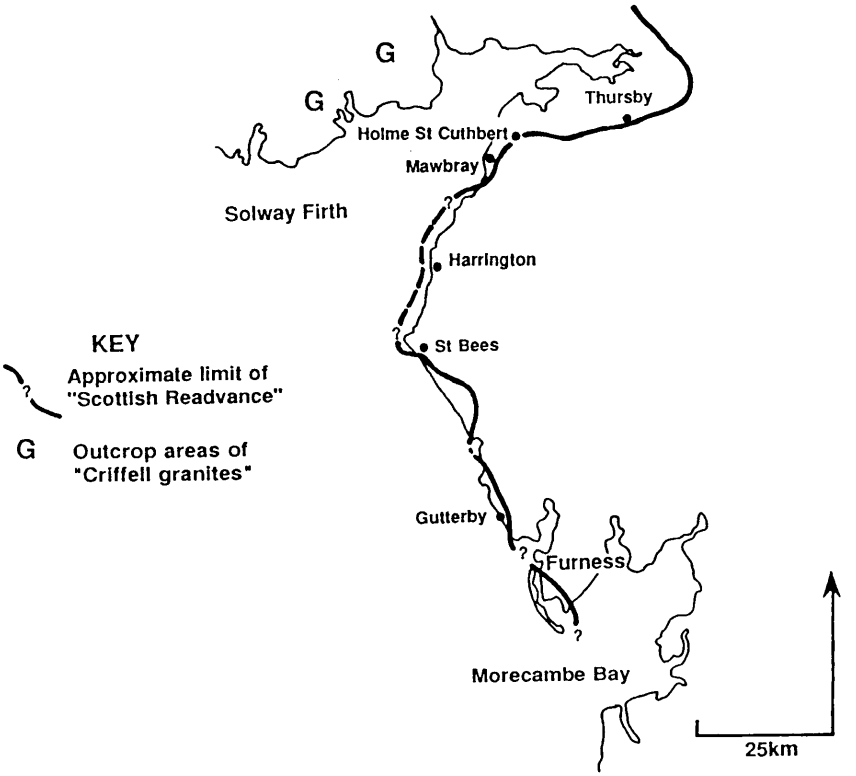


Figure 2 Limit of proposed Late Devensian ice readvance.

The sedimentology and morphology of the Holme St. Cuthbert fluvioglacial deposit indicate the following characteristics which are contrary to the interpretation proposed by Eyles and McCabe:

(a) a morphology of, NW-SE, ice-contact face, relatively flat plain with surface depressions, and delta foreset face. The ice-contact slopes face north-west rather than east where the ice would have been in the Eyles and McCabe model.

(b) a sedimentology which indicates a transition from top-set delta-surface, braided river through delta-front foresets into bottomsets, and which mirrors morphology.

(c) all palaeocurrents indicate a sediment transport from the north-west to the south-east, although in the foreset area there is some variability (Huddart 1970).

(d) the lithological suite with Criffel granite and Lower Calciferous Sandstone conglomerate reflects this transport direction (Huddart 1970).

(e) there are no marine microfossils as are often found in unequivocal morainal banks (Huddart and Peacock (1989)).

This sequence is interpreted as an esker-fed, ice-contact delta fed from Scottish ice to the north-west into a glaciolacustrine environment - ice ponded up water to the east in the Holme Dub valley. The height of the delta foresets gives an indication of the lake depth which was approximately 30m at Armstrong's Pit. There were two principal water levels during the lake's existence as indicated by distinct delta surfaces. The lower delta surface is best seen in the southern section of the complex near New Cowper. East of the topset-foreset depositional zone laminated lake clays would have been deposited in the lake basin now occupied by Cockley, Aikenshaw and Common Mosses. The conclusion is that the sedimentary environment was not that of a morainal bank but of a pro-glacial lake, that the associated ice was not then present to the east (inland) but to the north-west, and that the sediment sequence was

deposited after the drumlin stage and not intimately related to that phase (it is by chance they are now adjacent landforms).

2. Harrington - a high-level marine delta site?

Eyles and McCabe (1989) suggested that the morainal bank complexes merge inland with high-level marine deltas which were produced at major points, usually located in coastal valleys, of sediment supply from adjacent land-based ice-sheets. The significance of these landforms has been noted above. Most of the delta sites around the Irish Sea were said to occur in coastal valleys where ice-streams re-equilibrated and anchored after rapid wastage in glaciomarine environments. Only two of the proposed Cumbrian sites have such a setting. Alternative interpretations of these features have been suggested by Huddart (1970), Huddart and Tooley (1972) and Huddart (1991).

A site at Harrington (Fig. 2) is used in examination of the asserted presence of raised deltas along the Cumbrian coast. The sediments at the former Walker's Brow pit there are not deltaic but characteristic of an ice-advance proglacial sandur. Sediment sources were from the north-west and west, with corresponding palaeocurrent directions, rather than from the east as would be expected if the sediment had been deposited at a tidewater ice front by outwash from Cumbrian ice. As at Holme St. Cuthbert, the local relationship of sands and gravels (from west and north-west) to adjacent drumlins (aligned north-east to south-west) is one of subsequent rather than closely-contemporary formation.

This interpretation of the Walker's Brow sands and gravels is based on the following evidence:

(a) a horizontal coarsening upwards sequence constructed of pebble gravel units which in some instances have large-scale cross-stratified gravels below and laterally to the east. These gravel units are interbedded with and overlie cross-stratified and horizontally-stratified sands. The interpretation is of more distal transverse sand bars overlain by more proximal gravel bars which had occasionally built out into a deeper part of the channel to give gravel foresets at the downstream ends of horizontal bars.

(b) the difference in the erratic assemblages between the Walker's Brow sediments and the drumlin till to the east. In particular the presence of Criffel granite (17.6%), Lower Calciferous Sandstone conglomerate (1%) and St. Bees Sandstone (11.5%) in the sandur sediments at Walker's Brow illustrates sediment transport from the north-west.

(c) this is confirmed by the paleocurrent analysis of imbricated gravels in the pit with a grand resultant orientation of 289 degrees and a range of 76 degrees. Individual current vector distributions are all markedly unidirectional (Huddart 1970).

(d) additional evidence of an advancing ice margin is given by a plot of average intermediate pebble gravel axis length with height above the pit base for the gravel bars and a plot of thickness of gravel unit with height. This interpretation of the Harrington sediments is unequivocal. Eyles and McCabe (1989) produce no evidence for this site.

3. St. Bees: glaciomarine complex or readvance terminal moraine?

Eyles and McCabe (1989) showed ice-contact glaciomarine complexes preserved in confined bedrock valleys at many coastal locations in Cumbria and Wales. These sediment complexes were considered to be the result of subaqueous downvalley resedimentation of unstable piles of heterogeneous sediment released from the margins of tidewater glaciers. The sedimentary characteristics of the deposit almost completely blocking the southern end of the St. Bees valley (Fig. 2) were regarded as typical of such complexes. The following components of the St. Bees complex were identified:

(a) channels, up to 150m wide and at least 18m vertical extent, which are filled with

(b) stratified diamicts and poorly-sorted gravels (interpreted as subaqueous debris flows) and

(c) ripple cross-laminated sands (subaqueous outwash) and

(d) poorly-sorted, massive, coarse-grained gravels (high density turbidity currents)

(e) graded beds (turbidity currents)

(f) mud drapes and mud plugs infilling abandoned channels (suspended sediment from meltwater plumes).

Eyles and McCabe suggested that this sediment sequence is predominantly a record of downslope sediment gravity flow and subaqueous outwash directed along the bedrock channel from an inland ice margin. Under these conditions they envisaged steep substrate slopes which promote the cutting and filling of channels or 'chutes' by turbidity currents which result from the slipping of unstable ice-proximal sediment piles. The reported presence of mud drapes was seen to strengthen the glaciomarine interpretation. A marine ice margin from which the St. Bees sediment mass moved was mapped some distance inland in the St. Bees valley but no supporting evidence was given for a contemporary ice front there. These sediments had previously been interpreted as a proglacial sandur and terminal moraine sequence by Huddart (1970), Huddart and Tooley (1972) and Huddart (1991). On the coast south of Pow Beck near St. Bees is a till at the base of the succession. Overlying this till and to the north is a coarsening-upward sequence of distal to proximal sandur sands and gravels. At one location the St. Bees Silts and Clays are exposed and have been interpreted as proglacial lacustrine sediments. These sediments were complexly deformed by readvance ice push and an upper, fine-grained till was deposited from the readvance ice. The complex is thus considered to be a terminal moraine from ice to the west in the Irish Sea basin and not derived from ice in the St. Bees valley, as suggested by Eyles and McCabe.

4. The Thursby eskers

The origins of the esker group near Thursby (Fig. 2) and the associated sediments have been discussed by Huddart (1970, 1973)

whose conclusion is contrary to the proposition of marine incursion into the Dalston area implied by Eyles and McCabe. There is evidence for subglacial sediment transport from the north-west (a palaeocurrent direction of 304 degrees from Torkin and 296 degrees from How Hill), a lithology with a high percentage of Scottish granites and Lower Calciferous Sandstone conglomerate, and an ice-contact face to the north-west at Torkin. Eskers, fed from the north-west and indicative of unerosive contemporary ice, cross drumlin ridges formed by ice that had moved from the east, confirming the diachronous relationship between readvance and drumlin stage features noted from Holme St. Cuthbert and Harrington.

Evidence from Mud Drapes

Eyles and McCabe (1989) also used in support of the glaciomarine interpretation the reported widespread occurrence in lowland Cumbria of mud drapes over other glacial deposits. These would have been diachronous in deposition as areas of marine inundation altered with changes in the high relative sea levels. The authors stated that the mud drapes in Cumbria extend to 140m above present sea level: they are thus implied well inland of morainal banks and raised deltas. These drapes are, apparently, the deposit described by Trotter (1929) as a thin Upper Boulder Clay demonstrating a late extension of ice from south-west Scotland. Huddart (1970, 1971 a,b) showed this deposit to be confined to areas below about 40m OD, and not to reach the high levels described from the northern hill fringe of the Lake District by Eastwood et al (1968) and apparently accepted by Eyles and McCabe (1989).

As high-level deltas in the height interval 30-152m and morainal banks were supposed to mark the outer limits of contemporary land-based ice streams, as the sites of the Cumbrian examples are all close to the present coast, and as mud drapes are regarded as a marine deposit there is a problem of manner and occasion of mud deposition. The proposed altitudinal extent of the mud drapes requires a high sea level to about 140m after a fall of level from 152m to 30m. Earlier formation of mud drapes would have been precluded by lowland ice cover, the existence and extent of which the morainal banks and deltas were taken to demonstrate.

A very different explanation for the origin of this sediment was proposed by Huddart (1970, 1971 a,b, 1991), who concluded that it is a readvance subglacial till derived from ice moving out of the Irish Sea basin in a late stage of the deglaciation. Examples from the Carlisle plain where the readvance till shows incorporation of local bedrock and older glacial sediment (Huddart 1970) point to such an origin. This is particularly noticeable at the Eden bridge site on the M6 where the upper till overlies laminated lacustrine clays which are complexly folded and contorted, and where the till shows evidence of incorporation, with clasts of laminated clay within the till, as at the M6 Rosehill interchange. West of the Eden bridge on the M6, the upper till exhibits an irregular, erosional contact with the underlying white Kirklinton Sandstone.

Conclusions

The glaciomarine interpretation depends on adequate evidence for deposition in marine environments at sites categorised as morainal banks and marine deltas. It depends also on adequate evidence for contemporary ice margins at those sites and for ice cover landward of them. Evidence for late incursions of ice from the north, north-west and west onto the Cumbrian lowlands stands in the way of the glaciomarine hypothesis. Propositions of ice readvance place ice on the "wrong" side of morainal banks for the glaciomarine interpretation. The attempt by Eyles and McCabe to refute the readvance proposition is thus not unexpected but their assertion that it depends wholly on identification of high level lacustrine deltas and fine-grained Upper Boulder Clays (tills) is quite misleading. Important types of evidence in support of readvance are sediment input directions, sediment provenance and directions of meltwater discharge in localities where constraints on meltwater movement could not be explained by the glaciomarine hypothesis but are wholly compatible with the readvance model. Further, the readvance model is able to explain landforms such as eskers and meltwater channels at locations which would be marine in the glaciomarine model.

It is noteworthy that in direct juxtaposition to their comment that the Scottish Readvance proposition relies on identification of high level lacustrine deltas, Eyles and McCabe stated "sedimentological and microfaunal evidence indicate that the deltas [their high level glaciomarine

deltas] record local marine limits" for they presented no evidence, sedimentological or fossil, from the Cumbrian sites. The failure to report marine fossils from supposed glaciomarine Cumbrian sediments is of major consequence especially as these fossils are not uncommon in other areas of the Irish Sea fringes. The conclusions from the evidence presented in this paper are that the interpretations by Eyles and McCabe (1989) of glacigenic sediments in the Cumbrian lowlands have not been substantiated, that Cumbrian sites and sediments have been incorporated into their model without full regard for detailed evidence available from sedimentological, palaeocurrent and lithological analyses that suggest late readvance of Irish Sea basin ice onto the Cumbrian lowlands. However they have stimulated considerable recent fieldwork and debate. Austin and McCarroll (1992) and McCarroll and Harris (1992) suggested that glacigenic sequences in North Wales, interpreted by Eyles and McCabe (1989) as glaciomarine, are more readily explained in terms of stagnation and in situ decay of a terrestrial ice sheet which entrained marine sediments and reworked microfossils during passage along the Irish Sea bed. Similarly, Bevins and Donnelly (1992) have rejected a glaciomarine origin for the succession in the Pencoed area of South Wales. The terrestrial model had already been put forward for the Cumbrian lowland. Whilst it is not suggested that there were no marine ice margins associated with the Late Devensian deglaciation in parts of the Irish Sea basin, each area and sequence must be interpreted on the basis of its own evidence.

Acknowledgement

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THE SKIDDAW MASSIF PROBLEM

Dr R. Clark

Introduction

The Skiddaw massif is a distinct, compact upland clearly separated from the main Lake District hills by lower ground. Marr (1916) considered it to have been a site of discrete uplift, but the present relief has not been explained. Whether the massif's form owes more to the course of erosion working on a once-more-extensive upland, or to tectonism determining and sustaining the present extent of the upland seems not to have been considered. These alternatives must also relate to the surrounding lower ground. Though not pursued here, a further possibility is that present local relief derives from an Upper Palaeozoic landscape having been buried beneath younger sediments, with subsequent and, in view of landform characteristics described below, relatively late exhumation.

The Skiddaw Massif

The upland is remarkably compact in plan, about 13km across on both N-S and E-W diameters. Except for angular indentations on the north-west flank, its outline is very regular (Fig. 1). The principal surface rocks belong to the Skiddaw Group, with Eycott Group volcanics and the intrusive rocks of the Carrock Fell complex in the north where the boundary of the massif generally coincides with the contact with overlying Carboniferous strata. The base of the Carboniferous rises some 200m from the north-western edge of the Bassenthwaite lowland to the northern edge of the massif and falls away a little in the northeast.

Sections of the 40km periphery are quite straight, steep and smooth between the mouths of valleys. For most of its course the boundary of the massif traverses Skiddaw Group rocks and is thus unlikely to have been determined by major contrasts in resistance to erosion of rocks on opposite sides. A variety of rock types, lavas, granophyres, gabbro and Skiddaw Group strata, outcrop on the eastern boundary scarp with minimal effects on the course of the massif's margin. This suggests the

scarp was produced relatively recently or has been sustained in its present plan and steepness.

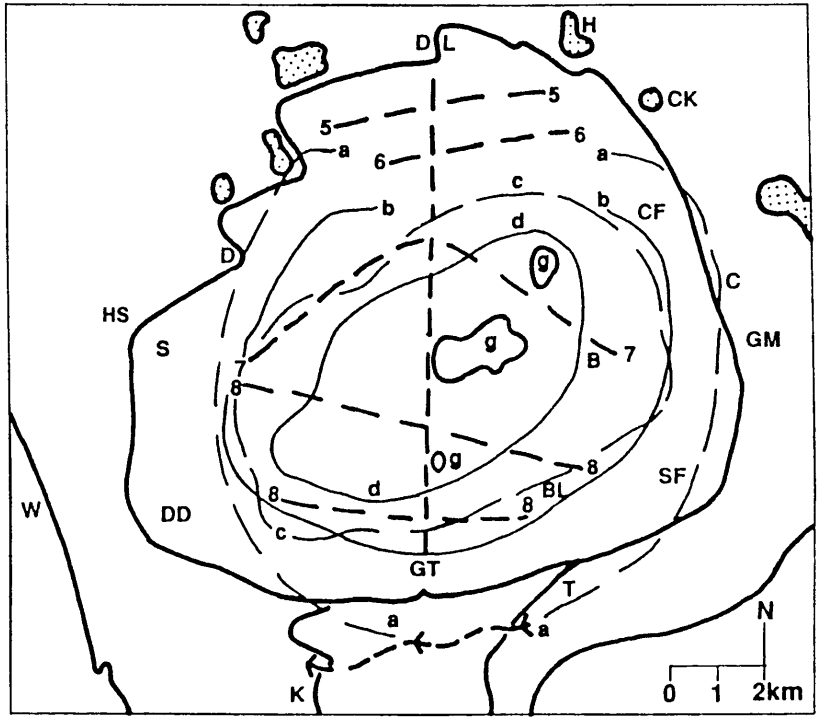


Figure 1. Skiddaw massif. Stippled areas represent 300m OD platforms. Numbered lines are generalised contours on summit envelope: numbers indicate hundreds of metres OD. Granite outcrops shown by 'g'. Line 'a': outer limit of steep gravity anomaly gradient, after Bott (1978). Line 'b': outer limit of very steep gravity anomaly gradient, after Lee (1984). Line 'c': outer margin of metamorphic aureole, slightly simplified in east, (Lee 1984). Line 'd': computed 0m OD contour on surface of granite dome (Lee 1984). Heavy lines show major relief boundaries including that of Skiddaw Massif. Line DL - GT is topographic N-S axis of massif, simplified. Arrowed line between T and K marks course of Greta gorge. Other capital letters denote place names as stated in the text.

Granite is exposed in small outcrops near to, and mainly to the east of, the massifs' N-S diameter, most extensively near the centre, in the upper valley of the River Caldew (Fig 1). Size and height range of outcrops show that the intrusion is virtually intact. Wadge (1978) did not include Skiddaw granite clasts among contributions to the nearby Upper Palaeozoic Mell Fell Conglomerate. Thus the granite, unlike the Shap granite of similar age, may have been unroofed only recently. That may mean there was no very strong uplift and associated erosion following intrusion of the granite which, in turn, somewhat reduces the likelihood of the massif being a lately-exhumed Upper Palaezoic landform. From gravity data, Bott (1974, 1978) and Lee (1984) suggested the granite intrusion is compact, steep-sided and flat-topped (Fig 1). Lee (1984) believed there may be elliptical culminations on the roof of the granite, one east, the other west of the main Caldew valley outcrop.

Associated with the granite is an area of negative gravity anomaly, somewhat oval in plan with major axis along the SW-NE reach of the upper Caldew valley. The gradient of variation in strength of anomaly is very steep away from the central part of the massif. The gravity field reflects the mass deficiency due to the granite. The altitude of the highest granite outcrop is some 300m greater than that of the lowest parts of the massif's margin (c.100 m.OD).

The massif has an inner basin largely drained by the upper Caldew, and a zone of outer slopes. North of the exits of Dash Beck (D in Fig 1) in the west and of the Caldew (C) in the east, the outer zone is almost everywhere over 3km wide. It is divided by steep-sided valleys with a dominantly angular pattern. In the south, the zone of outer slopes is narrower, steeper generally, with greater height range and greater hilltop altitudes.

In the interior basin the valley pattern is angular with three dominant alignments, N-S, almost NE-SW and SE-NW. There is an intersection of valley alignments close to the centre of granite boss and gravity anomaly. Angles separating alignments show only a moderate departure from the ideal least-work triple-fracture pattern over rising domes. The alignments are repeated along rectilinear hillsides on the north side of the inner basin (cf. the northern part of the outer zone) and suggest structural control of

erosion. The southern slopes of the basin are rather curvilinear though not everywhere and there is an approximate concentricity in the south between inner slopes, crestline and outer slopes. A N-S alignment bisecting the massif is followed by the Dale Beck (DL) in the north and Glenderaterra Beck (GT) in the south. Marr (1916) remarked upon it as a possible continuation of the Grasmere-Thirlmere fault zone. The three exits from the basin correspond with the three alignments noted above. The basin exposes the sequence of metamorphic zones over the granite but there is no clear relationship between detail of relief and degree of metamorphism.

In the circumstance of a once-larger upland, basin development would have depended upon peripheral erosion carrying low base levels towards the centre so facilitating basin deepening. Only the Caldew exit, over 100m above the lowest point on the upland periphery, has been involved in the later stages of deepening. The strength of this case depends upon evidence from the flanks of the upland (see below).

In the case of an upland of more-or-less constant extent there would be a different context for interior basin development though evidence for this case would also be sought from the outer slopes. Maintenance of the upland's extent would probably depend on continuance or renewal of uplift. Basin initiation need not have awaited cessation of uplift but rather on rock strain from intrusion and uplift becoming an effective influence on the pattern of erosion. A central basin could be initiated on a rising dome where structures were favourable.

Evidence for diminution of a larger upland and for stages in erosion is sparse on the outer slopes. That may be due to subsequent removal of diagnostic landforms, for example by ice that moved round the flanks of the massif. Such erosion was probably of limited intensity as is noted below. Only in the north are there indications, and those ambiguous, of stages in landscape development. At the base of the outer slopes are several near-horizontal surfaces cut across rock structures. More than one way can be proposed for formation of such surfaces. Where several surfaces occur in a locality at a common altitude thus forming a set, and where sets occur, each set with characteristic altitude, surfaces and sets are not readily explained other than as due to erosion influenced by

particular base levels sustained for some time. Eroded surfaces of this type are commonly termed planation surfaces or platforms.

Dunning (1992) noted 'a great variety of erosional landforms, chiefly plateaux and platforms, have been interpreted to imply pulsed epeirogenic uplift ..... of older Palaeogene date in northern England.' Dunning accepted the difficulties of defining and explaining platforms but concluded they 'do exist and are indubitably erosion surfaces: the main argument is whether they were formed at sea level and then rapidly uplifted or were carved by continuous and prolonged subaerial erosion.'

The surfaces at the north margin of the Skiddaw massif appear to be members of a set of small features at about 300m OD disposed in an arc from near Bewaldeth in the west for 24km to near Dacre in the east. Hollingworth (1936) and McConnell (1938) identified surfaces of comparable altitude in the Lake District. Planation surfaces at the north-west base of the massif near Longlands (L) lie against the angular, indented uplands margin. They may have been eroded in lower ground up to a pre-existing, possibly faulted, edge of the hills or, less likely, the massif may have risen within the planation flats after they were eroded. Similar features at about the same altitude near Hudscales (H) and Calebreck (CK), are adjacent to small offsets in the margin of the massif. Altitudinal correspondence of these features implies little disturbance since formation but that does not demonstrate that the massif within has not experienced movement.

The remaining parts of the outer slopes offer no greater evidence for episodes in erosion and greater extent of the upland. Breaks in the long profiles of the R. Glenderamackin (GM), Glenderaterra Beck (GT), and Southerndale Beck (S) might be consequential on uplift but other explanations are possible. However, the plan of the massif is also relevant. It displays an interesting symmetry about the N-S diameter (Fig 2): this includes some ridges and valleys in the SE and SW parts of the outer slope zone. There is also some symmetry of landforms in the central basin.

A proposition that the massif is an erosional residual should show not only how such a compact unfretted upland would be produced, but

how backwearing of slopes of different height, aspect and rock strength, with evacuation of debris by different routes, could give rise to such symmetry. It should demonstrate how erosion could be checked, possibly diachronously, just as a degree of symmetry was achieved.

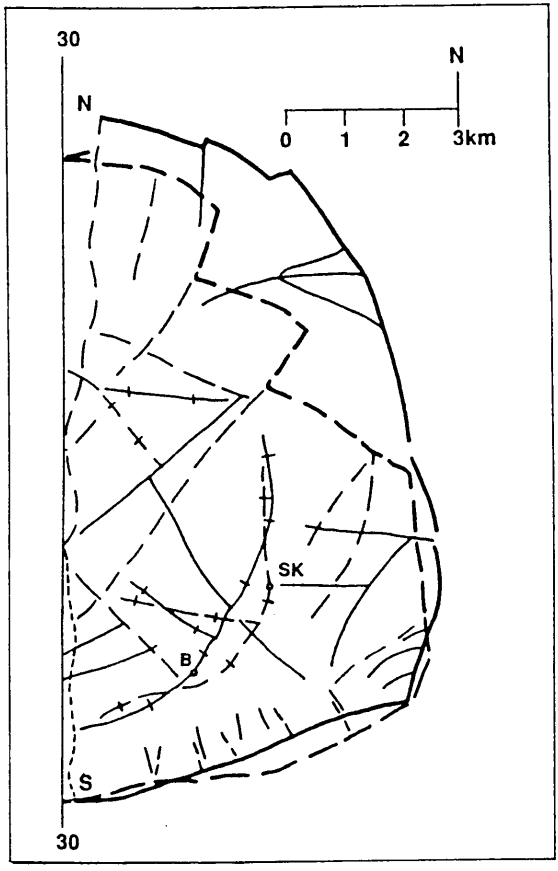


Figure 2. Skiddaw massif: east-west symmetry of landscape features. Axis of rotation is National Grid line 30. Broken line N-S is topographic axis. Heavy line shows edge of massif, continuous for east, broken for west. Other lines show trends of selected relief features, continuous for eastern side, broken for west. Ticked lines represent ridge crests: others show valley axes. SK-Skiddaw: B - Blencathra.

It should show that contemporary compactness and symmetry are inconsequential and ephemeral and will be destroyed by continuing erosion or that erosion proceeded to a point where a different structural-tectonic circumstance prevails and asserts a contrasting control over form.

The Skiddaw moat

Lower ground surrounds the massif like a moat. The higher northern part of the moat, 200 - 300m OD, is less prominent than the rest. From the Caldew's exit from the massif the moat falls from c. 230m OD to c. 140m west of Threlkeld (T). There the River Greta leaves the eastern section of the moat (Fig. 1.) by the gorge through which it reaches Keswick (K). This gorge traverses a barrier of somewhat higher ground that separates the eastern part of the moat from the western, the Bassenthwaite lowland. Discharge from the eastern moat and the Thirlmere valley would have passed to the western part during the later stages of landscape history - except during occasions of ice-sheet glaciation. Development of the present gorge has been discussed by Boardman (1982). This barrier is significant to the Skiddaw massif problem because differentiation of moat and barrier, too, may have been dominantly influenced by contrasts in rock resistance to erosion or by tectonism. The barrier is located where the Grasmere - Thirlmere line meets the N-S Skiddaw axis. The local gravity anomaly pattern (Lee 1984) shows a small independent negative anomaly over the barrier joined by a narrow neck west of Threlkeld to the greater Skiddaw anomaly. A wedge of positive anomaly widens west of Keswick into the Bassenthwaite lowland and a tongue of positive anomaly lies along the moat near Threlkeld. The intrusion of microgranite near Threlkeld is shown by gravity data (Lee 1984) to be broader than the outcrops indicate, but their exposure shows the area has experienced at least one episode of significant uplift.

This combination of features allows several interpretations of the local relief:

a. deepening of the moat encountered more resistant rock and the barrier developed in conjunction with a drainage route across it,

b. the present barrier appeared by exhumation from beneath cover rocks. This puts formation of the original barrier back in time and ascribes to more recent erosion the task of revealing it. This is cognate with the last potential explanation noted in the Introduction,

c. during a late phase in landscape history the barrier area experienced some uplift relative to the adjacent moat.

There appears to be no compelling evidence that the Skiddaw Group rocks exposed at the barrier are particularly resistant to erosion. The structural setting and tectonic history suggest a local potential for crustal movement. A possible trigger to uplift is considered below.

Discussion and Conclusion

The foregoing has outlined for the Skiddaw massif a combination of characteristics relevant to different accounts of relief development. The view that it is the remnant of a once-larger upland would be strengthened by the evidence for scarp recession given by a fretted outline of irregular spurs, outlying hills and recesses. The paucity of such features is indicative rather than conclusive, but the present hill margins do not point to previous extent of the massif in any direction. In the west an exit which would have controlled erosional deepening must have existed throughout development of Borrowdale and the Newlands valley. The linear east face of the Wythop Fells (WE) has been shown to follow a fault-line (Jackson 1978). The bend at Dodd (DD) on the western flank of the massif corresponds with one at Souther Fell (SF) on the east. It is not easy to conceive that erosion has determined the turn at Dodd just where it would create that symmetry. Ice passed through the narrows between Dodd and the Wythop Fells: there is evidence of erosion and deposition,

but not for substantial widening of the gap, and the bend seems to have been conserved. That conclusion does not strengthen the case for significant lateral erosion by ice elsewhere along the periphery of the massif.

The steep hillsides separated by gullies along the Blencathra (BL) southern front of the massif were said by Marr (1916) to be due to ice having truncated spurs. There is no evidence that spurs once projected from the mountain front there: that they had done so was an assumption. The present symmetry of the southern front of the massif would be improbably explained by cumulative spur truncation dependent on the contingencies of a sequence of glacial and intervening episodes.

Angular embayments and offsets on the massif's northern boundary, principally near Longlands, cannot easily be explained by backwearing of slopes where the boundary traverses rocks of similar resistance to erosion. The steep, straight reaches of the eastern boundary cross various rock types without much displacement at lithological boundaries. This part of the boundary calls for an inflexion amounting to some hundreds of metres to carry the bases of Eycott Group and Upper Palaeozoic rocks over the high southern fells, Bowscale Fell (B) and Blencathra, for example. The case there for structural and tectonic influences is strong where that for progressive erosional slope retreat carries less persuasion.

Along more than half its length, from Highside (HS) in the west, south and round to Carrock Fell (CF) in the east the massif's periphery has some resemblance to young or to only moderately-degraded fault scarps characteristic of upland terrains with active or recently-active fault movement. This may be linked with the higher summits being located in the south. Concentricity in plan of the massif's margin and the zone of steep gravity gradient strengthens the inference of structural and tectonic influence.

A context for local landscape history has been sharpened by recent studies. Burgess and Holliday (1979) considered the nearby Pennine scarp was produced by movements related to Alpine mountain building and 'which probably continue to the present day'. The Pennine blocks share with other northern uplands, main Lake District upland and Skiddaw block included, the presence of granite cores. Leake and Cobbing (in press) note the widespread occurrence of pluton tops at the present land surface, categorising that conjunction as transient (as in the Andes) or long-term. The latter case involves relatively stable crust in which pluton tops fluctuate vertically by up to c. 3 km on each side of an average sea level over intervals of hundreds of millions of years. Caledonide granites of the British Isles are among these. Leake and Cobbing consider that limited erosion, less than 1km of crystalline rocks in the case of the eastern Grampians since intrusion of local granite, exemplified that type of stability. The Lake District is not dissimilar. It is located near the boundary between exposed granites in more uplifted regions to north and west and, to east and south, an area where most granites remain concealed.

Data from fission track analysis on palaeotemperatures and dates of cooling of rocks now at or near the surface in north-west England and offshore allow Lewis et al (1992) to develop the context. There was, they propose, a regional cover several km thick of dominantly sedimentary rocks at the end of the Cretaceous. That cover has since been wholly or largely removed. In parts of the Vale of Eden 'the minimum amount of erosion .... is 3.3km and similar values appear to have been reached in the Lake District.' Erosion was, perhaps, initiated by thermal doming. Lewis et al note studies which suggest elevation of a dome with c. 1000km radius and central uplift about 2 km, and suggest that doming preceded rifting and spreading in the North Atlantic area. That is reminiscent of the model Cloos (1939) propounded for initiation of the large-scale relief pattern of the British Isles. With doming 'not only were basins inverted, but basement regions and areas previously considered to have been long-lived highs, such as the Lake District and the Pennines, have seen almost as much erosion as the basins' (Lewis et al 1992).

Erosion on the scale envisaged, much of which probably occurred in the Palaeogene, brought older crust back towards the surface. It would

also lead to further uplift by isostatic rebalancing and consequently to prolonged erosion. The influence of buried plutons on pattern of compensatory uplift would become proportionally greater as erosion bit deeper. In association with the effects of inherited structures and contemporary strain, they would increasingly affect differentiation of relief. The Skiddaw massif may be an element in that differentiation, the granite core exercising a growing independent influence on local relief as removal of thick sediment cover progressed.

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THE LAST 200 MILLION YEARS IN CUMBRIA

E. Skipsey

The framework of Cumbria

Cumbria consists of a small dome of ancient (Ordovician and Silurian) rocks protruding from beneath a cover of younger sedimentary (Carboniferous and Permo-Triassic) rocks which occupy the outer parts of the county. It has taken over 500 million years to create the Lake District we know today, with the first 300 million years overshadowing everything that followed. What happened in Cumbria during the 200 million years since the Triassic is largely guesswork since there are very few deposits from the times before the ice ages of the Quaternary. However the suggestion that significant thicknesses of Mesozoic rocks once covered the Lake District and Pennines was stated, either implicitly or explicitly, by many workers in the early years of this century. More recently in the Geological Society's "Atlas of Palaeogeography and Lithofacies" (1992) these areas are shown as emergent during Mesozoic times.

Whether a significant thickness of Mesozoic rocks once covered the Palaeozoic rocks, which now form the structural highs of the Lake District and the North Pennines has long been debated and this debate has been revived recently by apatite fission track analysis studies. Lewis, et *al.* (1992) have focused attention on a growing body of evidence which suggests that the region was covered by extensive Mesozoic sediments and that previously unrecognised kilometre-scale erosion has occurred over very large areas. This article reviews the conclusions of their paper and a subsequent one by Holliday (1993) which considers the implications.

The Mesozoic and Tertiary geology of Cumbria

Following the close of Triassic sedimentation, there are few records of later rocks in Cumbria. A very small patch of Lower Jurassic sediments is preserved west of Carlisle and the nearest Cretaceous rocks are in Northern Ireland. There are no Tertiary rocks other than the Armathwaite dyke, near Carlisle, which is dated at 60 million years old. Offshore in the adjacent East Irish Sea Basin there is no evidence of Cretaceous or Tertiary sediments, in contrast to the North Sea grabens with their thick, petroleum-bearing Tertiary sequences.

Consequently knowledge of later history is restricted by lack of preserved strata. However the Mesozoic appears to have been a period largely dominated by extensional basin formation (Jackson *et al.* 1987) with, in Late Cretaceous times, a period of widespread regional subsidence. An overall rise in sea levels at this time meant that the seas were more widespread than at any other time during the Mesozoic although the actual limits have always been contentious. There are substantial areas where there are no extant Upper Cretaceous sediments but which must have been submerged for at least part of the period. Consequently it is possible to contemplate the prospect that the Lake District and the Pennines were covered by chalk deposits that were subsequently removed by erosion during Tertiary times.

Evidence from apatite fission track analysis.

Estimates of Tertiary erosion of Mesozoic rocks have been deduced from the palaeotemperatures estimated from apatite fission track analysis (AFTA). Fission tracks, or trails of radiation damage, are produced within apatite grains at a more or less constant rate throughout geological time, as a result of the spontaneous fission of ^{238}U. Fission tracks are not preserved where the material has been heated subsequently, so that the number of tracks are related to the time intervals since the material was last at a certain critical temperature, such as a metamorphic event. Above 50° C the tracks are shortened by a process of annealing, and are erased above 120° C. Thus from the U content of the grains, and from the number and length of the tracks, it is possible to make important inferences about the thermal and burial history of a sample.

Lewis *et al* used the apatite fission track analysis of samples from northern and central England to analyse the thermo-tectonic history of the region, following the work of Green (1986). The analysis demonstrated that most of the rocks presently at outcrop had been subjected to palaeotemperatures greater than 90°C in the Latest Cretaceous or Early Tertiary times. They concluded that available data indicate palaeogeothermal gradients at that time were similar to present values and it is suggested that the high palaeotemperatures were due to the depth of burial of the sediments. They estimated that up to 3 km of post-Palaeozoic sediments lay across the Pennines, the Lake District and the Cheshire and Irish Sea basins by the end of the Cretaceous.

Subsequent Tertiary erosion has removed a considerable thickness of cover from the entire region. Assuming a palaeogeothermal gradient of 30°C km^{-1} and a surface temperature of 10°C, Lewis *et al* have estimated the total amount of erosion which must have occurred in different areas in order to cool samples to their present values. In the East Irish Sea and Cheshire basins this is between 2.7 and 3.3 km of sediment; supporting evidence from the East Irish Sea Basin (Bushell, 1986) also suggests that 2 to 3 kilometres of cover have been removed from above the Triassic rocks presently outcropping on the sea floor because, in order to generate the hydrocarbons of the Morecambe Bay gas field, Carboniferous source rocks must have been substantially hotter than they are today.

More surprising is the conclusion that considerable thicknesses of sedimentary cover may also have been removed from surrounding structural highs, such as the Lake District and the Pennines. In parts of the Eden Valley high temperatures suggest that the minimum amount of erosion is 3.3 km and similar values appear to have been reached in the Lake District. It should be noted however in the Lake District that local high geothermal values are sometimes associated with granites (Webb & Brown, 1984); high heat flows from these rocks may have marginally enhanced elevated palaeotemperatures.

Holliday (1993) has reviewed the regional geological data and has arrived at an estimated thickness of cover rocks eroded from the Lake District and Pennines in Tertiary times. He concludes that there is a significant measure of disagreement between these estimates and the AFTA results, although both indicate kilometre-scale cover. To account for these differences he examined some of the assumptions made by the AFTA workers, in particular the assumed surface temperatures and geothermal gradients used. Early Palaeogene mean annual temperatures in Britain were considered to be higher than those of the present day, being close to subtropical values of around 20°C, and he concluded that present-day geothermal gradients or palaeogeothermal gradients in preserved strata could not be directly applied to the eroded section. He therefore suggested that an AFTA-derived palaeotemperature of 110°C with a surface temperature of 20°C and a palaeogeothermal gradient of 53°C km^{-1} would suggest erosion of 1.7km of strata. This value is close to likely thicknesses of 1200 - 1700m inferred from the regional geological trends and brings ATFA results into line with other geological evidence.

Implications of the Mesozoic cover

The possibility of a thick sedimentary cover across the Lake District by the end of the Cretaceous implies a drastic review of ideas that the ancient core of the Lake District persisted as a landmass thoughout most of Mesozoic and Tertiary times, buoyed up isostatically by its granite batholith. In order that this sedimentation could take place, a subdued and low lying topography must have developed which was submerged at the latest by the world-wide rise in sea levels occurring during Cretaceous times.

The episode of Early Tertiary regional uplift and erosion identified in this and other studies appear to have affected an area extending over 1000 km from the Early Tertiary North Atlantic rift zone and almost 2000 km from the Alpine deformation front. The cause of this widespread erosional event is considered to have been related to both the rifting in the North Atlantic and compression resulting from the Alpine orogeny. These episodes were also associated with the Hebridean igneous province in western Scotland, of which the Armathwaite dyke is a component.

The total removal of this Mesozoic cover during the 65 million years of Tertiary times and the absence of any remnants today raises questions about its feasibility and the ultimate destination of the sediments thus removed. While periods of rapid and extensive erosion can be illustrated elsewhere in the geological column, the total absence of any residual traces is more surprising. Two examples in Cumbria can be cited to illustrate the rapidity of erosion.

The Shap granite has been dated at 393 ± 11 million years. It is believed to have been intruded at 5 to 10 km below the surface. Basal Carboniferous sediments, dated at around 350 million years, are exposed in Wasdale Beck, near the Shap Wells Hotel, and contain the very large pink megacrysts that are characteristic of this granite. It can therefore be inferred that 5 to 10 km of country rock enclosing the granite had been stripped away by erosion in some 43 million years.

Basal Permian conglomerates, known as brockrams and dated at about 260 million years, were deposited unconformably as outwash fans on eroded surfaces of Carboniferous rocks round the margins of Permian basins like the Eden Valley. The Carboniferous rocks exposed below the unconformity vary in age from Brigantian to Westphalian and it can be concluded that folding and erosion occurred after the deposition of the Westphalian sequences, around 310 million years ago. Where the brockrams were deposited on Lower Carboniferous rocks, such as at Hoff, near Appleby, a considerable thickness of Carboniferous strata must have been removed in some 30 or 40 million years.

However in both these examples, remnants of the eroded rocks can be found in the basal beds above the unconformities. In the case of the hypothetical Cretaceous sediments, there are no traces whatsoever to confirm their former presence. Hancock and Rawson considered this problem in a more general context. They concluded that it was particularly difficult to decide how far west and north of the present outcrop the Chalk originally extended. On the one hand, there is the argument of Cope (1984) that the speed of erosion and the amount of Chalk removed before the mid-Eocene in southern England means that the whole Cretaceous cover could have been removed during the Tertiary in regions where there was no basalts to protect it. Certainly the Cretaceous deposits in Northern

Ireland are covered by Tertiary basalts. In contrast to this view, there is the fact that in Europe generally it seems remarkably difficult to remove all traces of a Cretaceous cover; bits and pieces of Upper Cretaceous are found on many massifs of northern Europe where there is no general Cretaceous cover.

When compared with estimates of erosion identified in many of the basins around the British Isles during hydrocarbon exploration, the values quoted by Lewis *et al* are not very unusual. However the real significance of their work is that this widespread event has now been identified on-shore where it is seen to have been a much more regional event and not simply related to basin inversion (i.e. uplift in sedimentary basins).

Erosion probably continued throughout the Tertiary and may have been enhanced by subsequent pulses of inversion. The paper by Clark (The Skiddaw Massif problem) in this edition of the Proceedings indicates that later Tertiary uplift might have been a factor in the present-day prominence of the Skiddaw massif. However any Oligocene or Miocene events were comparatively mild compared to the main phase of uplift and erosion in the Late Cretaceous/Early Tertiary. In the North Sea basins, Tertiary sedimentation began in the Early Palaeocene and as much as 3 km of Tertiary sediments are present in the Central Graben (Lovell, 1990). The sediment infill for these basins may well have been eroded from the elevated mainland and the East Irish Sea Basin (EISB). It has already been noted that the EISB and onshore basins have remained elevated and do not contain any Tertiary sediments.

Conclusion

The possibility that up to 3 km of post-Triassic sediments lay across the Pennines, the Lake District and the Cheshire and Irish Sea basins by the end of the Cretaceous demands considerable revision of ideas concerning the Late Cretaceous/Early Tertiary geology of the region. The total removal of this Mesozoic cover during the 65 million years of Tertiary times and the absence of any remnants today also raises questions about its feasibility and the ultimate destination of the sediments thus removed.

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GEOLOGY IN THE CHURCHYARD

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(A short article adapted from the Geologists Association leaflet "Geology in the Churchyard")

Introduction

Geology is all around us - not only in the countryside and on the fells but in the towns and cities. Most villages, towns and cities in Britain reveal a wide range of natural and man-made building materials. The best examples of the large scale use of stone is in the construction of castles, churches, civic buildings and stately homes but it is often in the churchyard or cemetery that the most varied range of types of stone will be found.

Gravestones and memorials remain unchanged, except for weathering by the elements, while the original quarries which produced the older stones have long since disappeared. From the earliest gravestones in local churchyards, probably from the 17th century, up to the early 19th century gravestones invariably came from local quarries and we can class these as *native stones* . By the 20th century, ease of transport and changes in taste led to stone being imported from distant sources and, increasingly, from overseas. We can class such materials as *exotic stones*.

Recording And Surveys

Geologists have long been accustomed to visiting churchyards during field excursions but now that geology has found a place in the National Curriculum, many more people will be encouraged to discover the geological treasures of the churchyard, so often close at hand. A systematic survey is needed to appreciate the potential and a simple recording scheme might include the following points:-

1. Check a local geological map to gain the first clues to the local geology and likely rocks to be used.

2. Identify the main types of stone used for gravestones (i.e. sandstone, limestone, slate, granite, marble). Local monumental masons may be able to add specific names of stones used.

3. Make a record of the gravestones in the churchyard. These could be plotted on a map or plan obtained from the Parochial Church Council or the vicar. The record should include the type of stone, date of placement and condition of each stone and the frequency of each stone type.

4. Assess the degree of weathering of the stone in relation to the date on it. What has influenced this weathering ? Where does the stone stand in relation to buildings, walls, trees ? What is its aspect in relation to the prevailing winds and rain ? If the churchyard is in a frost hollow then stones may be subject to frost attack at ground level.

5. Study the relationship between rock type and lichen and moss growth. How many kinds of lichen and moss can you identify ? Is their distribution affected by the aspect or type of stone ?

6. Try to write a 'tombstone trail'. This geological trail can provide a textbook of geology and a local social history - you might find the graves of notable local geologists, like the grave of John Postlethwaite in St. Johns churchyard at Keswick.

7. Municipal cemeteries can also provide a wealth of stones, particularly the old Victorian ones, where you will find a much greater range of 'exotic' imported rock types, such as the intensely dark red Scandinavian granite, the white Italian marbles and the inky black "granite" from India.

Types Of Stone

One of the local stones will dominate the scene in most Cumbrian churchyards, depending upon the district. In Lakeland, gravestones were principally of slate while in West Cumbria and the Eden Valley, sandstones were the principal memorial stones. These stones have the following characteristics:

SLATE: This is one of the easiest stones to identify and represents a typical metamorphic rock (i.e. a mudrock which has been changed from its original character by pressure). Slate surfaces allow for very fine lettering and these are the kind of inscriptions which survive best of all in a churchyard.

SANDSTONE: This can be recognised by examining the rock under a hand lens when the individual sand grains will become evident. If a flake of stone has weathered from the slab, just crumble it between your fingers to regain the original sand. The individual sand grains are bonded by a mineral cement which may be either silica or lime. Iron oxides present in the cement impart a warm brown or orange colour to the stone. You can see why sandstones are sedimentary rocks.

LIMESTONE: These are also sedimentary rocks, built up from accumulation of shell fragments and fine lime. Limestones can also be recognised from their rough "ragstone", grainy "oolite" or massive "splintery" types of stone. You may find that the limestone contains fossils of sea shells or corals preserved in the stone.

GRANITE: This stone displays an internal structure in which the minerals forming the rock can be seen to be interlocking in a tight mosaic. It represents an igneous type of rock with a molten origin. With just a little practice, types of granite might be more precisely identified by colour differences and crystal shapes in the quartz and feldspars of which they are composed.

MARBLE: This was originally a limestone in which the lime has been altered by heat and the minerals re-formed (i.e. it is another metamorphic rock). The best known example is the white Carrara Marble found in almost all burial grounds and particularly popular in Victorian times for the ease with which it could be carved into three-dimensional sculptured monuments. The pure white colour never mellows or blends into the natural tones of an English churchyard and this is one of the reasons why it is often banned nowadays. But - beware of the terminology! Your local mason may quite happily lump "marbles" and "granites" together as they both take and retain a polish in commercial terms.

Gravestone Conservation

Churchyards usually have been carved out of meadowland or ancient pastures and are often remarkably rich in plant species. Even small ones of less than an acre commonly have well over a hundred different flowering plants and ferns. Many rare species are especially characteristic of old churchyards, which are often also the last refuge for cowslip or early purple orchids in the parish.

Churchyards managed by traditional means of cutting or grazing will have escaped artificial fertilisers or other chemicals. They will contain a wide variety of habitats such as rough grasslands, closely mown grass, disturbed ground, stone surfaces, paths, walls and areas of scrub and trees. Churchyards in towns and cities are obvious refuges for wildlife in an otherwise completely alien environment. Consequently a churchyard managed with sympathy for wildlife can be equally tidy as a close cropped burial ground and is often more attractive to people as well as to plants and animals.

The era of clearing churchyards of their gravestones seems to have passed and this no longer poses such a threat. However if gravestones have to be moved, stones should not be stacked in a pile but stored in a manner where they can be seen. Gravestones can be damaged by inappropriate treatment and the more powerful mechanical strimmers and lawnmowers now used can cause physical damage, particularly to inscriptions. The use of herbicides around the base of gravestones not

only leaves an unsightly, albeit temporary, brown circle of dead vegetation but could inadvertently attack the stone.

Restrict the cleaning of gravestones to a minimum. Certainly ivy and saplings should be removed from memorials and monuments but great care is needed in removing lichens and moss. Gravestones and walls of old churches can acquire a patchwork of up to fifty different lichens - particularly valuable in an area otherwise devoid of natural hard rock. They do no harm to the stone but much damage is often done in trying to scrape them off. Before you start, it is advisable to link up with a local lichenologist or genealogist so that you can agree a course of action.

Field work in churchyard or cemeteries can be a new experience for the orthodox geologist accustomed to wide-open spaces where one rarely meets other people. By contrast, many people from a local community find time or cause to slip into a churchyard or cemetery and they will nearly always have a curiosity as to what you are doing. Certainly keep the Parochial Church Council and the vicar informed about the progress of your investigations. These can lead to fruitful contacts and provide yet another challenge to the commitment of how best to conserve our natural heritage in stone.

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EXCURSIONS

THE VALE OF CHIPPING AND THE TROUGH OF BOWLAND

Leader: Dr Neil Aitkenhead (B.G.S., Nottingham)

3 May 1992 - Joint Meeting with the Westmorland Geological Society.

A group of over 30 members and guests met at Beacon Fell (SD 565 427) where the leader explained that the objective of the excursion was to examine parts of the late Dinantian to early Namurian succession in the Craven Basin. This was a relatively deep water basin that lay between the Southern Lake District High to the north, the Askrigg Block to the north-east and the Central Lancashire High to the south-east. The geology of the area is shown on the recently published B.G.S. 1:50,000 Sheet 67 (Garstang) and a memoir describing the geology of this sheet (Aitkenhead et al. 1992) is now at the printers. The named stratigraphic units referred to on the excursion are mostly described and defined either by Riley (1990) or in this memoir.

Beacon Fell is capped by an outlier of the Pendle Grit Formation and the first location visited was on the roadside on the northeast side of the Fell where the underlying Upper Bowland Shales are exposed. Blocky siltstones deposited at the distal margins of turbidity currents are interbedded with dark, inter-turbidite shales. The panoramic view on the east side of the fell shows the Bowland Fells, Longridge Fell and Pendle Hill, formed from the resistant rocks of the Namurian Pendle Grit Formation, with older Dinantian rocks of the Lower Bowland Shale Formation and Worston Shale Group cropping in the low lying Vale of Chipping and Clitheroe areas. The Ribblesdale Fold Belt forms a region of strong north-east to south-west folding with the folds shown by geophysical surveys to be related to disturbances in the basement rocks 2 - 5km below the surface.

Knoll-reef (Waulsortian build-up) deposits of the Clitheroe Limestone Formation were examined at Arbour Quarry (SD 619 407) where two different facies were exposed at the eastern end of the disused

quarry: a fine grained limestone formed from micro-crystalline calcite which built up in mounds on the sea floor and a crinoidal limestone which probably formed on the flanks of a mound. Fossil assemblages on the mounds of calcareous mud have been related to water depth with the lower parts having accumulated at depths of 300m below sea level. The lack of light penetration at this depth would prevent algal growth and Lees and Miller (1985) suggested cyano-bacteria as the mud producing agent. Some of the massive limemuds show a lamination possibly produced by cavities being filled by fibrous calcite rather than by algal secretions. Brecciation by dewatering and compression of the overlying beds in some of the limestones has resulted in the shapes of the clasts appearing to fit together (Miller 1986).

A limestone boulder bed exposed at the western end of Arbour Quarry forms part of the Limekiln Wood Limestone Member of the Hodder Mudstone Formation. Dr Aitkenhead explained that the base of the member represents an unconformity but the origin of the boulder bed is still somewhat controversial. One possibility is that it resulted from submarine back scarp retreat along active faults, and another that it is the product of wave action on the higher parts of Waulsortian mounds that had already been subjected to karstic erosion during a period of emergence. Palaeontological evidence also indicates a break in deposition as certain key foraminifera are absent.

A river cliff in the left bank of the River Hodder near Stakes (SD 6474 4341) was next examined where a sequence of rocks formed the upper part of the Worston Shale Group. The rocks here lie close to the axis of the Lees Syncline and are nearly vertical. The Hodder Mudstone Formation shows a cleavage which crosses the more competent siltstone beds almost at right angles but cuts the finer mudstones at a more acute angle. The overlying Hodderense Limestone Formation contains small burrows. The Pendleside Limestone Formation at the top of the sequence spans the Holkerian-Asbian boundary. Here, Dr Aitkenhead used the cross sections and the Bouguer gravity anomaly map provided on the margin of the published 1:50,000 Garstang geological map to illustrate the likely cause of the intense folding and cleavage at this locality. Seismic and gravity evidence indicated that there was probably a pre-Carboniferous high or tilt block at depth beneath the Bowland Fells

with a steep fault-bounded south-east margin. The end-Carboniferous Hercynian compression against this steep margin probably produced the structures seen at this exposure.

The party travelled through the Hodder Gorge to the disused limestone quarries at Sykes (SD 6282 5180). The valley cuts across the axis of the Sykes Anticline and the quarries worked the Hetton Beck Limestone Member of the Hodder Mudstone Formation which forms an inlier in the core of the fold and which is partly silicified, forming an area of higher relief. The medium grey limestone appears to have been deposited by gentle currents on the slope between the platform and the basin as silicified fronds of *Syringopora* are found in situ and there are lenses of crinoid debris. A small fold on the west side of the road is overlain by undisturbed beds indicating slumping rather than tectonic origin, further evidence of a slope environment intermediate between platform and basin. From the quarries the view to the south-east shows the landslips on Mellor Knoll; the Pendle Grit and underlying Bowland Shales have collapsed to produce a series of scars on the hillside. The topography of the surrounding area is related to geology with the high moorland country of the Pendle Grit contrasting with the lower topography of the side valleys in the Bowland Shale Group.

The final location was the Trough of Bowland (SD 625 528) where a stream section in Namurian rocks was examined. The shales and siltstones of the Upper Bowland Shale Formation are similar to those seen on Beacon Fell. The *Eumorphoceras pseudobilingue* and *Cravenoceras malhamense* marine bands are exposed together with fossil bivalves. The Upper Bowland Shales are succeeded by the Pendle Grit Formation, a coarse, feldspathic sandstone showing typical proximal turbidite features such as a variety of types of sole marking as well as shale-flake conglomerates. The lower part of the formation shows sheet bedding but the upper part not seen on the excursion appears to have been deposited in definite channels.

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THE BORROWDALE VOLCANIC GROUP OF THE UPPER CALDER VALLEY

Leader : David Kelly

3 June 1992

Members and friends met at Cold Fell Gate in the upper Calder valley for an evening excursion to examine an area previously visited by the Society in 1965 and 1981, (Shackleton, 1975). The upper Calder Valley is underlain by a complex series of rocks which are shown on the Gosforth and Whitehaven maps (Sheets 37 and 28). The new Gosforth sheet provides a modern interpretation of the area.

The Skiddaw Group crops in the north of the area and consists of laminated dark mudstones and siltstones containing fossils of Tremadoc age (Molyneux & Rushton, 1984). These are overlain unconformably by the hard, brown silica-rich Latterbarrow Sandstone. This was previously assigned to the Skiddaw Group but is now recognised as being much younger. The Latterbarrow Sandstone is overlain by the Borrowdale Volcanic Group rocks consisting of green volcanic sediments followed by lavas, probably andesites. Finally, the St. Bees Sandstone crops on Cold Fell. All the rocks younger than the Skiddaw Group show dips to the south-west of about 50°.

The first exposures examined were in the small valley near Cold Fell Gate on the track to Matty Benn's Bridge (NY 062 102). Here, the andesites of the Borrowdale Volcanic Group are strongly jointed, green and purple in colour and show large vesicles as well as quartz and agate amygdales. The slickensided and mineralised surfaces may indicate a minor fault zone.

The party then walked down the track to Matty Benn's Bridge (NY 064 103). On both sides of the river there are exposures of green and grey tuffs showing weak cleavage. Clasts up to 1cm in diameter are sub-angular and weather more slowly than the matrix. Small exposures in Caplecrag Beck (NY 066 102) indicate that the tuffs continue away from the river and may show slickensiding.

Finally, the party climbed the boggy slopes east of the River Calder to Caple Crag (NY 072 102). This feature is described by Pearson (1965) and by Shackleton (1975). The crag is a roche moutonnée surrounded by boggy ground with no other exposures; it is composed of a coarse conglomerate containing fragments of Latterbarrow Sandstone, andesite and what may be a rhyolite, all supported by a finer matrix. The fragments are sub-angular, up to 30cm across and appear to lie parallel to very crude bedding. The conglomerate is overlain by a well-bedded, finer sediment. The party tentatively concluded that the conglomerate represents a high energy, water-lain deposit but the absence of other exposures makes further interpretation difficult.

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WESTPHALIAN SEDIMENTOLOGY OF THE WHITEHAVEN AND LOWCA AREA

Leaders: Dr. Neil S. Jones and Dr. Paul D. Guion

13 June 1992

The party assembled at Whitehaven South Beach car park (NX 967 183). The leaders explained that the objective of the excursion was to examine evidence for a number of distinct environments including river channels, channel margins, crevasse splays, lacustrine deltas and low energy suspension deposits. Sedimentation was dominantly sub-aqueous with little evidence of marine influence, although thin marine bands do occur in the Westphalian. Following lake filling and channel abandonment, peat- forming mires developed - now represented by coal seams.

The first rocks examined were part of the cliff section south of the car park. Here sediments of Westphalian C age lying in the Brassy Seam to Unnamed E Seam interval are exposed. The lowest lithology exposed is a dark grey mudstone palaeosol with abundant rootlets. Ankerite and siderite nodules are common. This passes up into black mudstone with coaly laminations and then a bright, banded, pyrite-rich coal seam, probably the Brassy Seam. Some of the pyrite is probably primary in origin but much occupies the cleats and is a secondary deposit. The leaders explained the palaeoenvironment as a mire, occasionally raised and filled with rainwater and occasionally depressed and filled by ground water, thus allowing different plant species to flourish.

Overlying the coal seam is a fine-grained sandstone which in places erodes down into the seam and washes it out. The sandstone was followed to the south and it was noted that the bed thickened and that cross bedding foresets are consistently inclined to the south. The leaders interpreted this sandbody as a minor channel which flowed south in a straight, possibly braided form. Intermittent flows are suggested by the presence of rootlets and internal erosion surfaces. Inclined bedding surfaces may represent a mid-channel bar-form. The sandstone passes upwards into a dark grey, micaceous siltstone, possibly a lacustrine suspension deposit.

A second, younger sandstone is exposed higher in the cliff. This appears to differ in that there is no erosional base and the sand body thins to the south. It was not possible to examine this sandstone on the excursion but Mr. Jones explained that palaeocurrent readings from cross bedding indicate unidirectional flows towards the SSE. This features and the sheet-like form of the sand body indicate a crevasse splay event.

The party then moved to Bransty cliff to examine sediments lying above Unnamed H seam. The first section in what was formerly referred to as the Whitehaven Sandstone Series was in the disused quarry section next to William Pit shafts (NX 9750 1880). These sandstones were once considered to have an unconformable relationship to underlying strata on the basis of their different colour and lithology but they are now recognised as representing the deep oxidation of the upper 50-100m of Westphalian strata, producing reddening to an irregular depth. The cliffs at this location show the cross bedded sandstones of a large channel system with migrating dunes and ripples. Palaeocurrents were towards the south-east.

This sandbody was viewed 100m further north in a disused quarry at NX 9748 1904. A hierarchy of bounding surfaces divides the sandstone into different architectural elements with three major units present. Each unit has an erosional base with a lag conglomerate, representing the fill of an individual palaeochannel. Within each unit cross bedding was formed by the downstream migration of subaqueous dunes. The sandstone forms almost continuous exposures extending northwards for 0.5 km and the sandstone units are seen to be stacked both vertically and laterally. Mr Jones presented a model for these elements representing the deposits of variably-sized braided rivers. Channels were up to 10m in depth and composed of migrating bars and sandy bedforms.

The coastal track was followed northwards to a point about 0.5km NE of Redness Point, near the ruins of an old brickworks (NX 9770 1990). The cliffs at this point are composed of the Countess Sandstone which lies 90m above the Bannock Seam (Eastwood et al., 1931). A unexposed fault throws these rocks against the younger sediments seen at the previous location. At the base of the cliff dark grey micaceous siltstones are seen beneath the sandstone. The siltstone contains abundant

well-preserved plant material including *Calamites, Neuropteris, Annularia* and *Asterophyllites*, some of which are in their original life position. The leaders interpreted this facies as a plant-rich levee or channel margin which was inundated by sediment- laden overbank flows.

The yellow-brown Countess Sandstone was examined just to the north of the siltstone exposure. The base is erosional with pronounced relief and flute casts and a lag conglomerate of siderite and coaly clasts. Within the basal conglomerate is a slumped block about 2m across. The bedding within the block is almost vertical and folded into a series of folds with a of wavelength of about 2cm. This probably represents a channel bank collapse with the small-scale folding caused by the compaction of the overlying sediment.

The party travelled by cars to a point on the coast north of Parton (NX 979 213), then walked along the foreshore to examine rocks exposed at low tide between Providence Bay and Cunning Point. A thick sequence of sandstones within the interval between the Harrington Seam and the Middle Albrighton Seam was examined.

A thick sandstone is exposed on the wave cut platform at Four Foot Rock (NX 9780 2290). The erosional base has pronounced relief and is overlain by a lag deposit of coarse to granular sub-angular grains of quartz and coaly clasts. Recent marine erosion has exposed a series of preserved bedforms up to 12m wide and 0.7m high. The upper part of the sandstone shows cross bedding and ripple cross lamination. The sandstone is interpreted as the product of a minor channel which flowed to the south-west.

The final localities visited were at Top Four Foot Rock, Cunning Point, (NX 2980 5232) where the leaders demonstrated a lacustrine delta mouth bar sequence. The prodelta sequence is of laminated siltstones with rare horizontal and vertical burrows. This coarsens upwards into sandy siltstones and fine-grained sandstones while ripple lamination gives way to cross bedding. Above the large scale cross bedding are upper phase planar beds showing primary current lineation, perhaps suggesting shallower water depths on the bartop area. This indicates the progradation of the delta and the increasingly proximal nature of the delta mouth.

Primary current lineation and ripple cross lamination palaeocurrent readings suggest a palaeoflow to the north. Small vertical burrows are seen within the sand body.

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UPPER TEESDALE

Leader: Eric Skipsey

20 June 1992

A party of seventeen members and friends met at the Bowlees Picnic Park (NY 908 284) Newbiggin, near Middleton-in-Teesdale where the leader outlined the geology of the district. The base of the Carboniferous in Teesdale lies at the horizon of the D1 age Melmerby Scar Limestone while the overlying Yoredale Series forms the northern valley sides. A well- known feature of the area is the Whin Sill, reaching its maximum thickness of about 70m in Teesdale. The Teesdale fault, downthrowing to the north, runs obliquely up the valley and results in the Whin Sill cliffs forming the southern valley sides.

The Bowlees Park provides examples of typical Yoredale cyclothems, showing limestone-shale-sandstone-limestone sequences which the party traced along Bowlees Beck. The base of the section, near the road bridge, was formed by the 1m thick Cockleshell Limestone. No further outcrops were visible in the beck until the footbridge was reached, suggesting that friable shales above the limestone were concealed by river debris. The footbridge was founded on silty shales, which showed strong ripple markings on the bedding planes. A well-bedded grey sandstone occurred above the silty shale and was followed in turn by the Scar Limestone, 6m thick, which had been extensively worked in the old quarry. Above the quarry a fault, visible in the beck, formed a waterfall. Here the Scar Limestone was overlain by black shales and then a thick, strongly cross-bedded sandstone which some distance upstream formed another and larger waterfall, Summerhill Force.

A walk across the field to the River Tees, which was crossed by the perilous Wynch suspension bridge, enabled the party to see the top of the Whin Sill at Low Force (NY 903 279). An interesting feature near here was the 'raft' of baked siltstone caught up within the sill.

After lunch the party drove to the High Force hotel (NY 884 286) where the famous High Force waterfall was visited. The River Tees plunges over a lip of the Whin Sill which shows strong columnar jointing, interrupted by two thin transverse layers of baked shale. Below the sill at this point are shales and siltstone beds with the Tynebottom Limestone at the base. The intrusion of the Whin Sill has been dated at 295 million years. The sill was examined in detail at the nearby Hargreaves quarry (NY 878 290), visited with prior permission. Considerable variations in grain sizes were seen with massive patches of large needles of pyroxene and laths of feldspar which form a coarse pegmatite facies within the sill.

The party then travelled through Langdon Beck to the car park at the Cow Green reservoir (NY 813 309), located within the Upper Teesdale National Nature Reserve. The reservoir extends for over two miles, partly in Durham and partly in Cumbria, to the adjacent Moor House National Nature Reserve. The western skyline and watershed is formed by the peaks of the northern Pennines, reaching its highest point in the long-topped Cross Fell (893 m).

The track led to the reservoir dam and the head of Cauldron Snout waterfall, walking down dip across strata with a gentle easterly dip. Broad exposed areas of bedding planes in the Smiddy Limestone were first seen, followed by the underlying Robinson Limestone; beyond the gate was the Melmerby Scar Limestone. The Whin Sill itself crops in places and lies near the surface over much of this area; the heat from it having caused the metamorphosis of the Melmerby Scar Limestone to a coarsely crystalline marble, known as "sugar" limestone. Many of the rarer Alpine plants for which the Nature Reserve is famous grow on the soil weathered from it.

A small spoil heap at one point is all that remains of the waste material extracted in the 1950's from workings along Rod's Vein, which has yielded over many years both galena (PbS) and barite ($BaSO_4$). Eventually the track reaches the dam which is crossed by a public roadway. The dam, completed in 1970, is 600ft long and its height above the River Tees is 82 ft. It is a composite dam with over half constructed of concrete and founded on the Whin Sill while the remainder is an earth dam of boulder clay, gravel and rock obtained from within the reservoir

area. The earth section is mostly on boulder clay which fills an old pre-glacial channel of the River Tees. Most of the party then returned to the car park but some members went to see the nearby Caldron Snout waterfall.

CONTROVERSIAL IRISH SEA GLACIAL MODELS: SOME ANSWERS FROM THE CUMBRIAN LOWLANDS

Leader: Dr. David Huddart

28 June 1992

The group met at Greggains' Pit, Aikshaw, where the leader explained that the purpose of the field-trip was to examine evidence for a glaciomarine model for the Late Devensian geological history of the Irish Sea basin, presented by Eyles and McCabe (1989). This model is in apparent conflict with the traditional ground-based ice model with a late stage Scottish Readvance, first suggested by Trotter (1922).

Greggains' Pit is part of the Holme St. Cuthbert Complex, one of seven locations on the Cumbrian coastal lowlands which Eyles and McCabe interpret as being the sites of morainal banks, marking tidewater sediment accumulations at the retreating margins of glaciers. Each complex may represent a temporary halt of the margin because they are typically associated with bedrock highs and shallow water. Eyles and McCabe relate the banks to the presence of drumlins to the east, i.e. upstream of the banks.

Dr. Huddart presented evidence to show that the sedimentary environment was not a morainal bank but a pro-glacial lake. The ice was not present to the east (inland) but to the north-west and the sediments were deposited after the drumlin stage. Evidence includes the topography, lithologies and palaeocurrent indicators. He pointed out the steep north-west slope of the complex, interpreted as the ice contact face, with depressions at the foot of the slope being kettle holes. The summit of the ridge is a relatively flat plain inclined gently to the east which he interpreted as a delta plain with the slope to the south-east being a delta foreset face.

Several clay bands were observed, each being separated by 2 - 3m of sands. The clays indicate winter deposition from suspension, the sands being summer deposits when the discharge of meltwater was greater. Several examples of Criffel granite and Lower Calciferous Sandstone

conglomerate were found, indicating a transport direction from the north-west. A wide variety of palaeocurrent indicators were observed including imbrication in gravel bars, ripple drift and cross bedding. Previous measurements of these structures also indicate transport from the north-west.

The party then moved on to New Cowper Pit at the southern end of the complex. Similar deposits were examined including fine examples of delta foreset beds with gravity sliding on the face resulting in pebbly sands. The upper part of the sequence was well exposed in this pit with sandy, cross bedded, fluvial, topset beds.

Dr. Huddart's interpreted the Holme St. Cuthbert site as an esker-fed, ice-contact "Gilbert type" delta from Scottish ice to the north-west into a glacilacustrine environment. This ponded up water to the east in the Holme Dub valley. East of this depositional zone the laminated clays must have been deposited in the basin now occupied by Cockley, Aikshaw and Common Mosses.

Later the party stopped beside the A596 north-west of High Harrington (NY 013 261) to view at a distance the site of the old Walker's Brow Pit. Sites such as this were interpreted by Eyles and McCabe (1989) as raised marine deltas at 30m O.D. Other high level marine deltas were said to occur up to 152m O.D.. Dr. Huddart has interpreted this site not as a delta but as a ice readvance proglacial sandur sequence with a sediment source and palaeocurrents from the west and north-west (not the opposite direction).

The party then drove to St. Bees to examine the coastal section between the Seacote Hotel and Seamill. Here a deposit almost completely blocks the southern end of the St. Bees valley. Eyles and McCabe (1989) interpret such deposits as a record of downslope sediment gravity flow and subaqueous outwash directed along the bedrock channel from an inland ice margin. However the deposit has previously been interpreted as a proglacial sandur and terminal moraine sequence by Huddart (1970), Huddart and Tooley (1972) and Huddart (1991).

At the base of the sequence a till was examined. This was overlain by very coarse, partly bedded gravels and sands. The sequence is obviously deformed and was interpreted as being caused by a readvance ice push, with the whole complex a terminal moraine from ice to the west in the Irish Sea basin and not from ice in the St. Bees valley, as suggested by Eyles and McCabe.

Towards the southern end of the cliff, a small exposure representing a section through a kettle hole was examined. Pollen analysis, Carbon 14 and beetle carapaces have allowed the deposit to be dated. At the bottom of the section a sand represented a periglacial slope deposit. Above this is a late glacial peat, dating from the Allerod Interstadial followed by a pale clay and then a peat of post glacial age. This is succeeded by blown sand and finally soil. The leader was then warmly thanked by Tom Shipp for a particularly interesting excursion.

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KINNISIDE LEAD MINE, near Cleator Moor

Leader : Mervyn Dodd

7 July 1992

The party met at a small parking area near the River Ehen north-east of Hazelholme (NY 038 149). We then walked past Hazelholme and southeast along a narrow lane up a fairly steep slope to High Merebeck (NY 038 145) where we turned north along a farm track, possibly the original mine road. This track led to the open, but dangerous, Horse level with its small tips, consisting of soft, very fissile, fine grained Skiddaw Group rocks and very hard cream to brown vein material with much quartz. A little galena was found but no barite nor cerussite, as found on previous visits with other groups. The gently sloping ground below the level has been identified by Huddart as fluviglacial material, across which are minor collapses above the Adit level that drained the mine to the River Ehen.

Kinniside Mine was small, working fitfully from about 1791 to 1855, when its small ore bodies became too expensive to work. The vein, and a parallel, much poorer one, trend SSE-NNW in Skiddaw Group rocks close to the western edge of the contact aureole of a deep granite. The ore had a rather low silver content and assays proved minute quantities of gold. Initially the ore was smelted on site but in later years crushed ore of indifferent quality was shipped from Whitehaven to ports on the Dee Estuary below Chester for smelting.

Passing a small tip on the poorer, more easterly vein, the party walked up the western slopes of Kinniside Cop (NY 042 146), noting a fenced air shaft. Near the top there was a small exposure of very thinly-bedded Skiddaw Group rocks with cross-bedding and a near vertical dip. The gentle descent to the Engine Shaft was past the fenced entrances to very old workings and across an unfenced road to Meadley Reservoir. This shaft, sunk before 1827, is fenced but partly open so its red sandstone collar is visible. The location alongside the shaft of the Horse Gin and remains of buildings were suggested and the small spoil heap had some good galena samples.

On the roadside below the Engine Shaft the Skiddaw Group rocks were seen to be appreciably harder, more thickly-bedded and coarser than at previous sites, suggesting they were just inside the contact aureole. The original smelter was somewhere in the present Lizza Brow complex of buildings (NY 046 143) and the position of the original water wheel and a small reservoir just above Mere Beck were noticed.

Lizza Brow has a 10-15m cliff of bedded sands and gravels above it to the north, part of the fluviglacial material in the spillway between the Lake District Ice and Irish Sea Ice when the ice was wasting away in situ. The party returned down the narrow incised valley of the Mere Beck.

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THE PERMO-TRIASSIC ROCKS OF THE EDEN VALLEY

Leader : Dr Louis Macchi

25 April 1993 - Joint meeting with the Westmorland Geological Society

Some two dozen members from both societies met at Belah Bridge (NY 793 120) near Brough, Dr Macchi explained that during the Lower Permian the area of the present Eden Valley was a narrow, elongate half-graben valley, similar to Death Valley in the U.S.A. today.

Near Belah Bridge, a cliff above the River Belah exposes an outcrop some 2m high of friable red, cross-bedded sandstones. Strata inclined westwards overlies a series of flat bedded sandstones. The cross-bedded strata are asymptotic with well developed toesets and distinctive laminae of different grain size in the foresets.

Interbedded with the sandstones are brockrams, consisting mainly of clasts of dolomitised limestone set in a friable red sandstone matrix. Many of the clasts are hollow, resulting from diagenetic processes. These deposits originated in occasional flash floods working through wadi systems. Coarser material brought down by the floodwaters from higher ground augmented the aeolian sands available in the wadis and settled to form the brockrams. Discontinuous lenses in the brockrams implied that the water was temporarily ponded in pre-existing hollows during the floods and the imbrication of larger pebbles indicated a westerly depositional flow.

At George Gill (NY 718 189), near Appleby, a brief halt was made to view from a distance some small exposures of brockrams on the south side of the valley, from one of which Sir Kingsley Dunham in 1932 retrieved a dolerite pebble, which helped to date the intrusion of the Whin Sill.

On the north side of the valley a crag exposes a series of cross-bedded sets with marked asymptotic bases and a concave upward geometry. This evidence together with grain texture shows that the sandstone originated as a train of migrating aeolian dunes, of which only

the eroded remains are preserved. The dominant palaeowind direction in these and other Eden Valley sandstones was easterly.

The sandstone was very friable and coarse-grained. Very coarse grains seen at the base of some sets were identified as grain fall laminae, produced during the "creep" of fluvial inter-dune sediment when the rotational energy of the saltating particles was sufficient to transport larger grains with which they impacted. Networks of fractures in the sandstone are marked by white veins, resulting from the crushing of grains by small scale movements, and are typical of, and confined to, high porosity sandstones.

The party travelled to the north of Penrith to an area where the brockrams are absent. Here the aeolian sandstone is very well cemented with quartz. Evidence from fluid inclusion studies shows that the secondary quartz was deposited at high temperature, probably associated with the Pennine Fault. Slump structures caused by grain flow can often be seen on the sawn faces of quarried blocks.

Recent quarrying at Stoneraise Quarry (NY 533 352) has unfortunately obliterated the greater part of the exposure, which previously has revealed the bedding structures of a dune in three dimensions, with the main face perpendicular to the palaeowind direction. However, the "horns" at each end of the crescentic dune were still exposed, allowing the group to appreciate the overall geometry.

The Bowscar Quarries were then visited. At the first of these (NY 520 344) the exposure of the dune slip face is again perpendicular to the palaeowind direction. Both limbs of the face are cut off by erosion surfaces but plan views of these and their intersections can be seen from above and behind the quarry face. Two large scale cross-bedding sets trending ESE-WNW are still exposed in the second quarry (NY 520 343). The upper set reveals a palaeowind-parallel section; the lower appears as a series of scoops, providing evidence of interruptions in the progression of the dunes. Assuming that these interruptions occurred annually when there were major changes in wind speed, Dr. Macchi has estimated that with the increased wind velocities believed to have occurred during the Permian glaciation, the rates of dune migration would bear comparison

with measurements made in modern dune systems - an intriguing note to end this wet but worth-while excursion.

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MINERALISATION IN THE CALDBECK FELLS - A NEW PERSPECTIVE

Leader : Brian Young

8 May 1993

A large group assembled at Nether Row where the leader described possible mechanisms involved in the mineralisation of the Caldbeck Fells. This area lies adjacent to and to the south of the Solway Basin. The Maryport - Gilcrux fault (which extends eastwards as the Stublick Fault) at the basin margin was active during the Lower Carboniferous and the Permo-Triassic, allowing the basin to subside and great thicknesses of sediment to accumulate. It is possible that these sediments are the source of some of the elements in the Caldbeck Fells. The Eycott Volcanic group may also have provided some of the elements. Northerly dipping faults adjacent to the basin could provide the conduits for the mineralising solutions. This structural model may be analogous to the basin margin situation of many of the large deposits in Central Ireland.

The party followed the track up the fellside south of Nether Row and paused close to a prominent bend in the path (NY 323 370) at the site of a trial adit and dump, the lower of two on Nether Row Brow described by Kingsbury in the 1950's. Copper, lead, arsenic, vanadium and antimony minerals such as beudantite, scorodite, tetrahedrite, bournonite and jamesonite have been recorded from this site. Elsewhere in the Lake District similar mineral assemblages are regarded as being of Early Devonian age. Thick drift cover is a problem in mapping this area but a B.G.S. excavation was able to show that the vein at this locality has a north-east trend.

Further up the track the tailing heaps of the Lower Potts Gill barytes mine were examined (NY 319 365). Here the leader explained that there are two sets of veins in the area. East - west baryte veins, similar to the veins in the Lower Carboniferous rocks further north, containing few sulphides and north-east - south-west veins have a much more complex assemblage of primary sulphides and secondary minerals. These may be older than the east - west veins but the intersections of the two sets of

veins are not sufficiently well exposed to show the relationships clearly. The Caldbeck Fells, underlain by Eycott Volcanics, provide an excellent view of the area to the north. At the foot of the fells a depression is underlain by the basal Carboniferous conglomerate; the ground then rises to the limestone hills north of Caldbeck then falls away to the Solway Plain underlain by the Upper Carboniferous and Permo-Triassic rocks. Across the Solway Firth, line of the Iapetus Suture, Lower Palaeozoic rocks form the hillsides of Dumfriesshire.

Some 500m further up the slope the to the south-east at NY 322 360, the outcrop of one of the Potts Gill veins is exposed in an open cast cut. The veins were also worked by levels driven into the fellside lower down the slope. Adjacent to the vein the Eycott Volcanic Group wall rock is decomposed to a clay like material. Elsewhere in the area, away from known veins, there are broader belts of similarly altered rock, possibly resulting hydrothermal alteration associated with the mineralising brines. The main minerals at this locality are quartz and baryte with some manganese oxides. The baryte often occurs as pockets in the quartz and the quartz is frequently platy, either as pseudomorphs or epimorphs after baryte. Similar quartz pseudomorphs or epimorphs after baryte are common in the lead-baryte veins in the Lake District.

From the open cast at NY 322 360, the trend of the Potts Gill veins is clearly visible as two lines of open cuts and collapsed stopes stretching across the fellside from east to west. The party followed the line of the veins for about 1km to Deer Hills (NY 314 362), where a roughly N-S trending arsenic-rich vein intersects the barytes veins. After lunch the spoil heaps were examined. Here, various supergene minerals were tentatively identified including carminite, beudantite, scorodite, pharmacosiderite and the copper sulphide covelline.

1.5km to the east at NY 331 360, the spoil heaps of the upper workings of the Sand Beds Mine were examined. This mine worked the NE - SW trending Roughten Gill vein which is unusual in this area in that it follows a fault with a large throw. A variety of mineral assemblages are present in the vein, including chalcopyrite, galena, iron oxides and baryte. This may indicate polyphase filling of the vein. Minerals tentatively identified on the field trip included malachite, linarite, duftonite/bayldonite,

sphalerite and chrysocolla. A search for barium pharmacosiderite at a small branch vein further up the fellside proved unproductive because the stope had collapsed removing the previous spoil heap and adjacent outcrop.

The final stop on the excursion was at the outcrop workings on the Roughten Gill Vein on the hilltop between the Sand Beds and Driggeth mines at approximately NY 327 356. These were very early lead workings before the later barytes mining. Good specimens of greenish pyromorphite/mimetite with curved faces were found.

The leader was gratefully thanked for providing an excellent visit to an area where specimen collection is rapidly diminishing the quantity of minerals to be observed, and for explaining a new perspective on the mineralisation.

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THE SEVENTH LIMESTONE AT FRIZINGTON PARKS QUARRY

Leader: Andrew Thurlow

12 May 1993

A party of twelve members met beside the A5085 at Parkside Hotel between Wath Brow and Frizington and walked to Frizington Parks Quarry (NY 040 155) which lies in the private land of Scalelands Farm.

Approximately thirty metres of the Seventh Limestone is exposed in the quarry and this was examined, working up the succession from the lowest beds at the south-eastern end of the quarry through a diverse succession of limestones, sandstones and shales. The Seventh Limestone is generally regarded as being of Holkerian age, although in places the lowermost beds are Arundian (Mitchell, 1978). Although the base of the Carboniferous is not seen at this location, Eastwood *et al* (1931) conclude that only a very small thickness of the Seventh Limestone is present beneath the quarry. Thus the occurrence of the cerioid colonial rugose coral *Lithostrotion* only a metre above the base of the succession, which indicates an age no older than Holkerian would tend to suggest that Arundian deposits are either extremely thin or absent at this locality.

The lowest beds in the quarry are coarse, often sandy and mostly cross bedded limestones with highly fragmented crinoids and brachiopods. Cross beds pitch to the north-east. Thin beds of pure sandstone are common and one example was seen of a bed draping a smooth, hummocky surface developed on the underlying limestone. All of the above features are consistent with a storm dominated environment of deposition. These beds correspond to the "diagonally bedded sands" of the lower part of the Seventh Limestone, and the presence of *Lithostrotion,* as mentioned above, dates this clastic episode as Holkerian (*cf.* Mitchell, 1978).

Above these coarse beds are a series of finer grained, purer limestones containing Productid brachiopods, often in growth position, *Bellerophon* gastropods and the corals *Syringopora* and *Chaetetes*. The

presence of these tabulate species along with the scarcity of rugose forms is often considered to indicate a stressful environment. Within these beds is a thin calcite mudstone band, deposited in a peritidal environment which shows calcite filled voids, or fenestrae, related to rootlet structures (vertical fenestrae) and gases given off by algae (horizontal fenestrae).

Poorly developed coarsening upwards cycles of limestone dominate above this, with the tops of some limestone beds showing horizontal burrow structures filled with red sand, and occasional clusters of nested Productid brachiopods. Colonies of *Lithostrotion* can be seen to increase in size upwards through this series of beds, reaching a maximum diameter of 560mm (22 inches). *Syringopora* accompanies *Lithostrotion* in these beds and in one case the two can be found sited next to each other, almost intergrown, although no evidence exists that the colonies actually co-existed.

Stylolites are common in this part of the sequence and indicate the dissolution of carbonate material due to the weight of the rock column above. Towards the top of the series an extremely flat bedform occurs, in contrast to the irregular pressure solution surfaces found throughout the rest of the succession and formed in the same way as stylolites. This flat bedform is overlain by a very thin red clay resembling the karst related bentonite rich clays common in the later Dinantian of northern England, although the underlying limestone shows no sign of karstic solution. Water seeps out of the limestone as a result of this impermeable clay and has stained the underlying limestone surfaces a red colour, and it is this staining which makes the bed so easy to correlate across to the other side of the quarry.

Finer grained limestones conclude the carbonate succession in this quarry and show a fauna of *Syringopora* and *Siphonodendron* corals along with excellent examples of nested Productid brachiopods, apparently showing alignment with the northerly directed palaeocurrents. Cross bedded sandstones appear above this with cross beds pitching to the west. The variation in current directions is attributed to storms of varying wind direction rather than giving any indication of local palaeogeography. Trace fossils of both movement and resting type occur

at several horizons within these sandy measures, with the best examples being found in the scree material at the foot of the west face of the quarry.

The party walked back to the main road along the old railway line which is now a cycle path, observing subsidence associated with the haematite workings of the Parkside mine complex.

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BORROWDALE VOLCANIC GROUP ROCKS IN THE LINGMOOR AREA OF LANGDALE

Leader : Dr. Frank Moseley

June 5 1993

Dr Moseley welcomed the large party at the New Dungeon Ghyll Hotel and explained the stratigraphy of the lower part of the Upper Borrowdale Volcanic Group in the surrounding area. The valley floor and the lower slopes of Lingmoor are underlain by the acid volcanics of the Airy's Bridge Formation, including ignimbrites. Above this are the fine grained, andesitic, bedded Tilberthwaite tuffs in which the easterly dip can be seen from the valley floor. Side Pike is separated from Lingmoor by a fault forming the steep side of the Pike. The top of Lingmoor, including Oakhowe Needle, is formed from an andesite sheet which could be lava flows or a sill, the upper contact is not seen so its origin is uncertain. The Tilberthwaite Tuffs are much thinner here than at Tilberthwaite which may indicate that the andesite is a sill and does not lie at the top of the tuffs.

The party walked along the path from Side House below Oakhowe Crag and examined various transported boulders from the volcanic rocks in the area. At the northern end of Oakhowe Crag, the party left the main path and followed a small beck up the fellside (NY 306 060). First, the acid volcanics of the Airy's Bridge Formation were examined, including a eutaxitic ignimbrite. After about 150m, the well-bedded Tilberthwaite Tuffs were seen. The finer bands weather more rapidly displaying the bedding and various waterlain and slump structures. There is no strong cleavage visible at this location. The horizon is probably close to that of the Neolithic axe factory on Pike o'Stickle.

From this locality, the group proceeded to the currently disused Spout Crag Quarry (NY 306 051) and examined the Tilberthwaite Tuffs, here showing parallel bedding and a fairly weak cleavage. Quartz/calcite fault breccias were much in evidence.

From the south-east corner of the quarry, by the entrance, an amygdaloidal andesite sheet within the tuffs forms a prominent escarpment climbing across the fellside above Colt Howe Quarry (NY 308 047). This has been interpreted as a peperitic sill. The upper contact was not examined on the excursion, however the junction is irregular with cracks in the brecciated andesite being filled by tuff and it appears to be intrusive. The party followed the escarpment through the wood, then proceeding to the summit of Lingmoor (NY 302 046). After examining the andesites which form the summit and neighbouring Oakhowe Crag, Dr. Moseley described the geology of the fells seen in the panoramic view from the summit.

The bedded Seathwaite Fells Tuff was clearly seen to the north-west on Pike o'Stickle, Pavey Ark and as far east as Whitegill Crag. Various Neolithic axe factory sites have been identified from a hard, fine-grained horizon close to the base of the tuffs. The Seathwaite Fells Tuffs are likely to correlate with the Tilberthwaite Tuffs to the south. The lowest part of the fells on the north side of the valley are in the Airy's Bridge Formation. The leader explained the use of a stereoscope, both on aerial and ground photos , to pick out the topographic features formed by ignimbrites, for example on Gimmer Crag, Thorn Crag and Raven's Crag.

The upper part of Pavey Ark is formed from a very coarse breccia, probably reflecting proximity to a vent. The bedded Seathwaite Fells Tuffs can be clearly seen to the west on the slopes of Bowfell. There are also extensive exposures of tuff on Pike o'Blisco which are likely to be associated with the caldera described by Branney. Again the more blocky looking Airy's Bridge Formation crops out lower in the landscape on The Band.

More complex features are seen on Crinkle Crags, parts of Pike o'Blisco and Bleaberry Knott. These areas have been interpreted by Branney as a caldera collapse with complex faulting. The Blea Tarn - Rossett Gill fault has a marked topographic expression seen from Lingmoor. To the south across Little Langdale, the Wrynose Anticline has resulted in steep, south-east dips in the Tilberthwaite Tuffs of Hodge Close, seen in the distance.

The party descended via Lingmoor Tarn and Side House to the New Dungeon Ghyll Hotel and the leader was thanked for providing a most interesting excursion.

GEOLOGICAL FEATURES INVOLVED IN THE PLANNING AND CONSTRUCTION OF THE A66 TRUNK ROAD BETWEEN COCKERMOUTH AND KESWICK

Leader : Dr. Jim Cockersole

16 June 1993

The object of this evening excursion was to consider some of the geological features that had influenced the construction of the section of the A66 Trunk road between Cockermouth and Keswick.

At the meeting point (A66 - A5086 junction, (NY 114 295)), the leader sketched the geological background to the construction of the road from Penrith to West Cumberland undertaken between 1974 and 1977. The road traverses every major rock type exposed across the northern Lake District, but in this particular section Skiddaw Group rocks provide the rockhead, although much of the road is actually constructed in glacial and post-glacial deposits.

Before travelling east the party first examined the Harrot Hill cutting, 200m to the west of the meeting point, where fragmented Skiddaw Group strata dip steeply at about 60°. The leader explained how a slight northward realignment of the initial planned line reduced the volume of rock cut. The nature and dip of the rock influenced the design of the road (Figure 1). The instability of the rock necessitated a 45° batter on the southern side of the cutting where a fibre-glass mat was used to encourage soil retention and vegetation growth. To the east of this exposure the cutting extends into boulder clay.

At the crossing of the River Cocker, (NY 119 293), the rockhead has been proved at a depth of 15 metres by drilling . The difference of nearly 100 metres between this level and the height of the previous exposure a short distance away gives an indication of the pre-glacial land surface. Travelling eastwards the road passes through boulder clay cuttings and over embankments before joining the line of the old Workington - Penrith railway. Fluvio-glacial sand and gravel deposits are traversed around Embleton and these give way to lake bottom silts and peat before

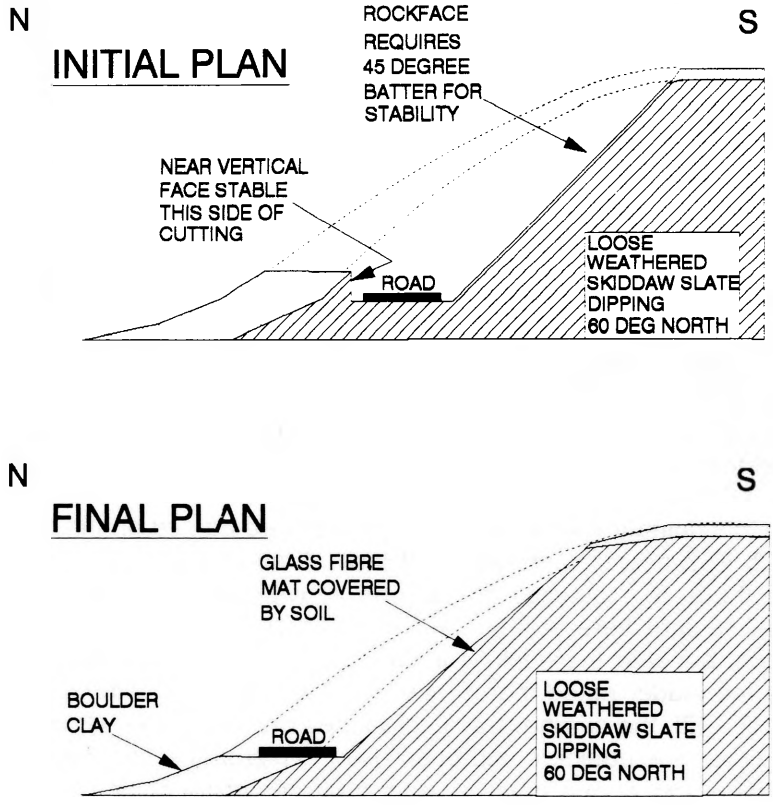


FIGURE 1. SECTIONS OF THE A66 AT HARROT HILL
(NY 114 295)

reaching Bassenthwaite Lake. Road construction over the old railway embankments gave rise to problems of differential settlement and very large amounts of peat had to be excavated to ensure a firm road foundation.

A halt was made in the lay-by on the dual carriageway section at NY 208 303. At this point the steep western valley-side consists of ancient consolidated scree with a cover of more superficial glacial deposits and problems have arisen because of movement on a slip plane. This has been countered by loading the toe of the slope and providing extra drainage.

The next stop was at Beck Wythop (NY 213 284) where potentially unstable vertical rock cuttings beside the old road had the effect of limiting the A66 to a single carriageway along the lake shore. The bedding and the cleavage in the distorted and fractured Skiddaw Group rocks were closely examined. The strike of the bedding was roughly at right angles to the line of the road and it was considered that the cleavage, more or less parallel to the line of the cutting, was responsible for the risk of rock-fall.

Continuing towards Keswick the cars were parked on the old road at NY 225 252 near Thornthwaite Church. A short walk leads to the A66 where there is a cutting through the alluvial fan of Chapel Beck. An unusual feature here is that the canalised beck crosses the road in an aqueduct beneath the deck of an accommodation overbridge. From this bridge the leader noted that a mile or so further north around Woodend, (NY 222 272), the carriageway encroaches on to soft lake clays and silts. Large limestone boulders had been used to pierce the silts down to a firm foundation and at one point a temporary embankment or "surcharge" of furnace slag was used to compress the soft sediments prior to road construction.

The leader was warmly thanked for an interesting and varied excursion concentrating on the practical application of geology.

Other Excursions

The following excursions were also held during 1992 and 1993.

17 May 1992: Coniston copper mines underground visit
Leaders: Alistair Cameron & Ian Mathieson

20 May 1992: Thornthwaite old mines
Leader: K.W. Bond

31 May 1992: Introduction to Carrock Fell geology for beginners
Leader: T. Shipp

13 Sept. 1992: Geology of the Kirkby in Furness area
Leader: D. Leviston (joint meeting with Furness Geological Group)

23 May 1993: Mapping exercise in Cross Fell inlier.
Leader: Dr. R. Wright

27 June 1993: Beginners introduction to St. John in the Vale.
Leader: D. Kelly

14 July 1993: Rocks & landforms on the shore of Derwent Water
Leader: Dr. R.A. Smith

12 Sept. 1993: Force Crag mine underground visit
Leader: D. Bridge (joint meeting with Cumbria Amenity Trust & Mining History Society).

LECTURES

NORTH SEA HYDROCARBON PLAYS

A lecture by Dr Stewart Brown of the Petroleum Science and Technology Institute, Edinburgh, on 18 March 1992 at the West Cumbria College, Whitehaven.

A hydrocarbon play is a set of geological factors which have combined together favourably in a sedimentary basin and resulted in the occurrence of entrapped oil or natural gas.

The North Sea petroleum province is characterised by the diversity of its hydrocarbon play types. The principal source rocks are the Carboniferous Coal Measures, yielding gas in the southern North Sea Basin, and Upper Jurassic marine shales, comparable to the Kimmeridge Clay of Dorset, sourcing oil and gas in the central and northern North Sea. The principal reservoir rocks in the southern gas province are sandstones of Permian and Triassic age, with more recent discoveries in the Carboniferous. In the central and northern North Sea reservoir rocks range in age from Devonian to Eocene, with the principal reservoir horizons occurring in the Jurassic and Palaeocene.

In the UK North Sea only siliciclastic reservoirs are of economic importance, with few exceptions. In the Norwegian and Danish sectors Upper Cretaceous - Lowermost Palaeocene chalk also contains oil reserves. The dominant structural elements in the North Sea are the broadly NNE-SSW trending Viking Graben and the NNW-SSE trending Central Graben which occur in the northern and central North Sea areas respectively.

The location of the different hydrocarbon plays, the play fairways, in these areas is determined by the distribution of the Upper Jurassic source rocks. Given typical North Sea geothermal gradients, the Upper Jurassic must be buried to depths of c.10,000ft before its insoluble organic material, kerogen, yields hydrocarbons capable of migrating in the sub-surface. In the central and northern North Sea the locus of Upper

Jurassic shale burial to 10,000ft. plus, the hydrocarbon-generating "kitchen", corresponds broadly to the location of the Viking Graben, Central Graben and related rift basins.

Reservoir rocks pre-dating graben initiation occur on the flanks of the grabens or on intra-basinal structural highs. These older rocks have later been brought into contact with Jurassic source rocks by faulting.

Structural or stratigraphic juxtaposition promotes migration of hydrocarbons into Jurassic or older rocks deposited within the evolving grabens. Finally a vertical migration component allows the charging of post-Jurassic reservoirs.

As well as a plentiful provision of source beds, reservoir-quality rocks, and trapping configurations, the North Sea has also experienced optimal timing of trap formation relative to migration of hydrocarbons. Hydrocarbon generation from the Upper Jurassic source rocks peaked in the late Cretaceous to early Tertiary, long after most traps involving Jurassic reservoirs were formed.

THE CHALLENGE OF THE LAKE DISTRICT'S BIG LANDFORMS

A lecture by Dr D. Clark on 23 September 1992
at Castlegate School, Cockermouth.

The speaker proposed that the Lake District can be seen as an assemblage of terrain units with distinct morphological characteristics and identifiable boundaries, the 'big landforms' of the title of the lecture. Prevailing accounts of pre-glacial Lake District landscape history are lacking in detail, very generalised and strongly influenced by Marr's classic analysis. His analysis assumed that the valley pattern is radial and takes little account of the structures in the Lower Palaeozoic rocks. The speaker suggested that neither assumption is securely founded and that groups of valleys are associated with particular major terrain units. Satellite images showed the Lake District to be divided by sets of

lineaments, some of which follow known fault-lines and major linear landforms.

Characteristic terrain unit landforms were illustrated from the Thirlmere -Buttermere area which abuts the higher Bowfell - Great Gable and Haystacks - High Stile ridges. The interfluves are divided by steep slopes into relatively level reaches at various heights, with unspectacular hills rising monadnock - like above some of the flatter reaches. Deep valleys separate major flat-topped interfluves. The implications of various interpretations of such a landscape were outlined.

The character of a terrain unit boundary was demonstrated by the Dunmail Raise - Thirlmere fault-guided trough. Contrasts of altitude and form across the trough and slope facets were pointed out. Unit sub-division was illustrated from the Loweswater area where more-or-less degraded linear scarps separate areas with different summit altitudes in an angular mosaic that repeats alignments at the adjacent faulted boundary between Carboniferous and Lower Palaeozoic rocks.

Dr Clark then outlined the problem posed by the Skiddaw massif - whether it is an erosional residual or a block tectonically determined and sustained. In particular, it was seen that the substantial E-W symmetry of landscape features would be less easily accommodated in a dominantly erosion-based explanation. The Howgill Fells were shown to repeat some of the features of the Skiddaw massif in a setting more complex, but more easily understood if differential tectonic movement (with accompanying erosion) preceded more general height increase relative to sea-level.

West from the Howgills and the fault-aligned Lune valley, three further landscape units of Silurian rocks were recognised, the fell country from Ambleside to Shap forming the northern part. That upland was separated from the more subdued relief of South Lakes by a sharp change in height with some features characteristic of fault or fault-line scarps. The lower country is crossed by rectilinear troughs and scarps, some of which join mapped fault lines. This area was reduced to low relief before the narrow crests of the higher ridges were truncated in facets now standing at about 300m O.D. Further south the base of the Carboniferous Limestone, outcropping in fault-bounded strips and nowhere attaining

300m falls towards the Morecambe Bay basin. Tectonic separations of the uplifted north, platform-like centre and downtilted south may have occurred during the development of the present landscape.

The major escarpment north from Black Combe by Coniston to the Brathay valley follows a much older line of uplift and is one of the more prominent landscape unit boundaries. The significance of variation in base height, from virtually sea level in the south to over 300m near Coniston, and the cross-cutting division of the escarpment into segments with different crest heights was discussed. The topographic alignments at the scarp were shown to continue across the Duddon valley towards Eskdale. The Coniston line and the Bow Fell - Great Gable ridge were shown to enclose a major terrain block lifted, tilted and broken into subordinate blocks, probably during development of the present landscape.

In overview the speaker suggested that characteristics and possible explanations of individual landscape units converged towards a general explanation. He considered it difficult to understand the landscape without invoking significant tectonic activity during the course of its development. The Lake District was represented as a set of terrain units differentially uplifted and tilted but probably not initially attaining their present altitudes. Erosion would proceed on those parts above sea level but later there was a more general increase in relative altitude and relief, perhaps not uniform over all parts. It seems that the Lake District batholith did not behave as a single rigid mass.

In reply to questions, the locally marked correspondences between zones of steep gradients in gravity anomaly changes and major boundaries of landscape units was noted. Crustal conditions associated with Atlantic widening, the north-south tract of early Tertiary igneous activity and mid-Tertiary tectonic activity along the west of Britain might have facilitated some of the processes that gave character to the big landforms of the Lake District.

LAKE DISTRICT VOLCANISM : CALDERA CYCLES AND CRUSTAL EXTENSION

A lecture by Dr. Dave Millward of B.G.S., Newcastle, on 14 October 1992 at West Cumbria College, Workington.

The geological history of the Lower Palaeozoic rocks of the Lake District is dominated by mudrock sequences of the Skiddaw Group, deposited between Tremadoc and Llanvirn times, the ?Llandeilo - Caradoc volcanics of the Borrowdale Volcanic Group and the mudrock sequence of the Windermere Group, between Caradoc and Pridoli times. The Skiddaw Group sequence of mudrocks and turbidite fan deposits forms the oldest rocks beneath the Upper Palaeozoic cover throughout Northern England.

A fundamental change in the style of deposition occurred with the onset of the ?Llandeilo - Caradoc vocanic episode. This marks the start of a major period of magmatism extending into the Lower Devonian. The Eycott Volcanic Group in the northern area has recently been shown to be a tholeiitic suite unconformably overlying the Skiddaw Group and possibly pene-contemporaneous with the Borrowdale Volcanic Group. These volcanic rocks represented a change from a deep water, marine environment to a sub-aerial one. The evidence of sub-aerial emplacement includes the absence of fossiliferous marine deposits and pillow lavas, the abundant occurrence of sub-aerial erosion features, mantled air-fall tuffs and surge deposits. (Descriptions of the products of effusive and explosive volcanism were given by M. G. Petterson in "Recent developments in the Borrowdale Volcanic Group", *in* Proc. Cumb. Geol. Soc.; 1990, Vol.5, Pt.2.). The Borrowdale Volcanic Group has a proven thickness of over 6 km but this is a minimum. At outcrop the Group can be sub-divided on inferred styles of the eruptive activity and composition of the products.

The Lower Borrowdale Volcanic Group consists principally of sheeted andesite complexes up to a total thickness of 2.7 km. The sheets can rarely be traced for more than 2 - 3 km and are separated by a few metres of volcaniclastic sandstones and breccias. In addition there are subordinate dacite and basaltic lava flows. The latter occur both in simple

and compound aa flows. Such compound flows consist of piles of slaggy, highly amygdaloidal flow breccias with discontinuous lenses of solid material - small preserved lava channels or tubes surrounded by the flow breccia. This effusive phase may have been erupted relatively quickly with small eruptions from multiple vents producing almost continuous lava piles.

The onset of the Upper Borrowdale Volcanic Group activity marked a dramatic change of style with a sequence dominated by catastrophic eruptions of dacite and rhyolite magma, producing vast volumes of pyroclastic flow deposits. Comparisons with typical ignimbrite terrains in the U.S.A. and South America with time spans between eruptions varying from 100,000 to 400,000 years suggests that hundred of thousands of years of repose time were required for the build-up of vast magma chambers which resulted in this cataclysmic style of eruption. Between each sequence of ignimbrites, thick sequences of volcaniclastic sandstones and breccias accumulated in shallow depressions and were intruded in some instances by basaltic andesite and andesite sills.

In contrast to the generally low dips and open folds along the northern margins, much steeper dips are found in the south with near vertical dips adjacent to the Windermere unconformity. However, the folds are difficult to define and it was Branney who suggested another explanation for the deformation. He found that folds described in the Crinkle Crags area were not true folds, but a series of listric fault-blocks with associated changes in bed thickness and contemporaneous deformation structures. He suggested that the faults were active during the eruption of the Airy's Bridge sequence, formed as a result of the evacuation of huge volumes of magma. Further evidence that the thick, widespread ignimbrite sheets were caldera-related include:

1) many of the sheets are 'high grade' ignimbrites and difficult to distinguish from rhyolite lavas; they are strongly welded and typical of the facies found within modern examples of large-scale calderas. In contrast, counterparts outside the calderas were much less welded.

2) at the base of lots of ignimbrites, particularly near faults, were chaotic breccias with blocks of welded tuff the size of houses.

3) also associated with contemporaneous faults were talus breccias which had slumped off the sides of fault scarps when caldera floor blocks were collapsing.

In this manner it has been possible to identify the location of caldera systems centred in the Central Fells and in the Ulpha syncline. The latter is supported by the occurrence of the only marine rocks, the Holehouse Gill Formation, in the narrow Ulpha basin.

Mapping by Petterson in the Wasdale and Gosforth district associated with the Nirex investigation has identified another ignimbrite sequence , the Craghouse Tuff which reaches thicknesses of over 1100m in the Sellafield boreholes. This unit contains thick, high grade ignimbrites and has been recognised as another and earlier complex caldera, largely under Permo-Triassic cover. In the Wasdale area the Craghouse Tuff is overlain by a sheeted andesite complex.

GYPSUM CAVES AND SUBSIDENCE IN THE VALE OF EDEN AND NORTH YORKSHIRE

A lecture by Dr A. H. Cooper of B.G.S., Newcastle, on 11 November 1992 at Lairthwaite School, Keswick.

Dr Cooper gave a well illustrated talk describing the development of cave systems in gypsum deposits. He first outlined the manner in which gypsum is deposited along the margins of highly saline evaporating basins in sabkha environments. Where the gypsum becomes deeply buried it is converted to anhydrite, the anhydrous form of calcium sulphate. Subsequent uplift may bring the deposit close to the surface where, in the right conditions of salinity and temperature, it may revert back to gypsum in fibrous and veined forms with a c.30% increase in volume.

He indicated that there are very thick evaporite deposits in the Permo-Triassic basins of the Irish Sea and the North Sea. The British commercial exploitation of gypsum is concentrated in the Permian and Triassic deposits of Yorkshire, the Nottinghamshire Triassic and the Permian of the Vale of Eden.

Gypsum is relatively soluble in circulating ground waters, resulting in systems of underground cavities near the crop. In the Vale of Eden, this feature was well displayed in cavities found in gypsum deposits extracted by surface mining at Houtsay Quarry, near Kirkby Thore. Here the gypsum is found within the Eden Shales, sandwiched between the Penrith Sandstone below and the overlying St Bees Sandstone. A complex cave system was exposed with a joint-controlled pattern of cavities up to 3 -4 m high and covered with scallop-shaped surfaces, indicating water flow in a phreatic (water-filled) system. In places the floor was covered by thick deposits of mud/peat left by the water, which could be misleading in boreholes cutting the systems.

Much more impressive series of caves occur in the Permian gypsum deposits of North Yorkshire. The geological sequence includes two major water carrying Permian limestones (Lower and Upper Magnesian Limestones) with two thick seams of gypsum, 40m and 10m respectively, with associated marl sequences. A large scale cave system has developed around the town of Ripon producing surface subsidence pits commonly in excess of 20m in diameter and up to 20m deep. Once initiated, subsidence tends to carry on as the surrounding gypsum is dissolved. Dr Cooper described and illustrated many examples of such pits and the subsidence damage that often resulted from them.

MINERAL HERITAGE OF THE NORTH

A public lecture by Brian Young of B.G.S., Newcastle,
on 25 November 1992 at Tullie House Museum, Carlisle.

This meeting in Carlisle was jointly organised by the Society and the Tullie House Museum, Carlisle, to support the exhibition "Crystals of the North" which was being presented by the Museum. The exhibition was a first venture into the Earth Sciences by the Museum and displayed many of Tullie House's spectacular specimens from West Cumbria, the Caldbeck fells and Alston Moor.

In his introduction, Mr Young emphasised that mineral collections like those on display were not just curiosities for museum show-cases but were true heritage items, comparable to important works of art. He reminded his audience that the North of England was one of the world's oldest mining centres and was famous throughout the world for exquisite mineral specimens and many rare and unusual varieties.

The Lake District area was so richly endowed with different mineral species that rather more than half of the total number of mineral species known in Britain occur within the area; no other region of the country had such a range. One unique feature was the occurrence of high purity graphite in the mines of Seathwaite, which had been known for many years and formed the basis of the Keswick pencil industry. Another important locality was the Carrock Fell mines which were the only place in Britain outside S.W. England where tungsten minerals had been extracted; they are famous for a wide variety of minerals such as Scheelite ($CaWO_4$); Apatite and Chalcedony amongst others. The Caldbeck Fells are notable for unusual minerals like Hemimorphite ($Zn_4SiO_2(OH)_2.H_20$), Pyromorphite ($Pb_5(PO_4)Cl_3$), Plumbogummite ($PbAl_3(PO_4)_2(OH)_5.H_2O$) & Carminite ($PbFe_2^{+3}(AsO_4)_2(OH)_2$) amongst a huge number of mineral species. Greenside and Coniston were the biggest producers, the former being the largest lead ore mine and the latter being the major copper producer in the Lake District.

Other mining fields of great importance were the iron ore fields of West Cumbria where large replacement bodies in Carboniferous Limestone consisted almost entirely of Hematite (Fe_2O_3), associated with Barite crystals ($BaSO_4$) and blue Fluorite (CaF_2). Similarly the west Cumbria coalfield produced its rarities like fragile Millerite (NiS) needles in ironstone nodules.

The north Pennines mining field is equally famous for its mineral species and Allenheads was the site of the Britain's biggest lead mine, producing 250 million tons of lead ore. This field showed zoning in mineral distribution with an inner zone carrying fluorite and galena while an outer zone yielded barite and galena. Witherite ($BaCO_3$) occurs in great quantities in this outer zone and is virtually unknown elsewhere; the Settlingstones mine near Hexham worked for 100 years producing the world's only source of witherite. Two other rare minerals - Alstonite and Barytocalcite - were first identified in the Alston Moor district and are very rare elsewhere. They have the same composition ($BaCaCO_3$) but have different crystallography.

Mr Young then talked about the work of the famous mineral collectors like Arthur Kingsbury and Sir Arthur Russell who have provided this heritage of minerals. He concluded with a reminder of the responsibilities of mineral collectors in preserving a national heritage in view of the vanishing resources of old mine tips. He was thanked by the President for an illuminating and entertaining talk.

VOLCANOES ANCIENT AND MODERN - THE BORROWDALE VOLCANICS IN CONTEXT

A lecture by Dr R. J. Suthren of Oxford Polytechnic on 10 March 1993 at West Cumbria College, Whitehaven.

Dr. Suthren introduced his talk by saying that the understanding of modern volcanic processes can be used to interpret ancient volcanic rocks. Volcaniclastic deposits (sedimentary rocks composed of fragments of volcanic material), are very different from those deposited in normal sedimentary systems. This is because:

a) many different processes are involved during explosive eruptions.

b) there is a much wider range of size, shape and density of particles transported - from gas rich pumice with a density of less than one to densities of more than four with some olivine or pyroxene rich volcaniclastic sediments.

c) extremely high rates of sediment supply into the sedimentary regime, during or after major eruptions.

d) the dangers of close studies of the processes in volcaniclastic transport systems, e.g. the death of Geoff Brown and colleagues in January, 1993.

e) the use of modern analogues presents a problem of scale since all the modern eruptions are small compared with those in the geological record.

f) volcaniclastic sediments are often very complex on a small scale, showing great lateral variations.

g) as volcanic rocks are composed of minerals formed at high temperatures they are modified by hydrothermal activity with the loss of original mineralogy, and tend to be unstable and quickly break down under surface conditions.

Four groups of processes involved in the formation of volcaniclastic rocks were described by Dr. Suthren, namely autoclastic processes, hydroclastic processes, pyroclastic processes and aqueous flow processes.

Autoclastic processes involve the mechanical breakdown of lava during movement of the lava. The top and bottom of lava flows cool while the centre remains hot, creating a caterpillar traction effect with massive flow banding and brecciated tops and bottoms. Auto-brecciated lavas have angular blocks with sediments filling the gaps.

Hydroclastic processes cause the fragmentation of magma as it interacts with water or ice. This interaction may be relatively gentle or violent, depending on the location. Where basaltic lava flows into the sea there is a huge temperature contrast but little explosive activity - pillow lavas are shattered. Violent reactions however occur where water gets into a vent and high columns of steam and pulverised magma result, with the bedded deposits forming steep sided cones with a wide range of particle size, from dust to blocks.

Pyroclastic processes involve the explosive release of gases contained within the magma. The wide range of eruption styles are dependant upon the viscosity of the lava. It is easy for gas to escape from fluid (i.e. low viscosity) lavas, explosive eruptions occur with viscous lavas where great pressures build up before energy can be released by major eruption, producing a large eruption column of material, driven first by the explosion or gas thrust. As the impetus of this lessens, another kind of upward movement due to convection takes over as the mixture of gas and ash has a density lower than the atmosphere. When it reaches a height at which its density is equal to the surrounding atmosphere, it can no longer rise and spreads out as a large mushroom-shaped cloud.

Material falling directly from the eruption is **pyroclastic air fall** material and the size of material settling ranges from dust to large blocks. While the large blocks are deposited only a few tens of metres from the source crater, the fine material gets spread over a vast area by the prevailing winds - the example of the Mount St Helens eruption was

quoted. Explosive eruptions with a low eruption column deposit material immediately around the volcano in cones.

Pyroclastic flow deposits are concentrated flows resulting from the eruption column collapsing on itself and moving down slope very rapidly under gravity as a flowing avalanche or "nuée ardente", with very destructive effects. The biggest pyroclastic flows occur during caldera collapse, when a volcano collapses onto its own magma chamber. As pyroclastic flows are gravity-driven, they tend to concentrate in depressions and valleys and are massive with little or no bedding. They often have flat tops, show regular thicknesses and are poorly sorted.

It has been recognised by Branney and other workers that there are large calderas in parts of the Borrowdale Volcanic Group, particularly the areas underlying the central and western parts of the Lake District. These are not simple circular fractures but formed more on a piecemeal basis where large blocks subsided at different times into the magma chamber.

Aqueous flow processes occur on the products of the above. Reworking of volcanic sediments may occur shortly after an eruption or later when the sediments have been weathered and lithified. **Debris** and **mud flows** are two aqueous flow processes with very destructive mixtures of water and volcaniclastic material, often generated by pyroclastic flows going into water. Mud flows are very serious in terms of loss of life, as seen in the Nevardo del Ruiz eruption in 1985 which took place beneath ice on the volcano summit. Loose pyroclastic material washed away by rain might be incorporated into mud flows. This loose material can be stabilised by vegetation in modern volcanoes but during the Ordovician there were no land plants and the material remained available for longer periods.

In the summit regions of volcanoes there are gases and hot fluids passing through the volcanic deposits, altering them to clay minerals. On steep slopes this clay, if mixed with water is likely to be unstable and to slide, resulting in mud flows. The material will also be transported by river systems to low lying areas and eventually to the sea in a more gradual fashion.

Similarities between the B.V.G. rocks and to more modern volcanic areas such as New Zealand, western U.S.A. and central America were highlighted. These are large andesite volcanoes with evidence of caldera collapse and the eruption of large volumes of pyroclastic flow material; so they can tell us much about the setting of the B.V.G.

HOT DRY ROCK GEOTHERMAL ENERGY RESEARCH

A lecture by Dr Hugh Richards of British Nuclear Fuels plc
on 22 September 1993 at Cockermouth School

Whilst geothermal phenomena occur in a wide varieties of situations world-wide, Britain affords few areas where geothermal energy is ever likely to be tapped. In Cornwall, however, the potential for extracting heat from hot dry rocks at depth suggested sufficient possibilities existed to warrant an extensive pilot experiment. Dr Richards, who worked on the project during the 1980's spoke both of the theory behind the idea, and the practical aspects of drilling and attempts to harness the energy.

The idea of the project was simple. By drilling pairs of boreholes, injecting cold surface water down one of them, allowing the water to pass through natural fractures in the rock, heat would be picked up as it moved through to the other borehole where it was pumped back to the surface. Geothermal gradients in the granite plutons of Cornwall are some of the highest in Britain and joint structures appeared to provide good linkages through which water could pass. Provided water losses from the system were not excessive and the cooling rates during extraction were low enough to ensure an economic life span, such ideas could provide an economic return as the input of energy required was minimal. Temperatures at depths of 6km were estimated to be around 200°C. Theoretically the amount of energy available was huge, but in practice less than 1% was capable of being tapped. However a life span of somewhere between 10 and 20 years was considered to be economic.

The speaker explained in detail various attempts to probe the granite and seek hydrothermal connections at depth. Four initial boreholes drilled to 300 feet proved of little use. Eventually two boreholes drilled to

2km. advanced the project, but connections between the boreholes were difficult to establish. Only 25% of the water pumped returned to surface. A third deep borehole achieved an 80% return, but there was progressive reduction in water temperatures as the project continued.

Dr Richards explained the technical difficulties surrounding the project in detail and conveyed the frustration of the scientists and engineers in turning a simple idea into an economic reality. After several years of technical innovation and change it had not been possible to prove or refute the concept. The lecture however kept an audience of over 30 members enthralled to the end. It was excellently illustrated with slide, graphs and technical data and led to a series of questions from members.

Dr Richards, who is a member of the Society was thanked by the President who reflected on the similarities of some of the engineering problems with those encountered in the oil industry.

THE RISE AND FALL OF AN ORDOVICIAN ISLAND ARC

A lecture by Dr Eric Johnson of B.G.S., Newcastle, on 13 October 1993 at West Cumbria College, Workington.

Dr Johnson outlined the known extent of the Borrowdale Volcanic Group (B.V.G.) - the present day outcrop together with an eastern area including the Cross Fell inlier and underlying Upper Teesdale and the thick sequence beneath the Permo-Triassic rocks of the Sellafield district. If the crust in this region could be stretched back to its extent prior to the Acadian Orogeny, then the original volcanic field must have covered in excess of 4000 sq. kms.

The volcanic province formed in a island arc situation with a southern continent, known as East Avalonia, migrating north and involved in continental collision with a northern continent, Laurasia, during the Ordovician. Subsequently these continents docked and fused together in Late Silurian to Early Devonian times.

The Skiddaw Group, Tremadoc to late Llanvirn in age underlie the B.V.G. It was deposited in deep water on the northern margins of East Avalonia. In the Buttermere district there is evidence of large scale post-depositional submarine slides, shown by olistostromes and chaotic debris flows. The oldest rocks of the Windermere Group, which overlie the B.V.G., are the Dufton Shales of the Cross Fell inlier and the Drygill Shales of Carrock Fell. These are of Longvillian age and indicate the waning of vulcanism. An interval of 15 million years thus occurs between the Skiddaw and Windermere Groups with little evidence of marine deposition. Allowing time for erosion of Skiddaw Group rocks before burial beneath the volcanics, it is estimated that about 8 kms of volcanic rocks were deposited in a period of around 12 million years.

The volcanic episode was originally considered as an element of an orogeny but it is now recognised that widespread uplift was associated with crustal stretching and extension. Continental extension must have occurred since the vulcanism tapped magmatic sources being generated deep within a subduction zone and the volcanic rocks were preserved within an intra-island rift zone.

The accepted view is that the Borrowdale Volcanic Group can be divided into a lower effusive sequence and an upper explosive sequence. The Lower BorrowdaleVolcanic Group rocks in the western Lake District show a sequence 3 km thick, dominated by lavas. However many features mapped as lava flows in the early geological surveys are now recognised to be sills intruded high in the sequence which reacted with wet sediments. The two are difficult to distinguish as most are brecciated. The lavas follow the laws of superposition in stratigraphic order while sills may come anywhere in the sequence, expanding the thickness up to ten-fold. One of the challenges with volcanic rocks is unravelling these complex sequences and the identification of individual tuff horizons has provided valuable marker horizons.

In the upper part of the Borrowdale Volcanic Group there was a great change in the style of vulcanism with three major types of deposits. In explosive eruptions, of which there were many, the basal ground surge deposits represented the lateral blast of the initial explosion. These are

succeeded by pyroclastic flow or ignimbrite deposits with bedded airfall ash deposits following from the huge ash cloud.

These features are found in calderas formed in a rift zone along the island arc. Several calderas have been recognised - one towards Sellafield marked by the Craghouse Tuff, another in the central fells and a third associated with the Ulpha or Duddon basin. The one in the central fells is described as a piecemeal collapse caldera with its floor composed of fragmented blocks of older volcanic rocks. The Ulpha basin caldera is more gentle; although there is evidence of eruptions around its margins, most material is sedimentary in origin, derived from the surrounding high ground. Further details are given in Dr. Millward's lecture of 14 October 1992.

The southern rift boundary, which roughly coincides with the line of the Windermere Group unconformity is known as the 'Southern Borrowdale Lineament'. To the north is a volcanic sequence up to 8 km thick while geophysics has proved much thinner sequences outside the major intra-arc rift zone. The Upper Borrowdale Volcanic Group sequences in the Duddon basin are very important as they contain the only marine rocks within the sub-aerial volcanic sequence (the Holehouse Gill Formation). These dark silty mudstones up to 450m thick contain acritarchs, microfossils of early Caradoc age, which provide the only firm date for the Upper Borrowdale Volcanic Group.

Very little is known about the extent of the land mass immediately prior to the transgression of the Windermere Group rocks at the beginning of the Silurian when marine conditions returned to the area. The great thickness of material deposited during the volcanic episode can be contrasted with the Silurian sequence which occupied a similar time-span of ten to twelve million years, and where the entire Llandovery sequence is less than a hundred metres thick.

THE BUILDING STONES OF CARTMEL PRIORY

A lecture by Mr Murray Mitchell, formerly of the British Geological Survey on 8 December 1993 at the West Cumbria College, Whitehaven

Mr Mitchell introduced his talk by indicating that building stones provided a fascinating insight into the geology of an area, often demonstrating the skills of builders in using geology to their advantage.

Nine Norman foundations were built around the periphery of the Lake District during the 12th century, Cartmel Priory was one of 4 built in the latter half of the century in response to a large number of Scottish Border raids. Cartmel Priory is the old "Priory Church" of Cartmel and sits in the middle of the Cartmel peninsula.

The solid geology of the area comprises a central low lying area of Bannisdale Slates (Silurian), unconformably overlain by Carboniferous Limestone to the east (Hampsfell) and bounded to the west by a large fault downthrowing to the west, with Carboniferous Limestone on the downthrown side. The Cartmel peninsula is characteristic of a number of similar features on the northern edge of Morecambe Bay where a series of such blocks, all downfaulted to the west, are the result of extensional tectonics associated with the opening of the Irish Sea Basin in Permo-Triassic times. The Carboniferous Limestone comprises thickly bedded carbonates with little shale. The Bannisdale Slates are turbidites, a series of unsorted sediments re-deposited from a shelf environment into the Iaepetus Basin. The slates are well bedded, highly fracture, folded and unfossiliferous and have proved very difficult to map. The total thickness of the Bannisdale Slates is estimated at 4 - 5 km. The glacial geology of the area is dominated by the effects of the Windermere Glacier which deeply scoured the Windermere Valley and then spread out to the south into the Cartmel Valley, depositing glacial debris on the valley floor and creating a large number of drumlins.

In post-glacial times the central part of the peninsula was covered by a large number of small lakes, with Lake Cartmel lying to the south, east and north of the Priory site. The location of these lakes are easily recognised by the low lying "reedy" land which often flood with water

following heavy rain. The Priory was largely built on a "crag and tail" feature of Bannisdale Slates - the only bedrock exposure in the valley. Originally the cloisters were built on the south side of the Priory but they were moved in the 14th century to the north side, this was probably due to the foundations on the south side sinking into the soft glacial material.

Mr Mitchell reviewed the potential of the rock types in the immediate vicinity of the Priory for building stone. The only available rocks were the limestones, which were difficult to work and the Bannisdale Slates which were totally unsuitable. A source of suitable building stone was however found in the sandstones at the top of the Lower Carboniferous sequence at Holker. Here, east-west trending ridges of Yoredale sequences occur in the Gleaston Group. Exposures in this area show 14m of sandstone overlain by 5m of shale with another sandstone above. The 14m sandstone can be divided into 3 units (A - C) on the basis of variations in proportions of quartz grains, cement and mineralogy. Sandstones B and C are very strong with a combined (grains and cement) silica content of 97%. Sandstone A contains 13% limonite and 7% feldspar and has a low strength. The sandstone (D) overlying the shale has a highly siliceous matrix (15%) with 7% limonite and 6.5% feldspar.

It is a remarkable tribute to the abilities of the builders that they were able to identify the different types of sandstone and use them accordingly. Sandstone A was not used in the construction of the Priory due to its low strength, sandstone B, almost pure white in colour, massive and compact was used for the ornate "dogs-tooth" carving in the interior of the Priory, sandstone C is both coarser grained and tougher and was used for the load bearing structures. Sandstone D was used as the freestone for the external walling. An ancient quarry in sandstone B is still visible on the foreshore and it is probable that the rock was transported by sea and then river as close as possible to the priory. The requirement for good quality rock was such that it was even mined.

Construction of the Priory was in 3 phases. In the first (1190 - 1220), the 3 choirs and the N-S transept were built. Between 1320 and 1340 the south side (town) choir was extended - this was the choir used as a Parish Church by the local residents. In the third phase, around 1440 the nave and the east window were constructed and an extra storey was added to

the tower. During this latter phase no sandstone was used, instead a mixture of cobbles, limestone and Bannisdale Slates was employed, this could have been due to either a lack of funds or masons.

A point of considerable interest was that the upper storey of the tower was rotated through 45° with respect to the lower portion. This was an ingenious solution to a problem that had manifested itself following the earlier phases of construction. The original design of the Priory was such that the arches under the lower portion of the tower took all the weight on the pillars rather than the centre of each arch, and had started to fail at the crest of the arch. To counteract this failure the second storey of the tower was rotated such that all its weight was concentrated on the crest of the arches thus correcting the problem. This remarkable feat of engineering undoubtedly saved the tower.

GEOLOGICAL MAPPING AND PHOTOGEOLOGY IN THE LAKE DISTRICT

A public lecture by Dr Frank Moseley on 23 February 1994
at Tullie House Museum, Carlisle.

This meeting in Carlisle was jointly organised by the Society and the Tullie House Museum, Carlisle.

Dr Moseley opened his talk by stating that he had undertaken photogeological mapping in several different parts of the world and his intention was to provide examples from various areas to illustrate the principals of photogeology and then show how he has applied these in the Lake District.

Dr Moseley described his methods of geological field mapping, stating that aerial photos were an essential part of mapping and he showed his design of map case which included an integral pocket for stereo pairs of aerial photographs. The method employed was to plot geological information onto a transparent film overlain on the photographs.

A brief description of the Lower Palaeozoic geology of the Lake District was provided, comparing the Ordovician subduction of the Iaepetus ocean and the generation of large volumes of volcanic material with the present day location of the Cascades mountain range in the western U.S.A. The Lower Borrowdale Volcanic Group (B.V.G.) consisted of andesites and basalts unconformably overlain by Upper B.V.G ignimbrites.

The merits of satellite and aerial photographs were compared. Although techniques of false colour imaging can be used to pick out mineral deposits on satellite photos the level of resolution from civil satellites (< 30m) was not yet good enough to provide the necessary resolution for surface geological mapping. It was noted that in the future it was likely that satellite imaging would improve to a point where it could be suitable. An aerial photograph of the St Johns-in-the-Vale area was used to demonstrate how much easier it is to establish geographical locations during mapping using aerial photos.

An example of the use of aerial photography in South Arabia in an area lacking topographic maps (Hallaniya) was presented. The aerial photograph showed a series of limestone escarpments, the height of which could be readily determined from a photographic stereo-pair - a task that is now routinely performed by machine. It was noted that there was still a need a traverse of the section to confirm the geological sequence. Another example from Hallinaya showing fault displaced Pre-Cambrian dykes in granite was used to illustrate the benefits of using aerial photography in mapping exercises.

Further examples for South Yemen and Southern Spain were presented to illustrate the invaluable nature of aerial photographs when mapping in inaccessible areas.

Dr Moseley then turned to the Lake District and provided a number of examples of the uses of aerial photography in geological mapping.

An aerial photograph of the High Rigg area showed an obvious unconformity feature not visible from the ground which cross-cut the basalt/andesite lava flows of the B.V.G.

A ground photo of Fairfield from St Sunday Crag which clearly showed a sequence of faulted bedded tuffs exposed in a large crag was presented. It was noted that plotting the correct location of the faults and the lithological units from the ground would be very difficult in this situation but that it became relatively easy when aerial photos were used.

Other examples of aerial and ground based photos from the Lake District were presented showing mineral veins in Newlands, faults at Boo Tarn (Coniston), Pike o'Stickle, Scafell, High Spy and ornamental tuffs at Hodge Close. It was noted that although the vertical bedding in the ornamental tuffs shows up very well on aerial photos it is not always easy to distinguish sub-parallel cleavage and bedding.

Dr Moseley then described one method of detailed surface mapping used to complement aerial photo data, that of conducting tape and compass surveys in stream sections, with examples from Spain and from the Coniston Limestone outcrops in the vicinity of Torver Beck.

An aerial photo of the in the area around Beacon Tarn to the south of Coniston showed readily discernible structures such as reverse faults, folds, anticlines and synclines.

Examples were also presented of the use of aerial photos in the mapping of clints and grikes in the Carboniferous Limestone at Hutton Roof and at Underbarrow. At these localities data had been obtained on the grike orientation both by field mapping and from aerial photos. It was readily apparent that the use of aerial photos provided more accurate data.

Finally Dr Moseley described some geological features that could not be identified from aerial photographs, these were generally small scale textural features such as lapilli tuffs, ornamental tuffs, ignimbrites, peperitic sills, flow folds in andesite and flow brecciated lavas.

Following the lecture the audience had the opportunity to examine a selection of Dr Moseley's aerial photographs from a variety of geographical locations and to view some fine examples of geological features using stereoscopes.

PERMO-TRIASSIC ROCKS OF CUMBRIA

A lecture by Dr L Macchi of Reservoir Associates on 9 March 1994
at Queen Elizabeth Grammar School, Penrith

In introducing his talk, Dr Macchi indicated that he would deal mainly with the Lower Permian rocks of the Eden Valley and West Cumbria.

Palaeogeographical reconstructions for Permian times show the West Cumbrian sequence to be a small expression of a much larger depositional basin in the East Irish Sea Basin (EISB) while the Eden Valley is also linked through the Solway Basin to the EISB. This basin in turn is linked to those of south-west of Scotland. Hence the Cumbrian sequences are parts of a much more extensive sedimentary province.

The line of the Pennines formed an upstanding eastern fault margin to the palaeo-Eden Valley, which was a narrow half-graben desert basin in Permian times. The western boundary was less rugged and passive. Death Valley, USA, was cited as a modern analogue. Here the mountains on the active margin are fringed by alluvial deposits and screes, passing basinwards into playa lakes and aeolian sand tracts. The rare but violent rainstorms strip off the shattered rock debris in the upland areas and move it down the canyons (wadis) onto the desert floor where the sediments are dumped very rapidly, forming large cones of coarse, poorly sorted material.

The brockram deposits, breccia-conglomerates which are the Permian equivalents are only exposed along the western side of the Eden Basin and little is known of the fill adjacent to the eastern faulted margins. In the Hoff brockram for instance the clasts are principally of limestone and represent distal alluvial fan deposits; none of the coarse proximal deposits have been preserved.

The Penrith Sandstone is a typical aeolian sand, characterised by large-scale, steep cross bedding. One of the commonest dune forms in modern desert environments are longitudinal dunes which show beds dipping in two symmetrical directions. There is no such symmetry in the cross-bedding in the Penrith Sandstone which shows uni-directional dips of 25° to 30° towards the north-west. Realstone Quarry, near Lazonby, and Trough Gill, Cliburn, are both large trough bedded structures which suggest barchan dunes with crescentic structures. However, barchan dunes are characteristic of regions with limited sand supply and rocky desert floor - it is evident that there was no shortage of sand in the Eden Basin and so the form of the dunes is still open to speculation.

The West Cumbrian sequence, best seen at Saltom Bay, Whitehaven, shows a much abbreviated Permian succession about 100m thick. The Lower Permian sequence consists of a purple conglomerate, only 2m thick, which rests unconformably upon the Whitehaven Sandstone of Westphalian age. Above the conglomerate is 5m of the Saltom Dolomite, which passes upwards into the buff and red St Bees Shales. The brockrams thicken dramatically towards the basin margin inland. It may therefore be concluded that the brockrams of Saltom Bay are the distal components of an alluvial fan, very similar to the southern end of the Eden Valley brockrams.

The Triassic Period is represented by the St Bees Sandstone, the local equivalent of the Sherwood Sandstone, and this formation is developed extensively in the region, overlying both the Eden Shales of the Eden Valley and the St Bees Shales of West Cumbria. The St Bees Sandstone reaches a thickness of 975m in West Cumbria, the top 935m consisting of fine-grained fluvial sandstone with scour channels and irregular, erosive bedding, produced by a low sinuosity river system that covered much of England. Even though this West Cumbrian sequence probably occurs in a half graben, bounded to the east by a major fault, there is no evidence of coarser deposits adjacent to the fault line which would suggest that the fault was active at the time. It may therefore be inferred that the Lake District massif had been largely peneplained and buried by Triassic times. (This last argument would seem to support the thesis advanced in the article "The last 200 million years in Cumbria", elsewhere in the Proceedings. Ed).

Other Talks

Several other talks were given to the Society, including:

Presidential Addresses by K.W. Bond

13 January 1993 - Geological features of the Canadian Great Lakes Lowlands

10 November 1993 - A geological enigma - Olistostromes in a South American oilfield.

A lecture from T. Shipp

12 January 1994 - Iceland : land of ice and fire.

ANNUAL GENERAL MEETINGS

THE 32nd ANNUAL GENERAL MEETING of the Society was held at Workington College on Wednesday 24 February 1993 with the President, Mr.K.W. Bond in the chair. The General Secretary reported on busy year and told members of the Society's two publications during the year. The biennial Proceedings of the Society (Vol.5, Part 3) was distributed in May. The Society's new field guide (Lakeland Rocks & Landscape) was published jointly with the Ellerbank Press, Maryport. This very successful book was edited by Mervyn Dodd with contributions by many Society members. The accounts for the year ended 31 December 1992 were presented and accepted.

THE 33rd ANNUAL GENERAL MEETING of the Society was held at Workington College on Wednesday 9 February 1994 with the President, Mr. K.W. Bond in the chair. The General Secretary reported on the year's activities . The Treasurer presented the accounts for the year ended 31 December 1993 which were accepted.

ANNUAL DINNERS - 1992 and 1993

The 1992 Annual Dinner was held on 11 April at the Trout Hotel, Cockermouth,

The 1993 Annual Dinner was held on 3 April at the Trout Hotel, Cockermouth, which had proved to be a popular choice on the three preceding years. The guest speaker on this occasion was Mr Jack Hartley, formerly of the Department of Earth Sciences at Leeds University.

The Charles Edmunds Award was presented to Mr Tom Shipp in recognition to his work and contribution to the Society over many years.

OBITUARY

J. A. Barras

The death in 1993 of an old member of the Society is recorded in the passing of Mr. J.A. Barras. He joined the Society in 1966 and was a member of the Council in 1971 and 1972. He worked for British Steel at Whitehaven and returned to Rotherham on retirement.

OFFICERS AND COUNCIL

Officers and Council elected for 1993 and 1994 are given below.

OFFICERS ELECTED FOR:	1993	1994
President	K.W. Bond	F.T.B. Lawton
Senior Vice-President	I. Gray	K.W. Bond
Junior Vice-President	E. Lawrence	R.A. Smith
General Secretary	R.A Smith	R.A. Smith
Excursion Secretary	D. Kelly	D. Kelly
Treasurer	F.T.B. Lawton	Mrs A. Marchant
Membership Secretary	Mrs M. Fox	Mrs M. Fox
Editor	E. Skipsey	C.J. Thompson
Publications Secretary	T. Loftus	T. Loftus
Librarian	M. Burton	M. Burton
R.I.G.S. Co-ordinator	M. Dodd	M. Dodd
Council Members	E. Curzon	E. Curzon
	G. Pinches+	D. Dickens
	D. Dickens	G. Pinches+
	Mrs A. Marchant*	S. Hewitt
	R. Clark*	R. Clark*
		E. Skipsey*

+ Honorary Auditor
* Editorial Board Members

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

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