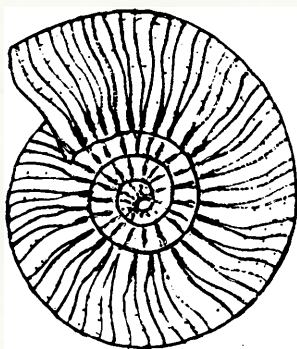


THE CUMBERLAND GEOLOGICAL SOCIETY



PROCEEDINGS

Volume 5

1986-87

Part 1

THE CUMBERLAND GEOLOGICAL SOCIETY

**Honorary Life President:
E. H. Shackleton, F.G.S.**

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EDITOR'S NOTE

I would like to thank all who have contributed articles, provided lecture and excursion notes and assisted in the preparation of these Proceedings. The typing, art-work and page arrangements have again been undertaken by Mr.J.D.Hinde to whom I extend thanks on behalf of the Society. I must also acknowledge the work over the past five years of Mr.S.H.Gate who retired as Editor in February, 1988, and who assembled all the material in the present Proceedings.

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

Eric Skipsey

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THE GEOLOGY AND MINERALISATION OF FORCE CRAG MINE, CUMBRIA

B.Young & A.H.Cooper

INTRODUCTION

Force Crag Mine (NY 200 216) at the head of Coledale near Braithwaite has had a long history as a producer of lead and zinc ores and barytes. Like many mines in the Lake District periods of active mining and exploration have alternated with considerable periods of abandonment. In recent years commercial interest has again been shown in the property which now has the distinction of being the only metalliferous mine working in the Lake District, albeit on a small scale.

The mine's history and the broad aspects of its geology have been outlined by several authors, e.g. Postlethwaite (1913), Eastwood (1921) and Shaw (1970).

GEOLOGY

The Force Crag Vein occupies a roughly E-W trending fault which cuts through mudstones and siltstones of the Ordovician Skiddaw Group (Figure 1). The oldest part of the Skiddaw Group cut by the vein (1.5km west of Force Crag) comprises the 900m thick Loweswater Formation. This formation of turbiditic greywacke sandstones is overlain by at least 1,500m of siltstone and mudstone turbidites assigned to the Kirk Stile Slates by Jackson (1978). The top of the Loweswater Formation is of early Arenig age (approximately the Didymograptus nitidus subzone). The overlying siltstones and mudstones on Grisedale Pike (NY 1988 2276) are of probable early Arenig age (Isograptus gibberulus subzone) but those on Outerside (NY 2110 2146) are late Arenig (Didymograptus hirundo zone). The regional dip here is to the south and at Force Crag Mine the Force Crag Vein cuts obliquely through this sequence.

In Gasgale Gill (NY 1834 2146) the Force Crag Vein cuts the junction between the Loweswater Formation and the overlying undivided Skiddaw Group siltstones and mudstones. The vertical displacement across the vein here appears to be small. At Force

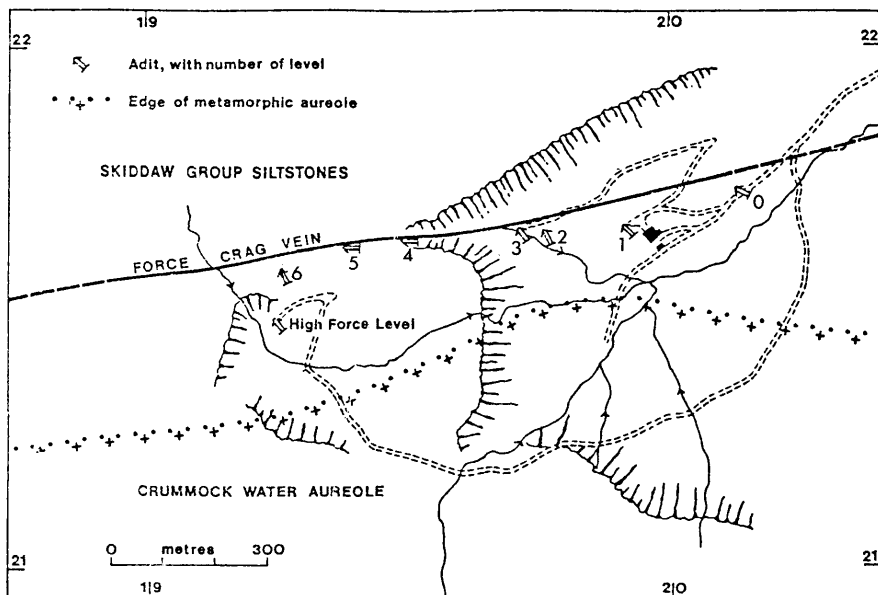


Fig.1 FORCE CRAG MINE - GEOLOGY AND MINE ENTRANCES

Crag there are no definite markers which enable the amount of fault displacement to be estimated.

In the vicinity of Force Crag Mine the generally southerly dip of the siltstones and mudstones of the Skiddaw Group is disturbed by abundant early slump folds. These folds are commonly recumbent, disrupted and confined between bedding-parallel shears. They are refolded by early Devonian (Acadian) folds which exhibit a generally ENE trend. The later folds have an associated upright cleavage which is moderately developed, a N to NW trending cleavage is also observed locally. These two cleavages are cut by another sporadically developed low-angled cleavage.

The Force Crag Vein runs parallel to and just north of the gradational northern boundary of the Crummock Water Aureole. This elongate aureole may be associated with a major basement fracture and is of probable early Devonian age. Stanley & Vaughan (1982) have proposed a Carboniferous age for the main mineralisation in the Force Crag Vein, though the structure may have been initiated at an earlier date and may have been influenced by the pre-existing aureole and associated buried intrusion.

MINERALISATION

Force Crag Vein can be traced for at least 3 miles (4.8 km)

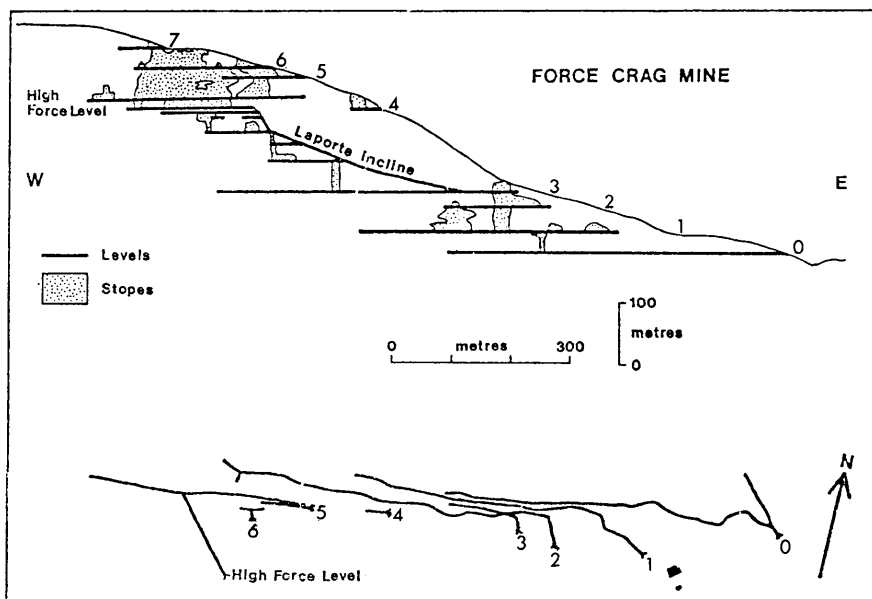


Fig. 2 FORCE CRAG MINE - SIMPLIFIED PLAN AND VERTICAL SECTION THROUGH MINE WORKINGS.

from the foot of Gasgale Gill in the west to Coledale Beck in the east. Mineralisation is not continuous along the vein and is most abundantly developed in the neighbourhood of Force Crag Mine (NY 200 216), though unsuccessful trials have also been made on it in Gasgale Gill (NY 163 210). The vein has been explored vertically over at least 350m, a greater vertical interval than most veins in the Lake District orefield. Laterally the workings extend over a distance of 1,200m. Payable mineralisation has been found and worked at several levels (Figure 2).

Unlike many orefields the Lake District field exhibits little or no lateral zonation of constituent minerals within the deposits. This is in striking contrast to the nearby Pennine fields. In part this may reflect the long and relatively complex history of mineralisation. However, within several veins in the Lake District, where exploration and development have been carried out over a large vertical range, a vertical zonation of component minerals is apparent. Force Crag Vein provides one of the area's best examples of this.

Throughout the Force Crag workings the vein is reported to have averaged about 1.5m in width, though widths of up to 6.1m have been measured locally. Both the hanging and footwalls are typically well defined. The vein generally fades northwards at

about 75° though it is vertical in places (Eastwood, 1921, p.21). In the lower parts of the mine, below No.1 level, the vein divides into two parallel fractures separated by up to 4.6m of barren ground. Several small strings diverge from the vein in places, though these are mineralised only near the intersections.

Above the High Force Level baryte (BaSO_4) is the main constituent, accompanied by abundant manganese and iron oxides and a little quartz. The baryte is typically coarsely crystalline with individual crystals commonly up to 15cm across. Much of it is almost pure white though locally it assumes a very pale pink colour. Near outcrop some is considerably stained by brown iron oxides. Large well developed tabular baryte crystals have been found in vugs. By far the major proportion of the mine's output of barytes was obtained from ore-shoots in these upper levels. Hard black to dark grey manganese oxides, generally referred to as 'psilomelane', are common as massive reniform or stalactitic masses. Excellent examples may be collected from the dumps on the hillside between High Force Level and the vein outcrop in the open stopes. In addition to its presence in the vein 'psilomelane' also occurs here as reniform nodules within the siltstone and mudstone wall-rock. The precise nature of the mineral or minerals present in this material has yet to be identified. Soft, earthy black manganese oxides, previously referred to as 'wad' also occur. Recent investigation of some of this material has revealed the presence of the relatively new mineral todorokite ($(\text{Mn}^{+2}, \text{Ca}, \text{Mg})\text{Mn}_3^{+4}\text{O}_7 \cdot \text{H}_2\text{O}$). Small tonnages of manganese ores are believed to have been sold in the past. Goethite ($\text{FeO}(\text{OH})$) may also be found here as dark brown reniform masses with an internal banded fibrous structure. Galena and sphalerite are almost absent from the upper levels of the mine.

When traced downwards below High Force Level the vein becomes barren of almost all but massive white quartz. This part of the vein may be followed in the gully on the north side of Force Crag. Exploration underground by the Laporte incline failed to find economic mineralisation in this interval.

Economic mineralisation reappears in the Number 3 Level near the foot of Force Crag. Here, and in the lower levels, sulphides become common with sphalerite and galena as the main economic minerals. Baryte is generally present only in subordinate amounts though workable pockets of this mineral have been found locally.

Sphalerite (ZnS) is abundant as dark brown to almost black coarsely crystalline bands. Numerous large vugs are lined with lustrous sphalerite crystals up to 2cm across, commonly associated with pale brown siderite. Force Crag Mine has long been known as a source of very fine specimens of sphalerite, examples of which are to be seen in many museum collections.

Galena (PbS) is less abundant than sphalerite. It typically

occurs as coarsely crystalline masses. Freely grown crystals are rare. According to Eastwood (1921, p.21) the silver content of the galena is about 30 ozs per ton of lead, though as much as 35 ozs per ton were found in some samples. The silver is likely to be present in solid solution within the galena. Recently Stanley & Vaughan (1981) have identified microscopic inclusions of bournonite (CuPbSbS_3) and native antimony (Sb) in the galena.

Chalcopyrite (CuFeS_2) and pyrite (FeS_2) are present locally as very small (up to 2mm) crystals usually coating quartz or baryte crystals.

Siderite (FeCO_3) is common in the lower levels of the mine forming clusters of small (up to 3mm) curved rhombs. When fresh these are generally pale yellowish brown in colour but become dark brown on weathering. They commonly encrust large sphalerite crystals in vugs.

Fluorite (CaF_2) is a rare local constituent of the vein in the lowest levels of the mine. Its presence, as small pale grey crystals, was first noted by Eastwood (1921, p.21) though no description of its position in the workings was given. In recent years small specimens of pale yellow cubes up to 5mm across have been found coating siderite crystals in small vugs in veinstone derived from the Number 3 Level workings. Similar pale yellow fluorite has also been seen forming narrow selvages to the vein in Number 0 Level. The mineral has recently been found in small amounts in the '1500 stope' above Number 0 Level. (L.Greenbank - personal communication).

In addition to the manganese and iron oxide minerals already noted from the upper levels supergene minerals at Force Crag include cerussite (PbCO_3) and rare traces of malachite ($\text{Cu}_2(\text{CO}_3)(\text{OH})_2$). Good specimens of the former mineral are now very rare here, though Greg & Lettsom (1858) and Goodchild (1883) note good examples.

Greg & Lettsom (1858) reported the first British occurrence of stolzite (PbWO_4) from Force Crag and the mineral was subsequently listed from here by Hall (1868), Kendall (1884), Goodchild (1885) and Eastwood (1921). However, some considerable doubt must surround the accuracy of this observation. No specimens of stolzite have been traced from here. Russell (1944) noted that no specimens exist in the Allan-Greg collection, now in the British Museum (Natural History), nor was there any reference to such specimens in the Allan and Greg manuscript catalogue. Further Russell observed that Greg and Lettsom's published figure of a stolzite crystal could equally be of wulfenite (PbMoO_4). Mystery still surrounds the occurrence of stolzite at Force Crag. The chemistry and paragenesis of the Force Crag Vein make it an unlikely host to even traces of supergene tungsten mineralisation. Wulfenite is present in several other Lake District lead veins and

could conceivably be present at Force Crag. The record by Kingsbury & Hartley (1957) of scheelite at the nearby Scar Crag Cobalt Mine is interesting in this context, as the occurrence there of tungsten could perhaps have allowed stolzite to form in that vein. If so, the Scar Crag Vein could have been the source of Greg & Lettsom's stolzite. At that time locality details were often imprecise and specimens from here may have been listed as from the better known and more prominent locality of Force Crag.

AGE OF MINERALISATION

Force Crag Vein is a member of the suite of Lake District veins dominated by lead, zinc and baryte to which Stanley & Vaughan (1982) have assigned a Lower Carboniferous age. The presence of inclusions of antimony minerals is characteristic of the galena of veins of this age and may result from remobilisation of antimony from vein deposits formed during an earlier, perhaps Lower Devonian, episode of mineralisation (Fortey et al., 1984).

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We thank Mr.L.Greenbank of New Coledale Mines for arranging access to Force Crag Mine and for information on recent developments. Mrs.J.Dunkley is thanked for preparing the typescript. This paper is published by permission of the Director, British Geological Survey (NERC).

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WAVELLITE AND VARISCITE FROM SCAR CRAG COBALT MINE, CUMBRIA

B. Young

INTRODUCTION

The aluminium phosphate minerals wavellite ($\text{Al}_3(\text{PO}_4)_2(\text{OH},\text{F})_3 \cdot 5\text{H}_2\text{O}$) and variscite ($\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$) are relatively uncommon in Britain. Wavellite was first recognised as a new species from High Down Quarry, Filleigh, near Barnstaple, Devon and named after the finder, Dr. William Wavell, a local physician (Palache *et al.*, 1951). Good examples of the mineral in the form of radiating crystalline spherules coating joint surfaces of Lower Carboniferous mudstone are still common at this locality. Wavellite is also recorded from Stenna Gwynn, near St. Austell, Cornwall by Greg & Lettsom (1858) who also comment on its occurrence on sandstone at Newcastle-upon-Tyne and in the Shiant Isles, Scotland. No further reference is known to either of the two latter locations: its presence on the Shiant Isles is not confirmed by Macpherson & Livingstone (1981) in their glossary of Scottish minerals. Variscite has been found in association with wavellite at High Down Quarry (Embrey, 1977).

The systematic collection of British minerals in the British Museum (Natural History) contains specimens of both species from Scar Crag Cobalt Mine, Causey Pike (NY 206 208), both collected in the 1950's. Several amateur collectors have subsequently obtained examples of the mineral from here, though to date no description of this Cumbrian material has been published. The author has examined a number of these specimens and in addition has recently collected both minerals in situ underground in the mine.

GEOLOGY AND MINERALISATION OF THE SCAR CRAG VEIN

The Scar Crag Vein occupies a NNE-SSW trending fault of very small throw in Ordovician Skiddaw Group slates on the east side of Long Comb. The slates, which are tentatively assigned to the Kirk Stile Slates, are here bleached and locally iron-stained within the Crummock Water thermal aureole (A.H. Cooper - personal communication). The veins form a small gully which may be traced for approximately 150m along the foot of the crags above the footpath

through Long Comb. It is well exposed above the portals of two short adit levels driven along it. These exposures show several parallel bands up to 0.5m wide, within an overall width of up to 1.5m, composed of massive quartz with abundant chlorite. In these bands occur local concentrations of arsenopyrite (FeAsS) much of which has weathered to cellular pockets of pale green to brown scorodite ($\text{Fe}^{+3}\text{AsO}_4 \cdot 2\text{H}_2\text{O}$). Dark red hematite staining is common along fractures and joints. Abundant spoil from the levels shows concentrations of large (up to 5mm diameter) prisms of white to cream apatite in chlorite-rich quartz veinstone.

Other minerals reported from the vein include alloclasite ($(\text{Co},\text{Fe})\text{AsS}$), glaucodot ($(\text{Co},\text{Fe})\text{AsS}$) and skutterudite (CoAs_2 - FeAs_2) (Iyer et al., 1979), childrenite ($\text{Fe}^{+2}\text{Al}(\text{PO}_4)(\text{OH}) \cdot \text{H}_2\text{O}$), loellingite (FeAs_2) and scheelite (CaWO_4) (Kingsbury & Hartley, 1957) and kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) (Strens, 1962). Much, if not all, of the smaltite noted by Postlethwaite (1913) may be skutterudite. Erythrite ($\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$) has also been recorded (eg Postlethwaite op.cit., Davidson & Thomson, 1948), though Kingsbury & Hartley (op.cit.) found that much pink material which superficially resembled erythrite was either scorodite or altered apatite. Unsuccessful attempts to work the Scar Crag Vein for cobalt last century have been outlined by Postlethwaite (op.cit.).

Stanley & Vaughan (1982) have suggested an early Devonian age for the Scar Crag Vein. Very similar quartz-chlorite-apatite mineralisation, though without sulphides or arsenides, has been noted in Ennerdale (Eastwood et al., 1931; Clark, 1963) and recent work by the author suggests that this type of mineralisation may be widespread in the area.

DESCRIPTIONS OF WAVELLITE AND VARISCITE

Specimens of these two minerals have been collected in situ from a quartz rib within the vein exposed at the eastern end of the stope in the upper level of the mine. In addition small specimens have also been obtained from loose blocks of exactly similar veinstone lying in the stope. Both wavellite and variscite are commonly found on the same fragments of veinstone. The only other mineral found in close association is scorodite which is commonly a pink cobaltian variety.

Wavellite occurs as colourless to white acicular crystals forming flat radiating or spherulitic aggregates up to 10mm across coating fracture surfaces in massive white quartz. The mineral is commonly very difficult to see against the quartz and is easily overlooked. Very rarely small hemispherical spherules up to 2mm across occur within small cavities in quartz.

Variscite typically forms bright turquoise-blue to green crystalline, and in places enamel-like, crusts up to 1.5mm thick coating fracture surfaces and lining small cavities in quartz. In

places radiating crystals up to 1mm long form botryoidal aggregates the surfaces of which locally exhibit small crystal terminations. In places extremely thin coatings of variscite along fracture surfaces give an overall turquoise-blue tint to areas of quartz.

DISCUSSION

Wavellite and variscite appear to be restricted to a relatively small area of the vein in the upper level stope. Both appear to be of supergene origin and are likely to have formed by reactions between aluminous clay minerals, such as kaolinite, and phosphorus-bearing waters produced by a partial solution or decomposition of the abundant apatite within the vein.

ACKNOWLEDGEMENTS

Thanks are due to the late J.P.Fuller, British Museum (Natural History) for arranging access to the collection of British minerals. Information from R.S.W.Braithwaite and N.Thomson is gratefully acknowledged. This paper is published by permission of the Director, British Geological Survey (NERC).

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PATTERN AND ORDER

IN THE LAKE DISTRICT LANDSCAPE

Dr.R.Clark

INTRODUCTION

The established perception that the main valleys of the Lake District radiate from a hub near High Raise, like the spokes of a wheel, is the primary element in a persuasive tripartite account of Lake District landscape. It is an account which has become increasingly entrenched since Hopkins (1848) advanced a reasoned explanation of how the landscape developed. The essential parts of this explanation still persist, in which the pattern of radial drainage is explained by a doming of the central core of the Lower Palaeozoic rocks. The outward dips of the younger rocks round the margins of the hills and the apparently radial drainage pattern, which the proposed doming was held to explain, were taken to provide the evidence for the doming. The concept of an arch with a Caledonian axis in which the largely outward dipping Eycott Lavas, originally undifferentiated from the Borrowdale Volcanic Group, formed the northern limb, meant that the present valleys discordant to that arch and other then-known structures in the older rocks were deemed to require explanations involving controls other than those structures. Importantly, Hopkins (1848) had suggested that radial faulting consequent upon doming would have influenced the actual location of main valleys.

When Marr (1889, 1906) and Goodchild (1889-90) gave further authority to the notion of radial valleys and doming, the significance of faults having controlled valley sites was somewhat discounted. The pattern of Lake District valleys could rather be explained by emphasis on superimposition. Divergent streams initiated on the domed cover of younger sedimentary rocks in due course cut their way into the underlying Lower Palaeozoic rocks and imposed their pattern on newly met structures, so that when denudation removed the last vestiges of the younger rocks the radial drainage persisted as a testimony to both dome and cover. The belief in the present discordance between valleys and structure made it easy for the threefold elements - radial drainage, doming and superimposition - to be united comfortably and sustained. Marr (1916) noted the eastward extension of the upland through

the Birkbeck Fells to the Howgill Fells with their apparently non-radial valley pattern. He described the whole upland as having a shape resembling an upturned 'caddy-spoon' with opposed valleys from a linear watershed along the eastern handle and the radial pattern in the centre and west.

Linton (1957) applied to the Lake District the idea that ice-streams overflowing from one valley to another could break mountain masses into smaller, discrete units and effect permanent changes to drainage systems. He suggested that since vigorous ice flow could modify drainage patterns, the Lake District valley patterns might have been modified, with the present radial pattern being a lately acquired characteristic. In particular he suggested that the modifications had taken place at the expense of an earlier system of north- and south-directed valleys from an original watershed running from near Crag Fell, south of Ennerdale, east to Shap Fells and beyond. Although certain western valleys (upper Cocker (Buttermere), Ennerdale, Wasdale) had developed by adjustment to existing structures, they had been further opened by ice. He discussed neither a possible origin of the earlier pattern nor the discrepancies between it and the orthodox pattern, although his proposition removed a need for the previous explanation of radial drainage but created a possible conflict between central doming and lateral watershed.

Bott (1974) noted the possible contribution of crustal mass deficiencies associated with large, low density granite intrusions to the initiation and maintenance of high ground in the Lake District. The distribution, trends and gradients of gravity value variations and the locations and intensities of negative anomaly areas are of great interest in considering relief diversity. More recently, Moseley (1978) acknowledged that several Lake District valleys followed linear structures in Lower Palaeozoic rocks. Nevertheless he continued to regard the valley pattern as radial and sustained the orthodox tripartite account of the landscape while noting that details merited closer scrutiny.

This paper discusses the compatibility of these explanations with landscape observations and considers whether there are significant landscape characteristics omitted from the existing explanations.

DISCUSSION

i. The orthodox account of Lake District relief

Firstly, it is necessary to consider the degree to which the present valley pattern can be described fairly as radial, for that ascription is the basis of the established account and Linton's alternative. It is also important to assess what aspects of valley pattern are most in need of explanation. It should as well be noted that even if a pattern is accepted as radial, notions of doming and superimposition require independent assessment. Nor

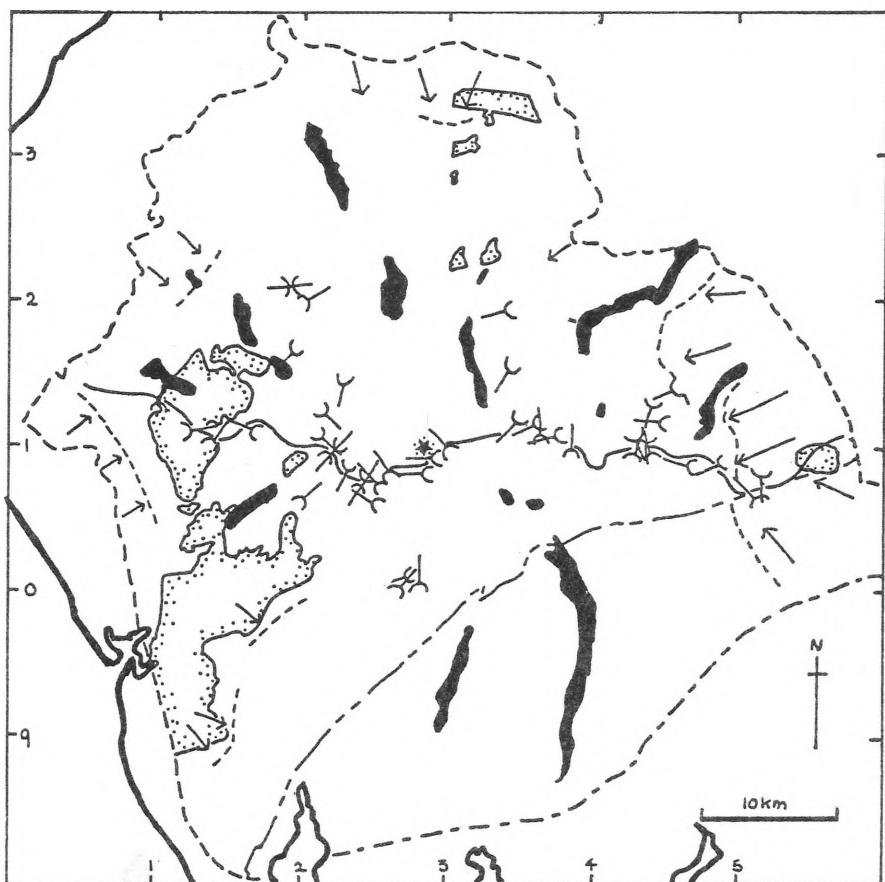


Fig.1 SKETCH MAP SHOWING SELECTED GEOLOGICAL AND LANDSCAPE FEATURES

-  Coasts, lakes
-  Valley heads and valley head axes
-  Approximate upper limit of identified exhumed surfaces and indication of extent
-  Northern limit of Upper Ordovician-Silurian sedimentary rocks.
-  East-west watershed
-  Inner limit of Upper Palaeozoic rocks
-  Northern limit of Carboniferous outliers
-  High Raise
-  Principal exposures of intrusive rocks

would recognition of different valley patterns invalidate, in itself, the possibility of pattern initiation on a now denuded cover and subsequent superimposition.

A truly radiate system of valleys would have a high proportion of all major valleys diverging from a relatively small central area. In a district the size of the Lake District that central area would be very small and departure from a high degree of radial symmetry would invalidate the description 'radial'. There is some subjectivity in deciding what magnitude of valley should be taken into account, and how many contributory valleys for each valley independently reaching flanking younger rocks should be considered. Locations of both valley heads and areas which include them may be used in evidence. In Figure 1 valley head locations and indications of upper valley head axis direction are shown, as is the position of the principal east-west watershed (Linton, 1957) and High Raise, the supposed centre of radiation (Mill, 1895).

The main area where valleys come to a head extends along the east-west watershed for about 30km with some local concentrations especially in an area extending for about 10km west of High Raise. Excluding the Skiddaw and far north-western districts, locations of valley heads occur in an area over 20km from north to south. There is no small compact central area in which streams rise that drain the greater part of the upland; and, supposing modifications of pattern may have taken place, the stream pattern gives no very strong indication of where a single compact centre of doming might have been. Just three of the major valleys, Ennerdale, Great Langdale and the upper Cocker (Buttermere) valley, contribute substantially to the impression of radiation, while also tending to obscure the opposed but broad parallelism of valleys in the Wasdale, Eskdale, Borrowdale and nearby areas. There is clearly less radial symmetry than generally supposed.

The strength of the proposition for simple doming is dependent upon that for radial drainage. Outward dips of peripheral younger rocks have been used as evidence for doming and for the earlier extent of a cover over the central area. Extrapolation of rock dip has limited validity. At the margins the interface between Lower Palaeozoic and younger rocks is broken, and the strike may be diverted by faulting and warping as, for example, west of Penrith. Also, the exhumed sub-Upper Palaeozoic surface can only be traced with confidence inwards for relatively short distances, as to the south of Caldbeck, west of the River Lowther and east of Calderbridge. Thirdly, there is evidence suggesting that in other parts, near Binsey, for example, the interface was originally irregular and thus now difficult to differentiate, if exhumed, from relief in areas further into the hills which have generally been assumed to present young erosional landscapes. Limitations on assumptions about the form of the interface from evidence at the strike are well exemplified in the north, from Little Mell Fell to the

neighbourhood of Ireby and Uldale. Rather small changes in the altitude of the interface along the outcrop accompany marked contrasts in topography on the adjacent Lower Palaeozoic rocks. Such projections inward of the interface that can be made run up into higher truncating terrain or terminate at the crests of the major scarps. Evidence is presented below to suggest that many such scarps may be located by structures that divide the upland into areas which have experienced different degrees of uplift, so weakening advocacy of simple doming.

The proposition of central doming should be tested also against the present locations of highest ground. The three highest places differ significantly in altitude, but are located 7km (Helvellyn), 8km (Scafell Pike) and 20km (Skiddaw) from the supposed centre of radial drainage. Skiddaw is almost peripheral, the remaining pair almost diametrically opposed and 15km apart. Only Scafell Pike is on or close to the east-west watershed. When the group of next highest summits is examined a set of significant locational facts appears. Skiddaw is accompanied by a 'mirror-image' summit, Blencathra (the interesting degree and significance of bilateral symmetry in the Skiddaw block is the subject of a separate study). Helvellyn and Scafell Pike are flanked by high summits not grouped around, but linearly alongside them. That arrangement is closely linked to the distribution of valley heads and of scarps. High summits not associated with the three highest summits are located far from the upland centre, Grassmoor about 15km from High Raise and as peripheral as Skiddaw, High Street some 17km from the centre but, like Scafell Pike, close to the east-west watershed. The middle of the upland lacks any of the highest summits. That is not wholly incompatible with central doming, but weakens confidence in its occurrence, and strengthens newer theories about Lake District landscape.

As to superimposition, Marr (1916) envisaged the development of radial streams on a cover rock which if Cretaceous chalk, as often supposed, would imply late Cretaceous or early Cenozoic uplifts. Divergent rivers would, Marr held, develop dendritic tributaries on the cover and eventually cut through into the underlying rocks. The pertinent questions are whether the present valley pattern does testify to such superimposition - whether it can be shown, rather than assumed, that particular valleys follow superimposed paths - and whether superimposition has a necessary place in explanation of the existing drainage pattern. The first question is difficult in the sense that the closer the pattern conforms to one expectable from superimposition, the stronger the proposition can be supported, yet still not conclusively demonstrated. On the other hand, the less it conforms the more it supports the modifications of pattern after rivers met underlying rocks and structures. In principle, the question should be separated from those of radial pattern and doming. To some extent the superimposition proposition is not an empirical matter, being

unamenable to rigorous testing for lack of data from older landscapes. Even so, some relevant observations can be made from evidence of present catchment and valley patterns and their relationships with other features. Among their characteristics is a pervasive asymmetry of valley systems within individual catchments. High length to width ratios of specific river basins, rectilinear parallelism of trunk valleys and catchment boundaries, and simple valley patterns in individual catchments are common. A marked tendency is also quite usual for just one or two directional trends of valley axes to prevail in particular catchments, rather than for directions of valley reaches to be distributed more evenly among several directions as in well-developed dendritic patterns. Such characteristics are closely associated with other linear relief features and it will be suggested that together they developed after Cenozoic re-exposure of the Lower Palaeozoic rocks.

There is also less than the supposed simplicity of valley pattern in the eastern handle of the 'caddy spoon'. The curious sinuous parallelism of Mosedale-Swindale and Mardale-Haweswater is a small example but generally there is not the back-to-back arrangement of valleys as described by Marr (1916) and expectable from a quite straight watershed, but rather a hemircular radial divergence from a hub near High Street.

It has not been possible to identify surely within the present valley pattern any evidence of elements derived from superimposition from cover rocks. To that extent the superimposition proposition is not essential to an explanation of the present landscape.

ii The effects of erosion by ice

Locations of crestlines tend to be among the most stable landscape features and it is thus instructive to compare the location of highest ground within the course of the main watershed. The Skiddaw and Grassmoor areas are obviously disassociated from its course. West from Crinkle Crag and Bow Fell it links those peaks satellite to Scafell and Scafell Pike along the crest of an asymmetrical ridge. Further to the east it descends to low passes at Dunmail Raise and Kirkstone. It skirts the southern flank of the Helvellyn ridge and sustains, with minimal diversion, an easterly course crossing ridges in the east like some lumpy backbone sending off prominent, sharp, long ribs. Linton regarded it as an early feature and one that had persisted despite the development of radial drainage. Whether it existed prior to the current stage of landscape development is a matter of conjecture but throughout its length there is a lack of evidence of stream piracy and significant lateral shifts.

Although the valley pattern is less radial than generally supposed, the possibility that it became more radial during the ice-age must be examined. The heads of the major ice-discharge

troughs in the Lake District lie close to the east-west watershed but are located along more than half its length, rather than confined to a small central area of ice dispersal. It is not evident that any widespread disruption of drainage by ice erosion took place. The diversion of the Aira Beck from Matterdale to Ullswater is on a col scoured by ice escaping from the south into Matterdale. Not only does the water now go the opposite way to eroded ice, but actual diversion may have been effected by meltwater erosion during deglaciation rather than by ice erosion. The Swinside (Derwentwater) col, a site of ice diffluence, has not become one of permanent diversion. Isolation of such hill areas as Setmurthy Common and Mosser Fell, though probably emphasised by ice action, may have been facilitated by structure, and in neither case is permanent diversion of drainage by ice demonstrated. Small examples of possible loss of headwaters by Miterdale and Mosedale to Eskdale might be, but are not certainly, due to ice erosion. Ennerdale, Great Langdale, and the Buttermere valleys, least divergent in direction from the east-west watershed among those which head near it, show no convincing signs of having their courses determined by ice erosion. Thus diversion of major drainage lines by cross-cutting glacial troughs has not been established for the Lake District. Nor, too, can it be demonstrated that the isolation of the Skiddaw block was accomplished by ice erosion.

It is also notable that Linton did not put forward specific examples of modification to support the general assertion. Furthermore, the present distribution of greatest precipitation, the locations of glaciers in the short but severe Loch Lomond Stadial, and the distribution of landforms due to intense erosion by ice combine to suggest that a Lake District ice dome would be markedly elliptical with two unequal culminations and extend about 30km from east to west. That would not be conducive to development of strongly-centred ice discharge with power to refashion the valley pattern. The conclusion is that the main valleys and principal watershed pre-date the Pleistocene glaciations.

iii Lineaments in Lake District landscapes

The presence of prominent fault or crush zones traversing the upland is well-known. The Threlkeld-Grasmere line is the example perhaps most often cited of a linear relief feature following a line of weakened rock. The number of such lineaments and the manner in which they divide the area into blocks of terrain have so far received little attention. Not all Lake District lineaments follow the traces of known faults though many share directional trend with mapped faults and major joints. Courses of selected lineaments are shown in Figure 2 and it can be seen that there are four main trends, one a little east of, another somewhat west of north, the others grouped close to north-east and east-north-east.

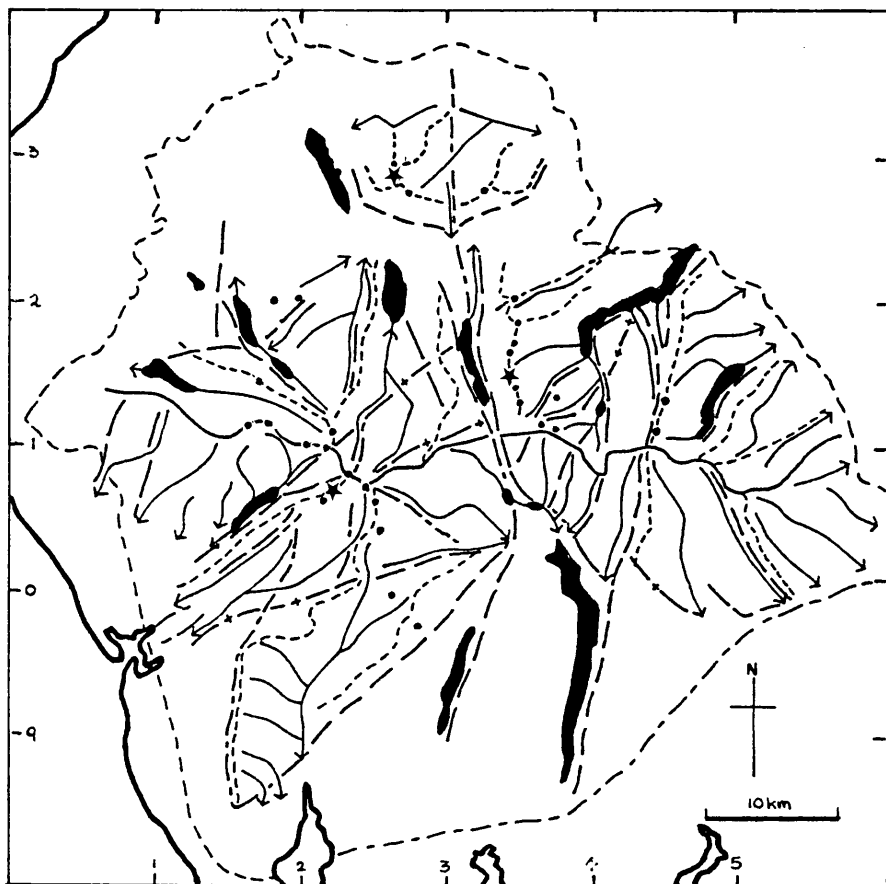


Fig.2 SKETCH MAP SHOWING LOCATIONS OF PRINCIPAL VALLEY AXES, WATERSHEDS AND LINEAMENTS.

- | | | | |
|---|---------------------|---|--|
|  | Coasts, lakes |  | Selected lineament |
|  | Valley axes |  | Indistinct or discontinuous lineament (selected) |
|  | Selected watersheds |  | Inner limit of Upper Palaeozoic rocks |
|  | Summits over 800m |  | Northern limit of Carboniferous outliers |
|  | Principal summits | | |
|  | East-west watershed | | |

Each group includes distinct and subtle long and short members (Sabins, 1978). Clarity and consistency in long lineaments vary between the sharp definition of the Threlkeld - Grasmere line and that linking Eskdale (west) and Wet Sleddale (east) where central reaches are less clear than outer. Short lineaments are common, that at Floutern Tarn is a good example.

Most lineaments take the form of valley sides or scarp slopes relatively undegraded at least for much of their lengths, or of notches, gullies and depressions on ridges as at Windy Gap near Great Gable and from Sprinkling Tarn to Rossett Gill, so suggesting localised greater erodability of rock.

Summit altitudes vary systematically across several lineaments. Hill tops from Haycock to Great Gable are higher by an average of about 120m than those immediately to the north across Ennerdale. Across the Threlkeld-Grasmere line the mean difference is about twice as great. At Floutern Tarn it averages about 100m. Height changes along the Black Combe-Coniston line are especially marked: this line presents particularly interesting problems of age and origin.

Linear relief breaks involving regular altitude differences between the opposed sides are not convincingly explained by normal progress of erosion, nor in the Lake District are there changes of surface rock type across many lineaments which could explain the variations in height. The Black Combe-Coniston line is followed by a geological boundary but not explained by it.

On many of the terrain blocks delimited by lineaments one or more of the following relationships can be observed:

NOTE:

Lineaments have been defined as 'mappable simple or composite linear' features with aligned reaches forming distinct surface patterns: a lineament 'presumably....reflects a subsurface phenomenon' (Sabins, 1978). The surface expression of a lineament is most frequently an escarpment, straight valley, depression or shoreline. Some lineaments are expressed as tonal changes which can be clear in satellite images but difficult to locate on the ground. Such linear tonal boundaries may reflect variation in vegetation type or vigour, rock or soil type, or soil moisture content.

Lineaments have long been known from surface studies and air photographs, but their widespread occurrence has been revealed by satellite observation. Both Sabins (1978) and Rowan (1975) showed that many lineament systems proved on field investigation to be the expression of faults or major fractures, of their newly-found continuations, or of previously unknown fault systems.

main and/or subsidiary watershed parallel with or close to lineament,

asymmetric pattern of valleys, one or more major internal stream(s) parallel with lineament,

streams joining at similar angles to lineament junctions,

trunk streams close to block boundaries.

These are characteristics of the sorts which were noted above as contributing to indicate that valley patterns were unlikely to be superimposed. In association they are diagnostic of fault-block landscapes (Cotton, 1948, Ollier, 1981) and structural control of landform patterns.

iv Cenozoic environments and processes

Cretaceous chalk continued to accumulate, as in Denmark, after deposition ceased over the British Isles, presumably due to uplift. The raised surface of chalk has been regarded as the initial land surface on which a new landscape became etched. The primary form of that surface has been of interest on both local scales (cp Marr, 1916) and regional (Linton, 1951, Sissons, 1960, Walsh, 1966 and George, 1967). In the west of the British Isles only Northern Ireland retains sufficient chalk to give general evidence of the nature of its bed (George, 1967). Most of the present irregularity of the sub-chalk surface there is demonstrably Eocene and later. The Cretaceous sea bed had very little relief and was cut indifferently across rocks of Dalradian to Liassic ages and across Highland and Southern Upland Boundary Faults. The significance for the Lake District is that adjacent tectonic relief has been suppressed and young Mesozoic sedimentary rocks subjected to erosion. Lias survived in Northern Ireland, as in the Solway Basin, but its pre-Cretaceous removal in parts of north Ulster indicates some phase of late-Mesozoic uplift.

Given the proximity of Northern Ireland, the thickness of chalk in western Britain, and the shared tectonic setting, it is probable that the Lake District accumulated at most a thin cover of Cretaceous rock. Evidence for Northern Ireland is again relevant: by the time the early Cenozoic basalts were erupted, erosion had removed some of the chalk cover particularly in the vicinity of the boundary faults, indicating both tectonic control of early uplift and effective early erosion. Present relief on early Cenozoic intrusions also suggests rapid Palaeogene erosion with some 800 - 1500m of rock being removed just to expose the plutons.

Further inroads into the plutons testify to continued effective combination of uplift, high precipitation, and steep slopes. The rapid denudation of young plutons stands in contrast with the lower degree of contemporary attack on Caledonian granites. Some of these were uncovered and re-covered in Upper Palaeozoic times yet are not re-exposed, while others retain portions of their roof

rocks. Only in the west of the Lake District has there been significant Cenozoic erosion on outcrops of the local Caledonian granites, but even if early Cenozoic erosion was less severe in the Lake District than over Skye, Mull, Arran, Lundy and parts of Ulster, it could not have been long before erosion bit again into Palaeozoic rocks.

Tectonism in Oligocene and later Cenozoic times increased relief contrasts in the British Isles as well as involving lateral shear movements. Separation of basins and blocks is exemplified from north-west Wales where the sub-Oligocene surface offshore is hundreds of metres below its potential continuation over the mountains. In the north of Ireland tectonic vertical deformation during and after Oligocene sedimentation was of the order of 1500m. The Ulster basalts are significant in that their pattern of valleys and escarpments is related strongly to the dominant trends of faults which also displace Oligocene sediments. Unless it can be shown that scarps (including valley sides) in the basalts are true fault scarps rather than being eroded along fault lines, it must be presumed that the present landscapes there are younger than episodes of significant mid-Cenozoic fault displacement. The general context extends to the Lake District where, however, the absence of basalts and young sedimentary rocks makes interpretation of relief more problematic.

The question of the extent to which scarps along fault lines in Cumbria are, to whatever degree, directly due to displacement rather than erosion remains open. The Pennine scarp dividing the Vale of Eden from the Alston Block is regarded as a true, if somewhat degraded, fault scarp of Cenozoic age. Two implications follow; that the origins of similar relief features in the Lake District should be sought and that the distribution and the top and base altitudes of any scarps identified as true fault scarps would be evidence on the extent, intensity and persistence of tectonism.

v Tectonism and erosional landforms in the Lake District

The pattern of lineaments in the Lake District is not unlike that of faults, scarps and valleys in the north-west of Northern Ireland. In earlier sections of this discussion it was concluded that the relief pattern in the Lake District is to a substantial extent structurally controlled. The form of the Pennine fault scarp suggests that it has not endured erosion throughout the Cenozoic which in turn suggests a contribution from mid-Cenozoic movement. Landforms on the Alston Block lead to the same conclusion. A corresponding history in the Lake District would include tectonic disruption of an early Cenozoic landscape. Surfaces projected tangentially to high points on the main terrain blocks have simple form. If those projections approximate at all to the early Cenozoic landscape they indicate that it was not one of strong relief at the time of the mid-Cenozoic disruption. The actual landscapes on the blocks are more complex. In places there

may be little modified exhumed sub-Carboniferous to Triassic facets. Some present ridges and hills might be little below projected positions of Palaeogene landscapes. Much is due to Neogene and younger erosion cutting deeper into the blocks.

Crests of the higher blocks are broken by relatively shallow cols which might be thought to mark possible valley courses on an older undisturbed landscape, but many present valleys head in the flanks of hills rather than below these cols, and traces of once more extensive Palaeogene valleys broken by block faulting have not been identified. The high block rims do however contain evidence of complex development. A compact example comes from the Ennerdale area. The Great Borne - Starling Dodd part of the northern ridge (c.600m OD) is separated by a major step from the Red Pike - High Crag part (c.740 - 800m OD). Does that step and a similar one west of Haycock mark an inner limit to erosional encroachment in the present phase of landscape development, a division between more and less raised parts of a block, or pertain to the Palaeogene landscape?

Within several blocks the orderly arrangement of summit heights may be explained by the occurrence in individual blocks of an axis of uplift trending at high angle to a raised block rim. Main and satellite summits have developed in the rims of tilted arched blocks. The Scafell and Helvellyn blocks are good examples. If the highest block rims are the denuded upper edges of elevated warped surfaces that previously had smaller relief amplitude than is presently the case, then hills such as Great Dodd, north of Helvellyn, or Bowfell, east of Scafell Pike, will not have suffered more denudation than the highest place on the rim, nor will they have been initiated in a later episode of denudation.

Long lineaments present the problem of whether the relief features along their lengths developed at more or less the same time or whether some lineament reaches were lifted and exposed to erosion later than other parts. The base of the Black Combe - Conistoun linear scarp rises in altitude by about 350m and the crest height by a somewhat smaller amount from south-west to north-east. Is this a scarp that was tilted during or after formation, or one that has extended south-westward as base levels lowered and denudation progressed, the east flank of Black Combe being younger than the mountain sides west of Conistoun?

Several authors (Hollingworth, 1937, McConnell, 1939, 1940, Parry, 1960) identified fairly horizontal benches cut across rock structures in the Lake District, grouped the eroded flats and hill-tops into various height intervals, and ascribed them to erosion controlled by a sequence of distinct base levels. Partly owing to difficulty in achieving replicable objective identification of such erosion facets, and partly because of problems in dating and explaining flights of hillside benches, there has been a general decline in interest in that class of feature. Nevertheless, it is

of considerable potential utility in the study of relief development in the Lake District.

Parry (1960) described a sequence of ten benches within the height range 460 - 290m OD in the south and south-west of the Lake District, suggesting that lower members of the suite were made by marine erosion and that the upper were eroded subaerially. The study area, from St. Bees Head to the Kent valley, extended over several lineaments and blocks. If there has been general crustal movement or independent movement of blocks since any members of a bench sequence were eroded, then, unless all movement has been equally vertical, height differences and departures from horizontality could have occurred. Thus satisfactory identification of benches provides a possibility for determining location, direction and degree of crustal movement. The distribution of dislocation among the members of a bench flight such as described by Parry (1960) would, in principle, allow a bench sequence to be used as a time-scale. Also, the possibility is enhanced of discrimination between fault scarps and fault-line scarps. Alternatively, it might be found that no disturbance has occurred at levels below the higher block-rim summits. The prospect of using bench fragments and hill-top heights successfully in this way is, of course, dependent upon reliable identification of relevant landforms.

Where minor glacially-eroded valleys join major, the tributary streams in many instances cascade to the main river. That is commonly regarded as a consequence of less effective valley deepening by ice erosion in the minor 'hanging' valley. Where the marked steepening of a valley long-profile occurs close to where a valley crosses a lineament another possibility arises, that a valley step initiated by tectonism at a lineament has not been eradicated by later erosion. Clearly it is not easy to discriminate among origins in particular cases. The locations of steeper reaches on the River Duddon, Church Beck (Coniston), and River Brathay close to the Black Combe - Coniston line, and of similar breaks close to the upland edge in those valleys descending towards the Rydal - Windermere lineament suggest the possibility of tectonic influence on valley development.

vi Relief and gravity anomaly patterns

Some correspondence would be expected between intensities of uplift and location of main low density plutons particularly during occasions of tensional stress such as experienced at passive continental margins during ocean floor spreading (Bott, 1974). Characteristics of the local gravity field, such as direction and intensity of variation, locations of rapid change in direction of variation, and locations of anomalies are shown in Figure 3. Comparisons may be made between them and various aspects of relief.

The case of the Lake District is particularly interesting for its low density intrusions had been involved in relief development

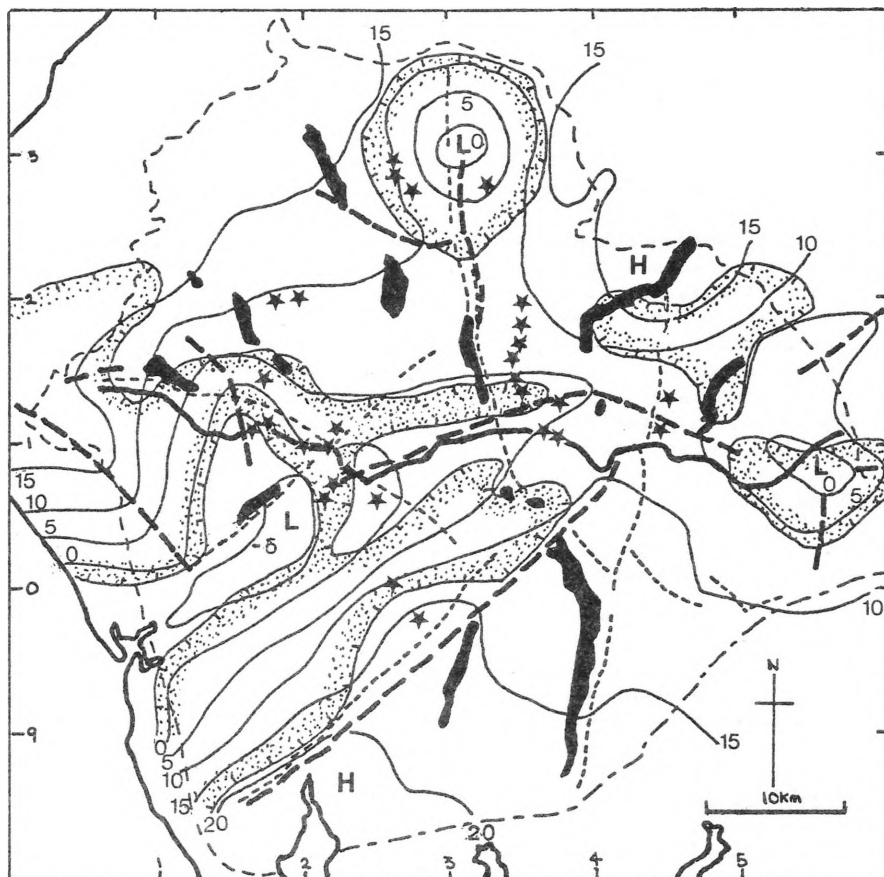
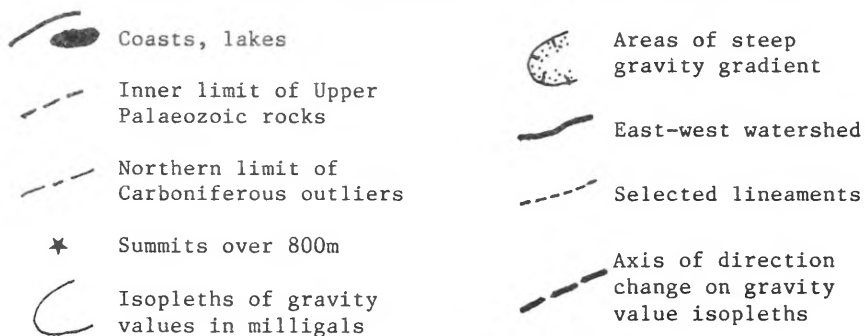


Fig.3 SKETCH MAP TO SHOW RELATIONS BETWEEN GRAVITY FIELD (ADAPTED FROM BOTT, 1974), GEOLOGICAL BOUNDARIES AND PROMINENT LINEAMENTS.



in earlier orogenic episodes. The Ennerdale, Eskdale, perhaps Threlkeld, and Shap (Kimber and Johnson, 1986) pluton culminations were exposed before the end of the Upper Palaeozoic, and may have acted at that time to locate areas of greatest uplift and erosion prior to subsidence and burial beneath Upper Palaeozoic sediments. Now none of the highest summits and only a handful of the second rank summits are on intrusive rock. Of the highest hills, the Scafell group is in an area of considerable negative gravity anomaly (Bott, 1974) and Skiddaw is near a very well-defined negative anomaly, Helvellyn and High Street are on a 'saddle' between high and low values. The main areas of negative anomaly are outside the central part of the Lake District where the Threlkeld microgranites are the only plutonic rocks to be exposed.

Any unity the pluton may once have had was lost in such a way that at latest by mid-Cenozoic times sections appear to have functioned as basements of discrete terrain blocks. Some blocks were lifted with pronounced outward downtilt, inner rims and in-facing scarps. East of the Threlkeld - Grasmere line the principal direction of downtilt is to the east, in the Skiddaw block to the north, and in the south-west blocks to west and south-west. The country between Scafell Pike, Skiddaw and Helvellyn is crossed by several straight and curved lineaments. Despite the consequent terrain complexity there are indications of block asymmetry with some scarps facing into the arc south to west.

The pattern of granite outcrops, negative gravity anomalies, principal summits and terrain blocks gives the impression that the outer parts of the western and Shap granites have sagged towards the bounding troughs while the inner parts of associated blocks were raised. How it is that the Skiddaw Granite remains so little exposed and the Helvellyn ridge has been so much raised, though distant from exposed granites and not in an area of strong negative anomaly, are among questions prompted by the pattern.

The valleys which with Ennerdale contribute most to the impression of radial drainage parallel known faults. The upper Cocker (Buttermere) valley follows the northern flank of the Ennerdale Granophyre where sharp lateral gravity variation may have induced movement. North of Buttermere the valley follows linear faults and lineaments. The head of Great Langdale adjoins the zone of cols and depressions which continues from the head of Ennerdale by Windy Gap to Rossett Gill. Though in its lower reaches Great Langdale departs from the high block edge of Bow Fell it follows a fault trend matching that of the Ennerdale line.

vii The significance of summit altitudes

Marr (1916) suggests that Skiddaw, built of weaker rocks than are the Scafell Pike and Helvellyn areas, will duly be eroded to a much lower level so losing its place in the hierarchy of summits. In doing so Marr tacitly implied that Skiddaw had once been higher

than now and higher than the other summits and hence that the present correspondence of heights is entirely ephemeral. That the summits should have come to match so closely just in time for contemporary observation is a large and curious coincidence made larger by a similar argument (Sissons, 1967) being used to account for the present close match of highest summit altitudes along the Southern Uplands of Scotland. It is no less likely that correspondence of heights will long remain and has so remained over a long period of time for it is consequent not on rock types and erosion alone but reflects their interplay with mass, temperature and stress attributes of the local crust. Consequently the similarity of heights may be determined by uplift as much as by erosion.

CONCLUSION

Several fundamental landform characteristics of the Lake District are not explained in the orthodox account of landscape development. That account owed much to rather uncritical acceptance that the valley pattern was highly radial and discordant upon structures in the Lower Palaeozoic rocks. The scale and persistence of tectonic activity after the late Cretaceous uplift was less well-known when the orthodox account was constructed, though it was clearly sufficient to disrupt landscapes formed in early Cenozoic times. Also, the concealed form of the local intrusions had not been interpreted in detail. There is now more understanding of how their complexity would influence both Cenozoic crustal strain and large-scale landforms. The classic tripartite account relied as well on appeal to superimposition which is not necessary to understanding of local landscape and for which the present valleys provide no obvious support.

The required alternative synthesis must at present contain provisional elements for it has to accommodate major features recently appreciated and only partly understood. Its initial departure from the orthodox explanation is in stressing probability of relative thinness or absence of Upper Mesozoic sedimentary cover and unevenness of initial uplift. It includes the proposition that landscapes formed in the Palaeogene would be disrupted by late Oligocene and Miocene earth movements. It could accept evidence that tectonic movement continued into Pliocene or even Pleistocene time. The present major relief features are regarded as dominantly a product of post-Oligocene block movement and denudation affecting surfaces established in a Palaeogene phase of landscape development.

Although some of the stripping of sedimentary cover is of relatively recent occurrence at the hill margins, the likelihood that the cover was thin over the central area implies that the core of older rocks would be re-exposed early in the Cenozoic. Thus structures in the older rocks, inherited and new, would have early influence on the progress of erosion. The pattern of Upper Cretaceous - Eocene uplift is not surely known and correspondence

between Palaeogene and Neogene landscape patterns cannot be assessed at present.

The framework outlined is compatible with recent interpretation of Northern Ireland's landscapes (George, 1967) and appears able to accommodate pervasive features not taken into account in the orthodox tripartite explanation. There is abundant room for a more detailed developmental history and there are prospects that landscape problems of the types touched upon in the present discussion can be investigated within the limits of that framework. Of major value would be an assessment of precise locations of lineaments as rock partitions rather than as landscape areas and of the nature of rock movements along their courses.

The interpretations of Lake District scenery advanced in the discussion may stimulate more examination and enquiry. The authority of the established account seems to have protected it from scrutiny for rather a long time.

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THE SOLWAY BASIN: ITS EVOLUTION AND ENERGY POTENTIAL

E. Skipsey

SUMMARY

The Solway Firth, situated between the Lake District and the Southern Uplands, lies in a deep sedimentary basin which forms the western component of a Caledonide structure extending east-west along the Anglo-Scottish border. During the Carboniferous several kilometres of shallow water sediments accumulated in this subsiding basin. Deposition of terrestrial sediments during the Permo-Triassic may be related to the neighbouring N-S aligned basins of Dumfries, Lochmaben and Eden rather than reflecting continuing downwarping of the Solway Basin. The basin may have significant hydrocarbon potential. A major coalfield has been proved in the Canonbie-Longtown district but complicated faulting reduces its attractiveness. Gas and oil prospects are more speculative with potential source rocks identified. However, the presence of good traps in suitable reservoirs remains to be tested. Both geothermal and tidal prospects have been studied but neither have justified detailed evaluation.

INTRODUCTION

The area of the Solway Firth and Carlisle Plain has been something of a geological backwater until recent interest in the possibilities of on-shore hydrocarbon exploration caused oil companies to evaluate the basin. The past lack of interest has been due to a variety of reasons including limited outcrop evidence, resulting from the widespread cover of superficial deposits, and the division of the Geological Survey's activities until recent years into English and Scottish regions with all mapping and maps ending at the Anglo-Scottish Border.

The first major studies date back over 100 years to the publications of Binney (1855), Harkness (1862) and Murchison and Harkness (1864). These authors describe both the Permo-Triassic rocks of N. Cumberland and Dumfriesshire and possible extensions of the W. Cumberland and Canonbie coalfields under the Carlisle plain. Extensive geological reviews were contained in two Geological Survey publications, namely the Carlisle, Longtown and Silloth memoir (Dixon et al., 1927) and the Economic Geology of the Canonbie Coalfield, Wartime Pamphlet No.42 (Barratt & Richie, 1945).

More recent published work includes studies on Dumfriesshire by Nairn (1956) and by Deegan (1973) and the B.G.S. report 'The Carlisle basin and adjacent areas - investigations of the geothermal potential of the U.K.' by Gale, Carruthers & Evans, 1984. Considerable unpublished seismic work has been and continues to be undertaken by several petroleum companies.

GEOLOGICAL HISTORY OF THE SOLWAY BASIN

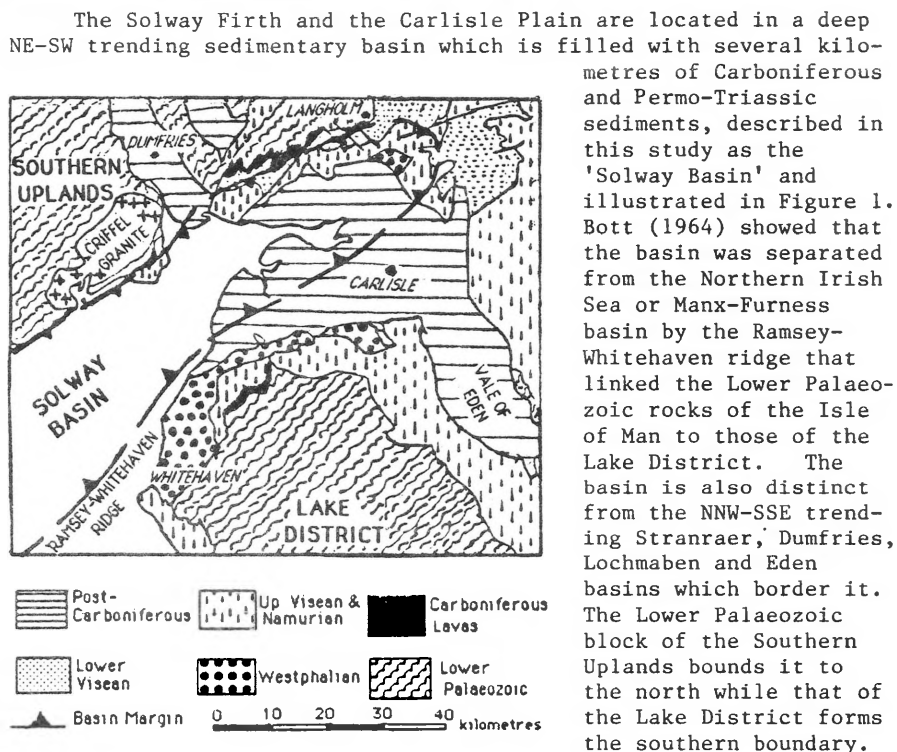


Fig.1 OUTLINE GEOLOGICAL MAP OF THE SOLWAY BASIN.

The Solway Basin is the western component of

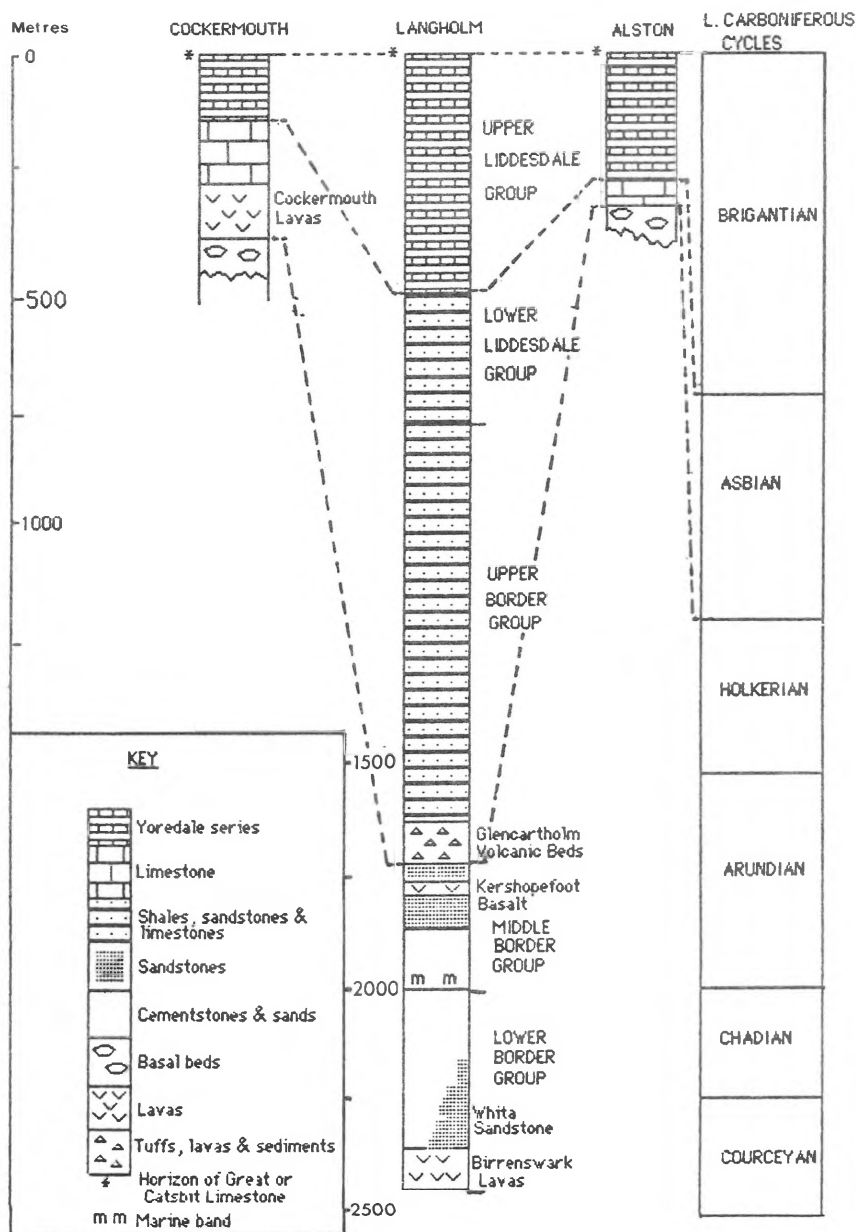


Fig. 2 COMPARATIVE SECTIONS OF LOWER CARBONIFEROUS STRATA IN THE SOLWAY BASIN.

a larger structure of Caledonide NE-SW trend known as the North-umberland Trough and is separated from the Tweed and Northumberland basins in the east by faulted basement blocks beneath the Carboniferous cover which extend the line of the Pennines northward (Johnson, 1984). The granitic intrusions of the Southern Uplands on the northern flanks and those of the Isle of Man, the Lake District and the North Pennines in the south were the results of deep-seated crustal instability linked with a late Caledonian magmatic phase. The intermittent history of volcanic activity in the region was the surface expression of this magmatic phase, extending from the Devonian Cheviot lavas in the east to the Lower Carboniferous lavas of Langholm and Cockermouth further west and possibly also the Scarlett volcanic centre in the Isle of Man. The Solway basin was initiated in the early Dinantian, possibly resulting from isostatic readjustment of the Caledonian plutons to north and south (Leeder, 1982).

LOWER CARBONIFEROUS

Although the centre of the basin is concealed, outcrop evidence marginal to the basin suggests that a full sequence of Carboniferous sediments is present amounting to several kilometres in thickness. Fluvial sedimentation in the Scottish Borders commenced in late Devonian times (Leeder, 1971) but was terminated by the eruption of basalt lavas which marked the beginning of the Carboniferous; the remnants of these lavas can now be seen in the outcrops of the Birrenswark lavas (Leeder, 1974). There was a radical change in the palaeogeography with the initiation of the basin subsequent to these eruptions. The earliest formation of the Carboniferous, the Lower Border Group comprising a sequence some 2km thick of grey shales with thin, impure limestones, often algal, and with bands of sandstone, was deposited in coastal and lagoonal environments. A number of local deltas receiving sediments from the Southern Uplands periodically advanced into the lagoonal deposits of the basin from its northern margins; there are no visible signs of fluvial input from the southern margins (ibid).

However, the massive sandstones of the Middle Border Group represent a change of sediment source with the advance over the basin of a major delta complex bringing sediments derived from a land mass to the north and east. Thereafter marine influences increasingly resulted in the alternation of shallow water limestones, sandstones and shales which characterise so much of the Lower Carboniferous sequences of the Solway basin (Lumsden, 1967).

Differential subsidence is indicated by the contrast between the extended sequence of Dinantian sediments present within the basin and the thin Upper Dinantian sequences found on the shelf areas of the Southern Uplands at Sanquhar and Thornhill and on the northern flanks of the Lake District in the Caldbeck - Cockermouth district, illustrated in Figure 2. There is evidence of

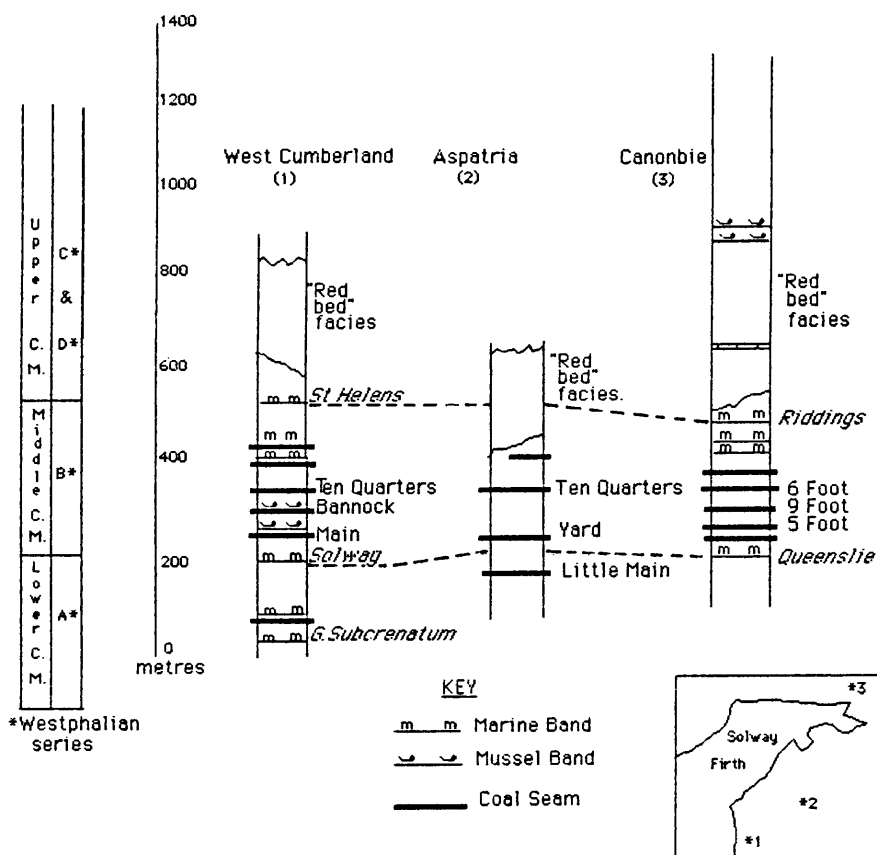


Fig.3 COMPARATIVE VERTICAL SECTIONS OF COAL MEASURES IN THE SOLWAY BASIN.

syn-sedimentary or growth faults along the northern margins of the basin, with the North Solway fault exposed on the coast near Dalbeattie providing a good example (Deegan, 1970). Well exposed coastal sections here show the fault actively controlling the sediment supply and deposition of fanglomerates, with a rapid transition from scree breccia along the fault line to reworked fan breccias and sandstones a short distance away.

UPPER CARBONIFEROUS

By Silesian times differential subsidence had largely ceased although it persisted longer on the northern flanks, as illustrated by the significant unconformity between the Upper Namurian and Westphalian A at Canonbie and the abbreviated Westphalian B

sequence at Sanquhar. Widespread delta-top swamps eventually covered the whole region, resulting in the thick peat deposits which have yielded our northern coalfields. Deposition continued around the Solway basin into Westphalian D, much later than in the coalfields of N.E.England, and cumulating in a thick 'red bed' sequence, illustrated in Figure 3. However, a significant difference can be recognised in this phase across the basin with an erosional episode affecting the southern flanks alone, resulting in widespread reddening of the exposed Dinantian, Namurian and Westphalian strata (Eastwood et al., 1968). This reddening of older exposed strata is distinct from the deposition of the highest Westphalian D 'red bed' strata which particularly characterises the Canonbie sequence. The 'red beds' consist of reddened sandstones and shales with occasional fresh-water limestones containing the fossil Spirorbis, suggesting deposition in shallow lakes within an emergent land area and indicative of the onset of rather arid conditions. The most likely cause of this Westphalian emergence has been described by Johnson (1982) as resulting from a eustatic lowering of sea-levels.

The Variscan Orogeny marks a geological watershed, resulting in the folding of the Carboniferous strata of Northern Britain into broad synclinal basins with erosion stripping away Upper Carboniferous rocks on the intervening anticlinal regions. The prolonged period of denudation resulted in an angular unconformity between the Carboniferous and the overlying Lower Permian beds; the deposits of the Solway basin were preserved in one of these synclinal regions.

PERMO-TRIAS

The Permo-Triassic sequence of the basin is only exposed in marginal outcrops but has been proved in the Silloth No.1 well, 25km west of Carlisle, which reached a depth of 1342 metres and terminated in what was believed to be Lower Carboniferous rocks. A summary geological log is given in Figure 4 and the significance of the findings is considered in Gale, Carruthers & Evans (1984).

The north-south compression of the Variscan Orogeny was followed by an east-west tensional phase which led to the formation of the major oil-bearing grabens of the North Sea (Glennie, 1984). Strike-slip fault movements associated with this tensional phase also resulted in the development of a number of smaller north-south trending half-graben basins with faulted eastern boundaries in western Britain. These include the Clyde, Stranraer, Dumfries, Lochmaben, Eden, Irish Sea and Cheshire basins. While deposition in the Solway basin continued throughout this period until at least the Lower Lias, this may not have been an expression of further regional downwarping but rather of subsidence along the lines of the north-south aligned basins of Eden, Lochmaben and Dumfries.

The Permo-Triassic rocks of the Solway area are largely

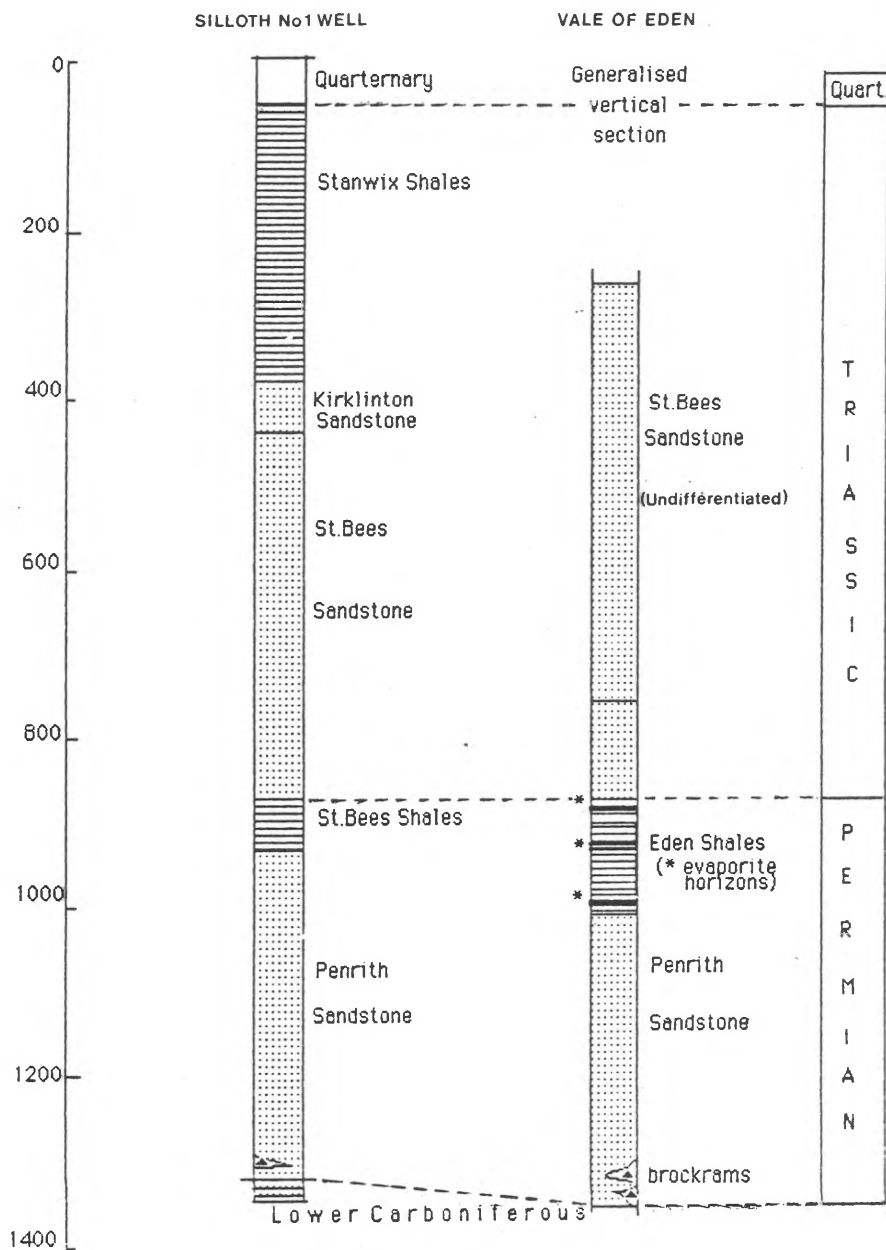


Fig. 4 VERTICAL SECTIONS OF PERMO-TRIASSIC STRATA

continental in origin and are characterised by their strong red coloration, indicative of arid depositional environments. Since the earliest Permian sediments contain no fossils their precise age cannot be ascertained and since the boundaries between the different formations are diachronous, it is more satisfactory to recognise three lithostratigraphic units. The oldest unit is represented by the Penrith Sandstone and the north-south trending basins around the Solway area all contain very thick sequences of aeolian sandstones and outwash fan deposits that are characteristic of this unit. In contrast these desert deposits appear to be absent around the margins of the Solway basin where the younger St. Bees Shale or St. Bees Sandstone units (Arthurton et al., 1978), which are fluvial deposits, lie unconformably on Carboniferous rocks. However, the Silloth No.1 well (Figure 4) proved the presence of over 300 metres of aeolian sands beneath the St. Bees Shales while a further exposure of aeolian sandstone can be seen in the River Esk below Canonbie. These provings suggest that sequences of the lowest aeolian unit may have been preserved in extensions of the north-south basins concealed beneath the younger and more extensive Triassic fluvial sediments. A further intriguing question, as yet unproved, concerns the possibilities of significant thicknesses of evaporites being present in the Solway basin. Thick deposits of gypsum/anhydrite have long been known and exploited in the shales of the Eden basin and in West Cumbria (ibid). The presence of similar deposits in the Solway basin could have significant hydrocarbon implications.

ENERGY IMPLICATIONS OF THE SOLWAY BASIN: 1. COAL

The important coalfield of West Cumberland has long been exploited and the extension of this coalfield along the north-west flanks of the Lake District between Maryport and Bolton, near Wigton, is fairly well known (Eastwood, 1930). Although underground mining in this district ceased many years ago, records show that seams tend to thin and deteriorate northwards and are buried beneath increasing thicknesses of Permo-Triassic beds. Consequently there has been little interest in underground mining prospects in this district.

The area in the north-east near Canonbie offers a much more attractive prospect, for here coal mining commenced in the eighteenth century and continued until the closure of the Rowanburn mine in 1922 (Barratt and Richie, 1945). The Productive Series of the Westphalian extend from the small exposed coalfield southwards beneath the younger cover. Spasmodic exploration has occurred over the past thirty years and has established the presence of an important coalfield with a large tonnage of workable reserves lying in a synclinal area between Canonbie and Longtown. Recent boreholes have proved seams of 2 and 3 metres thick lying at depths of 300 to 400 metres. However, the complicated pattern of faulting proved in

this coalfield make it uneconomical to extract the fragmented reserves and no mining is envisaged in the foreseeable future.

2. OIL AND GAS

Hydrocarbons offer much more speculative prospects and since oil companies release little information, deductions have to be based upon basic information and principles. Five conditions need to be fulfilled in the search for suitable structures which might yield hydrocarbons, namely:

- (a) source rocks from which the hydrocarbons may have been evolved,
- (b) permeable reservoir rocks in which they may be contained,
- (c) structures containing suitable traps to retain the hydrocarbons,
- (d) the reservoir must be sealed by impervious beds,
- (e) the source rocks needs to have been matured by heat and pressure to release the organic fluids or 'kerogen'.

A review of the geology of the Solway basin will at least enable the reader to assess the possibilities of hydrocarbon resources.

The Solway basin contains two possible series of source rocks: the coal seams of the Coal Measures, which would generate principally natural gas, and the marine facies of the Lower Carboniferous, which might yield both gas and oil. The Permo-Triassic sandstones extending south from the Dumfries basin could provide suitably permeable reservoir rocks, provided that adequately sealed trap structures are present. Here any seal provided by the St. Bees Shale above the Penrith Sandstone is crucial, especially if evaporites are present. So far as Lower Carboniferous sources are concerned, the thick sandstones of the Middle Border Group and the local delta fans in the Lower Border Group may provide reservoirs but they are very deep and, as yet, nothing is known of their permeability.

Estimates of the degree of maturation of the possible source rocks can be deduced by comparison with the nearby Morecambe Bay gas field (Bushell, 1986), which suggests that depths of 3000 to 4000 metres are necessary to achieve adequate maturation. The Silloth well and seismic information indicate the presence of some 1300 metres of Permo-Triassic strata; this cover could have conceivably been greater before the Tertiary erosion of possible Jurassic and Cretaceous cover now removed. Hence Lower Coal Measures may have been buried to 2-3000 metres in the past, adequate for natural gas generation. The Lower Carboniferous source rocks would occur beneath a further pile of some 3000 metres of strata and so would be at adequate depth for maturation. The validity of these estimates is confirmed by the extensive

exploration being pursued in the basin by several oil companies at the present time.

3. OTHER ENERGY SOURCES

In a review of the geothermal resources of the basin the Silloth No.1 well was evaluated. Gale, Carruthers and Evans (1984) concluded that although the Penrith Sandstone had the greatest geothermal potential, it did not form a large geothermal resource when compared with other Permo-Triassic aquifers in the U.K. and that it could only be utilised if used in conjunction with heat pumps.

Periodic interest has been shown in the Solway Firth as a site for a tidal barrage scheme to produce electricity. The potential of the area was evaluated by Wilson, 1965, who proposed a barrage between Southernness and Dubmill Point in Cumbria, and by Kay, 1969, No recent work has been undertaken although the Solway barrage scheme is often quoted alongside other proposed schemes.

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EXCURSION NOTES

THE SKIDDAW GROUP NEAR LOWESWATER

Leader: Dr.P.M.Allen

9th June, 1985

The party met at the car park near the head of Loweswater (NY 121 223).

Locality 1. Darling Fell (NY 125 224)

Here Dr.Allen outlined the structural history of the Skiddaw Group. Four fold-phases have been recognised: (a) first folds - recumbent with no cleavage; (b) second folds which are open cleavage folds representative of the main Caledonian event; (c) third folds which are sideways-closing, open folds, with a cleavage and (d) fourth folds which are minor structures in kink bands.

The regional trend of the second folds and the associated cleavage is NE to ENE, but at this locality in thin bedded grey-wacke and mudstone of the Loweswater Flags a first fold was seen to be re-folded by NW-trending second folds. This orientation for second folds prevails in this area. The reason is not fully understood, but it can be explained using the transpression model for closing of Iapetus; i.e. closure of the ocean in one simple compression combined with sinistral shear.

Locality 2. South flanks of Low Fell (NY 136 221)

An excellent series of exposures in the hillside of a series of recumbent first folds stacked on top of each other in Loweswater Flags. The folds are overturned to the east. They are part of a major first fold anticline which can be traced from here for several kilometres northwards to Harrot. The direction of closure is opposite to that of the major first fold on Robinson. This was the most important clue to suggest that these folds were slumps and not of tectonic origin.

Locality 3. Old Quarry on Darling Fell (NY 127 222)

Several exposures of Loweswater Flags were examined in and near the quarry, showing structures relating to the first fold deformation including variably plunging minor folds and eastward-directed thrusts. The evidence for the direction of movement on the thrusts is present in overturned beds just above the road.

The party then drove to Lanthwaite Green car park (NY 158 207) and had lunch.

Locality 4. Liza Beck (NY 164 211)

From here onwards the excursion was to look at the Crummock Water hydrothermal alteration zone. This zone is 25km long, 3km wide and extends from near Outerside towards Egremont. It is interpreted as resulting from the hydrothermal alteration of the Skiddaw Group by fluids derived from a buried granite.

Exposures of Kirk Stile Formation mudstone on the hillside above the beck at the edge of the alteration zone are medium to dark grey. Downhill they gradually become paler grey; such bleached rocks characterise this zone. Immediately above the beck in an exposure of Loweswater Flags, many minor first folds display structures indicative of a slump origin.

The party returned to the car park and drove to the Cinderdale Beck car park (NY 162 194). They walked across the fellside to Rannerdale Knott.

Locality 5. Above Cinderdale Beck (NY 165 195)

Here the Kirk Stile Formation mudstone is bleached pale grey, hard and splintery. There is a strong jointing, spaced 2 - 5cm trending roughly E-W which is presumed to represent the cleavage. The alteration is later than the cleavage. Tourmaline veins are common within the zone. This black mineral is a complex aluminium borosilicate with alkali metals, iron and magnesium. It forms in veins several metres wide, commonly brecciated and veined by quartz. Lumps of both are found in the screes.

Locality 5. Rannerdale Knott car park (NY 165 184)

This area of very complex folded rocks is near the southern margin of the alteration zone. The rocks are bleached and extensively tourmalinised. In the rocks above the small car park beds a few centimetres thick are totally replaced by tourmaline.

EXCURSION TO THE KIRKBY-IN-FURNESS AREA

Leader: Mr.D.Kelly

22nd June, 1985

Eleven members braved a wet, breezy June day and assembled in the village of Kirkby-in-Furness. The purpose of the excursion was to examine the Lower and Upper Palaeozoic rocks forming the eastern shore of the Duddon Estuary.

The party made its way to Dunnerholme Point (ED 212 797), a small, raised peninsula of Carboniferous Limestone, where the geology of the surrounding area was outlined. The upland mass of Bank House Moor and Moor Side Intake is underlain by Upper Ordovician and Silurian rocks. A major northerly trending fault, the Park Fault, at the foot of the slope, throws Carboniferous rocks down to the floor of the estuary. Apart from Dunnerholme Point there are few exposures on the flat land east of the estuary; however, boreholes indicate that much of the area is underlain by the Carboniferous Basement Beds, a series of conglomerates, sandstones, shales and thin limestones. The thickness of the Basement Beds increases from east to west across the Furness peninsula, culminating in a thickness of 240 metres in the estuary. This may indicate that the area was a pre-Carboniferous hollow and a subsiding basin in early Carboniferous times.

The morning was spent investigating the limestones which are exposed in the low cliffs and old quarries of Dunnerholme. The Red Hill Oolite (Arundian) crops out on the south west side of the peninsula and is a pale grey, poorly bedded calcarenite (not a true oolite), displaying characteristic small, irregular, curved joints. Clasts averaging up to 3mm in diameter, cross bedding and minor erosional horizons indicate a relatively active, high energy environment of deposition. In addition to large gastropods, Koninckophyllum sp. and Syringopora were identified.

The underlying Martin Limestone (Chadian) is seen on the north east side of the peninsula. Although lithology varies, it is generally a dark, very fine, hard, flinty, well-bedded rock with shale partings and represents a quieter, possibly lagoonal, environment. The top of the Martin Limestone is marked by an Algal Band about 1 metre thick, containing gastropods, solitary corals and algal nodules possible representing an inter-tidal environment. The Algal Band was best seen south west from Dunnerholme Cottage.

The party examined the NNW-SSE trending faults which differential marine erosion has picked out as upstanding ribs of fault breccia. Large dolomitised and hematized fragments up to

30cm in diameter are cemented by coarsely crystalline calcite. Other breccias, particularly at the north-west end of the peninsula, are overlain by undisturbed limestones. There was much discussion as to the origin of these breccias; it was generally agreed that they were formed by collapses into solution cavities during periods of low water table, but the date of the collapse was not clear. It may have been during the Permo-Triassic uplift or during phases of uplift within the Lower Carboniferous.

As the rain poured down, members consoled themselves with the fact that at least it wetted the limestone and highlighted some of its features, particularly a large number of burrows, seen both in horizontal and vertical sections.

The afternoon was spent following the Upper Ordovician and Lower Silurian succession in the vicinity of Mere Beck (SD 227 794). (See the following diagram).

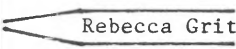
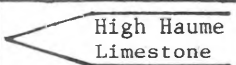
	Series	Stages	metres	Rock units (Rose and Dunham, 1977)	
SILURIAN	WENLOCK		600	Horrace Flags	
			200 - 300	Harlock Grits	
			300	Brathay Flags	
	LLANDOVERY		50	Browgill Beds	Stockdale Shales
			15	Skelgill Shales	
ORDOVICIAN	ASHGILL	Hirnantian (and part Rawtheyan)	300	 Rebecca Grit	Ashgill Shales
		Cautleyan	120 - 150	 High Haume Limestone	High Haume Mudstone

Fig. 1 SECTION OF MERE BECK AREA (Stratigraphic breaks in the Ordovician are not indicated).

The general dip of the rocks is 30° - 40° to the SE or ESE so that progressively younger beds crop out further up the slope. The Coniston Limestone Group outcrop trends NNE along the lower slopes of the valley side. The outcrop does not continue further north that Kirkby and re-appears near Millom approximately 6km to the west. Rose (in Rose & Dunham, 1977) has suggested that this displacement could be due to a major WSW-ENE tear fault, the Kirkby Tear Fault.

The High Haume Limestone was examined in Mere Beck (227 794) and near the lane to High Mere Beck (227 795). The rock is a hard, blue-grey calcite mudstone with crude cleavage. No fossils were found but specimens of Favosites and the solitary coral Streptelasma found at these localities were passed around.

The Rebecca Grit was examined on the steep slope east of High Mere Beck and in Mere Beck at 2283 7937. The coarse, porous sandstone is interbedded with mudstone and weathers to a 'gingerbread rock'. Here, the Ashgill Shales appear to be much thinner than elsewhere in Furness, possibly due to faulting. The Rebecca Grit and High Haume Limestone both show dips to the NW instead of the SE, again possibly indicating proximity to a fault. The Grit shows a cleavage and forms the scarp east of High Mere Beck.

The Ashgill Shales above the Rebecca Grit were examined in the bed of Mere Beck at 2286 7936. A search for examples of the characteristic brachiopod fauna proved unsuccessful. The rock is a cleaves, dark blue-grey shale which breaks into 'pencils'.

The Llandovery rocks of the Stockdale Shales are not exposed in Mere Beck but were investigated in Bridge House Gill (233 801). The stream section shows the upward transition from the Browgill Beds to the Brathay Flags. The former are pale green, hard, silty mudstones with a hackly fracture similar to that of a tuff.

The Brathay Flags were examined in detail in Mere Beck and in a small digging immediately north of Mere Beck at 2303 7933. The beds are dark blue-grey mudstones with paler silty laminae and weather to a greenish brown. The unit represents the first appearance of extremely distal turbidites in the area. Closer to fold axes the beds show strong cleavage but here the rock splits along bedding planes dipping SE at 30°. The Ashgillian rocks contain a neritic fauna but this is replaced by graptolites in the Silurian as subsidence deepened the trough. In the Brathay Flags many monograptids were found, one being tentatively identified as M. riccartonensis from the lowest rocks of the Wenlock. An examination was made of the section described by Rose & Dunham (1977) between 2303 7929 and 2312 7927.

To conclude the day, some pf the party visited Bush Green Quarry near Foxfield (210 866). Magnificent examples of flute casts up to 30cm in diameter were seen covering a vertical bedding plane of the Silurian Coniston Grits. The orientation of the fluting indicates a palaeo-current direction from the NW.

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EXCURSION TO HAWKSHEAD HILL AND APPLETREEWORTH

Leader: Dr.J.D.Gunner

6th July, 1985.

The excursion had two aims: to examine Silurian turbidites at Hawkshead Hill and to study Borrowdale Volcanic and overlying Ordovician and Silurian sedimentary rocks at Appletreeworth near Torver. This report should be read in conjunction with the Society's Excursion Guide (Cumberland Geological Society, 1982), Excursion 12.

14 members and friends assembled at High Cross Quarry, Hawkshead Hill (SD 327 985). The leader outlined the aims of the visit, noting that the rocks in the quarry were turbidites classified as Middle Coldwell Beds (Moseley, 1978) and emphasised the variety of sedimentary and tectonic structures present. Among those structures seen were graded bedding, sole marks, prod marks, plane- and cross- lamination, load-and-flame structures and a fault with fault breccia and associated calcite veins. Ripple-like markings on bedding surfaces caused debate, the consensus being in favour of a tectonic origin.

At Appletreeworth Plantation the group made a brief stop at the eastern corner. Here they examined Brathay Flags containing Monograptus in a small cutting beside the forest track (SD 256 931) and folding of Brathay Flags caused by soil creep in a quarry beside the track (SD 255 931).

The group lunched at Hawk Bridge (SD 239 920) and spent the afternoon in Appletreeworth Plantation visiting localities mentioned in the Excursion Guide.

ACCESS

High Cross Quarry, Hawkshead Hill is owned by Cumbria County Council and used as a depot for road making equipment. Appletreeworth Plantation is owned by the Forestry Commission and application for a permit to enter it for geological purposes should be made to their regional office, Grizedale, Satterthwaite, Ambleside, Cumbria.

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GEOLOGY OF THE WALNA SCAR AREA

Leader: Mr.D.Leviston

7th July, 1985.

This was a combined excursion with the Westmorland Geological Society, the party meeting at the Torver crossroads (285 942). The leader outlined the basic geology of the area and stated that the purpose of the excursion was to examine the boundary between the volcanic rocks and the overlying sedimentary rocks of the Ashgill Series.

The party then proceeded along the A593 turning off onto a track at 285 946 where Coniston Grits could be seen making prominent features in the nearby fields. Exposures were examined along the track leading to Tranearth. Passage from the Coniston Grits to the Coldwell Beds was demonstrated, and a small quarry (284 953) in these rocks was examined. Following the track to Tranearth (284 957) the party proceeded down the succession into the Brathay Flags at Banishead Quarry where the fine laminated structure characteristic of these silty mudstones was clearly evident.

Continuing across the moors the downward traverse through the Brathay Flags culminated at a low feature by the Walna Scar track. This rise is formed by the rocks of the Browgill Beds whilst the linear depression containing Boo Tarn (282 986) is in the less resistant Skelgill Beds.

After lunch the party followed the Walna Scar track to Timley Knott (284 971) where the Applethwaite Formation forms the main crag. Here alternating bands of calcareous mudstones and limestones with occasional interbedded sandstones were studied. Nearby rocks of the underlying Longsleddale Formation containing sandstones made of volcanic fragments were seen in contact with the Yewdale Breccia.

The contact between the Yewdale Breccia and the Longsleddale Formation was traced westwards, where fossil brachiopods were collected at many exposures.

The Walna Scar track was followed to the bridge (271 965) over Torver Beck, where Yewdale bedded tuff with near vertical bedding planes was seen. Following the path downstream exposures of columnar-jointed ignimbrites were seen at 274 963, and, where the wall crosses, the upward passage of Skelgill Beds into Browgill Beds was followed. Further downstream on the right hand side the Browgill Beds were seen to gradually pass into the laminated silty mudstones of the Brathay Flags. After thanking the leader for an interesting day, the party returned to the cars.

EXCURSION TO WANLOCKHEAD

Leader: Mr.E.Smithson

20th July, 1985.

The Lead Mining Museum at Wanlockhead, Scotland's highest inhabited village at over 400 metres above sea level, was the meeting place for about 20 members. The Museum had an interesting display which illustrated the everyday life of the lead miners, including an excellent reproduction of an early miner's cottage interior. Mining machinery and implements together with the various processes involved in the extraction, preparation and smelting of the ores illustrated mining methods of the nineteenth century. There was a collection of local minerals (of which over 60 species have been recorded), some of quite good quality but regrettably not displayed very well and many without proper labelling.

After half an hour in the Museum the party crossed the road for a conducted tour of the old Loch Nell Mine which was worked from the early 1700's to 1860. This was an easy, level walk of some 200 metres, lit throughout by electric lights. The mine has been retained as far as possible in its original condition, to give an impression of the environment in which the miners worked. The guide pointed out the vein of galena while at one point an old shaft, open to a lower level, was crossed on a wooden platform. A reproduction of miners working had been set up at the end of the adit.

After lunch the party drove down the main street of the village, past the restored beam engine on the Straitsteps Mine, to the New Glencrieff Mine. This was the last mine worked in Wanlockhead, closing in 1934. It was re-opened by the Rio Tinto Zinc. Co. in 1954, but closed permanently in 1957. On the extensive waste tips the party collected mineral specimens including quartz, dolomite, ankerite, galena, sphalerite, pyrite, chalcopyrite, malachite, hematite and hemimorphite.

Later in the afternoon the party walked up the valley known as Whyte's Cleuch, passing on the way the old miners' cemetery with some interesting graves, and the site of William Symington's first commercial atmospheric pumping engine, built in 1789 to pump water from the Bay Mine. This mine, named after the convict settlement at Botany Bay in Australia, was worked from 1790 to 1799 and the valley is strewn with waste heaps from its workings. On these the party collected mineral specimens including golden-yellow quartz, pyrophanite, hematite and chrysocolla. One member found a very fine specimen of linarite - a rare find indeed at this locality! Most members managed to find some reasonable specimens for their collections. Mr. Smithson was warmly thanked for taking over the leadership of the excursion.

GRANOPHYRE - GRANITE - B.V.G. BOUNDARIES IN WASDALE

Leader F.Jones

14th September, 1985

The aim of this excursion was to examine the junctions between the Ennerdale Granophyre, the Eskdale Granite and the Borrowdale Volcanic Group.

Two excursions have visited this district in recent years to examine the Eskdale Granite (Slater, 1978 and Burton, 1981). These notes include information from observations made by the leader in 1984, which is illustrated in Figure 1. Firman (1978) reviewed the evidence concerning the origins of the Ennerdale Granophyre and the Eskdale Granite, while Clark (1964) in a paper on the Borrowdale Volcanic Series suggested that the emplacement of both intrusions was controlled by the base of the B.V.S. rocks.

Both the boundaries of the intrusive rocks and their aureoles are poorly exposed while the small scale geological maps are difficult to interpret. The Ennerdale Granophyre appears to lie on top of the granite, possibly forming a 'cap rock' for it. The granophyre contains more pink perthitic feldspar than the latter but is much finer grained and has graphic intergrowths of alkali feldspar and quartz. The granitic rocks and lavas appear to merge along zones up to 50m wide except in the area west of Sealatter where dacite and granophyre combine in a band of composite rock approximately 1km wide. The proximity of the boundary may often be recognised by perthitic phenocrysts in the andesitic matrix or by ingrowths of granite veins into grey outcrops with hardening of adjacent rocks. These features may be recognised in three areas shown in Figure 1:

1 North Birk Crag area

The granophyre is largely hidden in the Blengdale area, but fellside crags (125 065) define the boundary as far as Cat Biels (130 070) which is andesitic. Birk Crag (127 080) is composed of a coarse grey crystalline rock intermediate between granite and dacite.

2 Central 'island' of granophyre at Windsor Farm

This isolated area is somewhat masked by loose weathered granitic material, but good exposures of its southern margin can be found along the road (120 053).

3 Granophyre in Nether Wasdale

Good exposures of the boundary with the B.V.G. are found in Gill Beck (130 055) and at the water edge towards the pump house (155 058) where the granophyre disappears beneath Wastwater. Further south the junction between the granophyre and the Eskdale

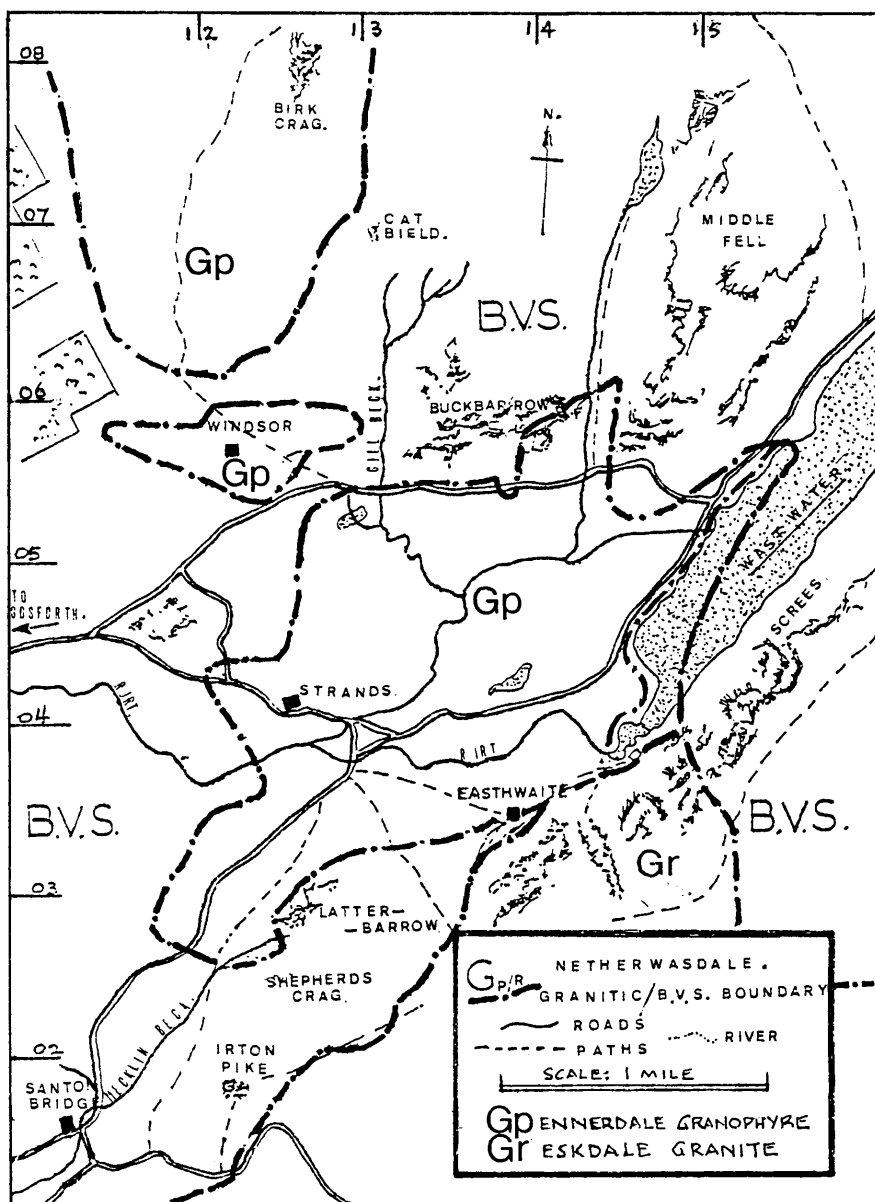


Fig.1 GRANOPHYRE - GRANITE - B.V.G. BOUNDARIES IN WASDALE

Granite was thought to lie behind Eastwaite Farm (137 033) but the crags here are andesitic and the contact must lie further east towards the Pump House. Latterbarrow Crag (125 027) is composed of tuff and andesite and there is little evidence of contact with the granophyre until Shepherd's Crag where the two types of rock occur together at the most northerly outcrop (122 025). The western margin of the outcrop runs north in exposures alongside the road (117 027) and at the road fork near Nether Wasdale - Strands (121 044).

Eskdale Granite

The Eskdale Granite enters the district to the east of Irton Fell (122 016) and continues along the fellside at the 250ft. contour, finally curving downhill to the west of Eastwaite. It appears again at the south-western end of the Screes between the Pump House and Pens End.

Further reading

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In addition to those reported the following excursions were held:

17th May, 1986	Carrock Fell Mines, leader T.Shipp
12th July, 1986	Ashgill and Torver, leader A.McAdam
12th April, 1987	Garnets - Seathwaite, leader S.L.Caunt
27th June, 1987	Force Crag Mine, leader B.Young

GLACIAL AND PERIGLACIAL GEOMORPHOLOGY AROUND KESWICK

Leader: Dr.J.Boardman

5th April, 1986.

Twenty seven members of the Society assembled in the Lakeside car park, Keswick.

The morning was devoted to an examination of glacial land-forms and sediments between Crow Park (NY 263 230) and Broom Hill Point (NY 267 215). The dominant landforms of the area are a suite of small, poorly-streamlined drumlins which extend north from Broom Hill Point, through the town of Keswick, along the eastern shore of Bassenthwaite and on to the Solway Plain. Occasional examples occur in upland valleys at the head of Borrowdale (Wilson, 1982) but they attain classic drumlin shape where the ice sheet moved over less topographically-confined areas. Crow Park is a particularly good example of a drumlin.

Within the suite of streamlined forms several are seen as rock-cored, the Castle Head dolerite forming the core around which lodgement till is plastered. Where the rock-core is at the up-glacier end the feature is often referred to as 'crag and tail'. Examples at Cockshot Wood and Friar's Crag were commented upon but it was pointed out that many of the drumlins in the area may be rock-cored. West of Friar's Crag the complexity of some of the features was demonstrated, drumlins less than 100m in length being difficult to distinguish from adjacent forms three or four times their size (NY 266 223).

Geomorphological mapping of the crest line of streamlined landforms allows us to reconstruct the direction of ice movement in the area (Boardman, 1982, Fig.5). Confirmatory evidence is provided by erratics and the location of high ground.

During the excursion there was discussion of theories of drumlin formation. It was suggested that stress levels at the base of the ice sheet were a primary control (Smalley and Unwin, 1968). These will depend on ice thickness but drumlin shape will be influenced by ice velocity and the composition of the till.

The walk from Crow Park to Broom Hill Point crossed several drumlins which vary considerably in shape and size. Local factors such as the presence of bedrock and till variability are probably responsible. A lake shore exposure at Broom Hill Point provides a section of the bouldery till which forms the interior of a small, eroded drumlin. The potential of till fabrics to assist in reconstruction of ice movement direction was discussed: results from this site indicate movement from the south or south-east (Boardman, 1982, Fig.6), broadly in sympathy with the orientation

of drumlin crest lines in the area. The exposure is also of interest for the compact, 'fragic' horizon in the soil developed in the upper 1.5m of till. Compaction is thought to be the result of the growth of ice lenses when permafrost existed. Fragic horizons are widespread in Cumbrian soils and can adversely affect the drainage of agricultural land (Matthews, 1976).

Three short stops were made around the shores of Calfclose Bay to examine landforms resulting from deglaciation (NY 270 216). Systems of low eskers may be seen. These are branching and winding ridges which are formed by the deposition of sand and gravel in either closed tunnels or open crevasses as the ice melted after stagnation. There are no good exposures, but gravels are evident in stream banks and rabbit holes. Exposures along the lakeside show gravels which form a kame terrace (NY 270 213). Eskers, kame terraces and kettle holes were seen from footpaths between Calfclose Bay and Brockleside (NY 271 225). The leader suggested that the ice-stagnation topography is a result of the melting of the Late Devensian ice sheet between 18,000 and 14,000 years B.P. The party dispersed for lunch in Keswick.

In the afternoon three sites were visited illustrating different types of periglacial slope deposits.

An exposure in a cutting for a forestry road at Throstle Shaw (NY 237 272) shows two units (Boardman, 1985). The upper unit is composed of angular, gravel-size, slate particles. It is relatively well sorted and bedded. The bedding probably results from pauses during deposition during which some weathering occurred. The well sorted character of the gravel implies redistribution of rockfall scree by water. Under periglacial conditions, when low altitude screes were active, this is likely to have been snow melt-water. Units similar to this occur at other localities in the area and are referred to as 'stratified scree'. During discussion of the mechanism of transport of the scree material, the leader suggested that if permafrost existed within the accumulating scree, then seasonal flow of water across the surface was feasible; arctic analogues can be cited (Howarth and Bones, 1972). The lower unit at Throstle Shaw is poorly sorted and unbedded; it contains rounded and angular clasts and the occasional glacial erratic. The fabric suggests downslope movement and an origin as a debris flow was put forward. Debris flows are not uncommon on Cumbrian slopes at the present time and lack of vegetation and permafrost during parts of the Late Glacial period (15,000 - 10,000 B.P.) would increase their frequency and effectiveness. The surface of the flow appears to have been channelled by water prior to deposition of the scree.

At Sandbeds (NY 234 291) good exposures exist in a large inactive fan. The sediments that make up the fan are edge-rounded gravels with varying amounts of finer matrix. The fan contains a deep channel filled with coarse, bedded gravels. Fabrics in the gravels indicate radiating flow from the apex of the fan. Some of

the matrix-rich beds may represent debris flow activity rather than true fluvial transport. Lenses of soliflucted till occur near the base of the fan. The volume of the fan is estimated at 153,000m³, and based on the assumption of formation during the Loch Lomond Stadial (11,000 - 10,000 B.P.), the mean rate of surface lowering within the catchment was 0.58mm yr⁻¹ (Boardman, 1985). Rates of movement of bedload in high-gradient Lakeland streams at present (Newson and Leeks, 1985) are about an order of magnitude lower than those estimated for formation of the Sandbeds fan.

The final site was at Thorny Plats (NY 269 243) overlooking the Keswick bypass. Site investigation for the road showed a thick sequence of stratified scree overlying till (Boardman, 1978). Engineering problems of road building on and through such material were discussed. In particular, the scree posed problems for embankment stability and slope drainage.

The meeting ended with a plea from the leader for engineers to be more aware of the complexity of many superficial deposits especially those of a glacial and periglacial origin which cover much of the British Isles.

Thanks are due to Mr.T.M.Scott, District Forest Manager, Forestry Commission, for arranging clearance work at the Throstle Shaw site; also to Major J.H.Spedding for access to the Sandbeds quarry.

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EXCURSION TO THE LANGHOLM AND NEWCASTLETON AREAS

Leader: I. Gray

27th April, 1986

The party met at Skipper's Bridge, south of Langholm (370 835) where the Birrenswark Lavas, olivine basalt flows at the base of the Carboniferous, appear in the river bed and form the foundation on which the bridge is built (location 1 on the sketch map). They show numerous vesicles containing chlorite, calcite and quartz and are crossed by quartz veins, some almost attaining the character of agate. Rafts of more vesicular material are seen to be 'floating' in less gassy lavas. The dip is to the south and good exposures appear on both sides of the river. Upstream of the bridge Silurian (Wenlock) greywackes and slates are exposed north of the Whita Fault, near to the old distillery and modern garage.

The party then moved down the Esk valley on the east bank of the river to Tarras Foot (380 810 - locality 2 on the map) where the upper part of the Whita Sandstone (Carboniferous) is exposed beneath the bridge. This sandstone also forms the prominent Monument Hill at Langholm. Walking up the valley of the Tarras, the cementstone facies consisting of buff, thin bands of impure or algal limestone separated by shales and thin sandstones, are seen as gently undulating beds, overlain by recent coarse river-terrace gravel deposits. The cementstones are the eastern and later development of the Whita sandstone, formed in a sabkha environment

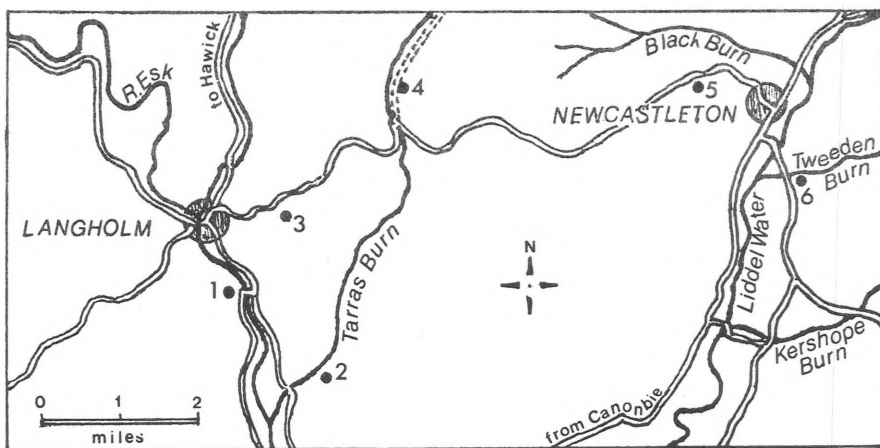


Fig. 1 SKETCH MAP SHOWING SITES VISITED.

(a low-lying lagoonal coastline), with the Whita Sandstone as a possible delta or river system invading the area from the north.

At 385 814 is the fascinating Marl Well, a petrifying spring, once the source of water for the Tarrasfoot distillery. The lime is probably derived from the marly bands of the cementstone, and around the spring the moss has been turned to tufa.

The party then returned to Langholm and, just to the north of the town, took the hill road which leads to Newcastleton. A mile or so out of Langholm at 375 853 and close to the south side of the road are some small quarries worked for road metal (locality 3). These are in slate and thin greywacke of Wenlock age, showing tight folds and faulting. Monograptus-type fossils have been found here. Walking southwards up the hillside small exposures of the Upper Red Sandstone, containing quartz pebbles, are seen lying unconformably on the Silurian. The Old Red Sandstone dips eastwards at a few degrees. Following a tiny stream flowing across the red sandstone and climbing slightly eastwards brought us to an outcrop of badly weathered Birrenswark Lavas resting on the Old Red Sandstone.

The party then drove a couple of miles to the bridge over the upper Tarras Burn, crossing on the way the peat covered moorland and noting scattered boulders of Whita Sandstone. Along the picturesque Tarras valley (the haunt of cattle rieviers in the 16th and 17th centuries) are small waterfalls caused by harder beds of the Whita Sandstone (locality 4) and well exposed at 402 874. Further upstream near Arkletonshields and near the confluence of Greenlea and Tarras Burns (405 884) more exposures of the Old Red Sandstone can be seen, again containing white quartz pebbles and green reduction patches; they are particularly well exposed in the burn where strong beds form a 10ft. waterfall. Above the red sandstone in the headwaters of the Greenlea Burn, the Birrenswark Lavas reappear, this time less weathered. Large feldspars are visible in the basalt. Further upstream the rocks are mainly Wenlock greywackes with patches of Old Red Sandstone, together with much glacial debris. Looking eastwards the high ground near Cooms can be seen. It is formed by the Birrenswark Lavas and contains a good example of corrie formation.

Retracing our way back to the Newcastleton road, the next stop was at Bedda Hill (465 880 - locality 5), the vent of a small volcano in which a small quarry beside the road shows weathered rounded blocks of Jedburgh-type basalt in an agglomerate containing small phenocrysts of labradorite and some olivine. The vent is small and can be conveniently perambulated, its boundaries defined by the contrast between the acidic bent-grass vegetation of the surrounding Border Group cementstones, and the fine turf on the weathered vent. The view to the north shows other vents towards Hawick (see figure 2).

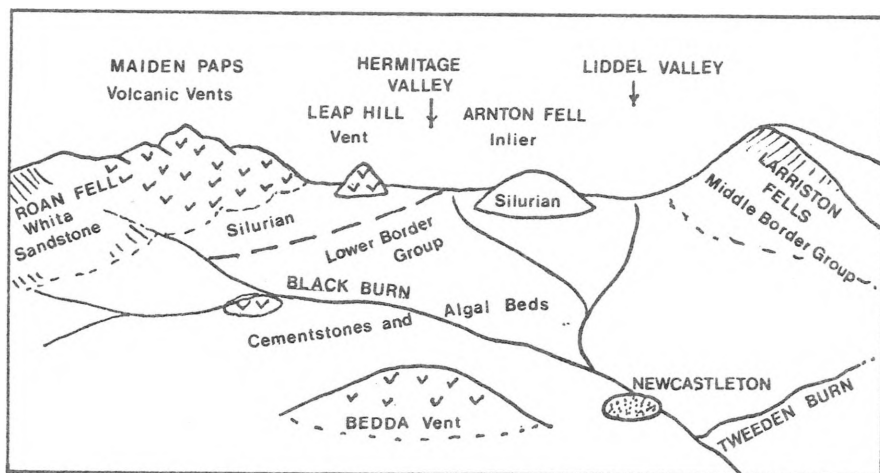


Fig. 2 VIEW FROM BEDDA HILL, NEWCASTLETON.

The final stop was at the bridge over the Tweeden Burn (locality 6 - 484 865), a tributary of Liddel Water, south of Newcastleton on the minor road to Gilsland and Brampton. Here, on the east bank, opposite the track, are algal masses in cementstone which form mounds composed of layers of algal growth. This is a Site of Special Scientific Interest, and although plants and trees are tending to obscure the finer specimens, at least two remain visible.

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ALSTON MOOR GLACIATION

Leader: Dr.A.G.Lunn

11th May, 1986

The party met at the Hartside Café on the A 686 road and travelled to Garrigill, stopping 2km out of Alston on the Middleton road (B 6277) to look at the asymmetry of the cross-profile of South Tynedale. Here the valley is steep-sided and benched on the east, owing to the contrasting Yoredale lithology, but gentler and smoother to the west; this difference is ascribed to 'lee and stoss' erosion by ice sheets flowing ENE across the valley. The complement noted in the profile of Park Fell (NY 699 455) west of Alston is a 'stoss and lee' hill which is steep up-glacier and gentle down-glacier. A probable marginal meltwater channel was noted parallel to and west of the road, meltwater discharging northwards into a subglacial chute, now Nattress Gill.

The main objective of the excursion was the Bullmans Hills (NY 70 37), reached on foot along the mine road south-west from Garrigill towards Cross Fell. These hills, at about 600m above O.D., are remarkable displaced rafts of the Great Limestone, each about 100-200m long and 20-30m high. They are represented on the Geological Survey 1" map as landslips, but the topographical context makes this impossible. They are interpreted as giant erratics, rafted by a Cross Fell ice cap some 1km from an outcrop to the south or south-west. It is proposed that a combination of weak shales between resistant strata of the Yoredale sequence and patchily cold-based ice resulted in the rafting. The surface of the Great Limestone became frozen on to the base of the ice sheet, causing intact segments of the stratum to be dragged forward as the subjacent, unfrozen shales yielded. There is no indication as to which glacial stage the giant erratics belong, as there is dispute as to whether Cross Fell was glaciated in the Late Devensian. The Bullmans Hills are discontinuously covered by till and this by blanket peat, in both of which subsidence dolines (shake holes) have developed. The Lambgreen Hills, 1km to the SSE, were visited on the return journey and also appeared to be giant erratics, emphasising the fact that this is a strikingly glacially-modified landscape.

EXCURSION TO ESKDALE AND BIRKER FELL

Leader: Dr.E.W.Johnson

8th June, 1986

Members and friends assembled in the car park of the Woolpack Inn, Eskdale (NY 190 101) to examine the succession of lavas that form the lower part of the Borrowdale Volcanic Group and their

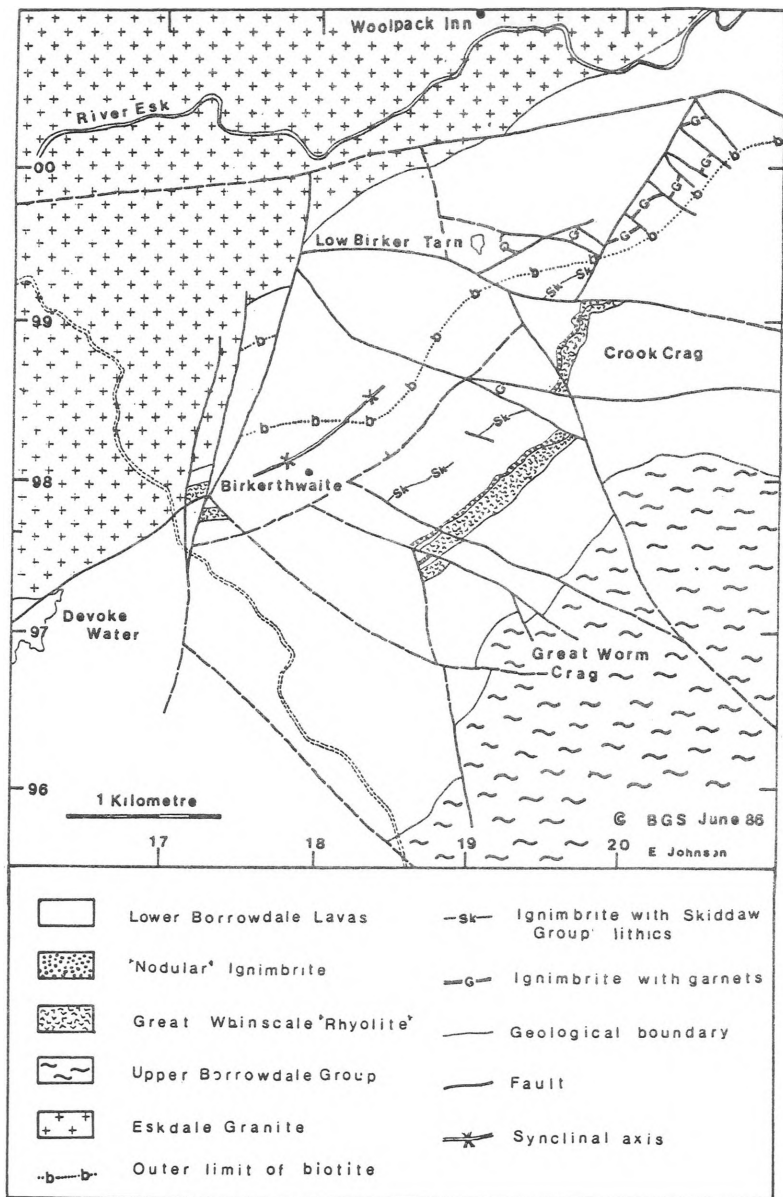


Fig.1 GEOLOGICAL SKETCH MAP OF THE AREA EAST OF DEVOKE WATER

contact with the Eskdale Granite, on ground recently mapped as part of the British Geological Survey's revision of the Ambleside geological map.

The leader outlined the Ordovician palaeogeography of the Borrowdale Volcanic Group, indicating that the volcanic rocks were thought to have been formed as part of an orogenic andesite suite, related to south-eastward subduction at the southern margin of the Iapetus Ocean, in the Upper Llanvirn to late Caradoc/early Ashgill interval. He indicated that the 'Borrowdale stratovolcano' comprised an interbedded succession of lavas and pyroclastic rocks and explained that the growth of this volcano could, simplistically, be considered in terms of effusive and explosive phases; the former being dominated by extrusion of lava whereas in the latter large volumes of pyroclastic rocks were erupted, mainly as ignimbrites, with denudation producing epiclastic sediments.

The volcanic rocks were subsequently intruded by the Eskdale Granite, part of a major batholith that underlies much of the Lake District. The age of the Eskdale Granite was considered, along with other Lake District granites, to be end-Silurian/early Devonian until a radiometric Rb/Sr age of 429 ± 4 Ma was demonstrated by Rundle (1979). This late Ordovician age for the granite is supported by field evidence found during the B.G.S. re-survey of the area; the intrusion cuts early Ashgill (pre-Coniston Limestone Formation) folds and is penetrated by cleavage associated with the end-Silurian deformation.

After crossing the River Esk at Doctor Bridge, the track was followed, via Low Birker, southwards to crags of Eskdale Granite at NY 189 002. Hereabouts the granite is cut by the Hardknott Fault, an ENE trending fracture, located in a well-defined linear hollow. High on the valley side (NY 1884 0008) the contact between the Eskdale Granite and the Borrowdale Volcanic Group is well exposed. The contact dips at 25° to the south and is essentially concordant with the volcanic rocks. The low angle of the contact, along with the broad metamorphic aureole, here and elsewhere in Eskdale, indicate that it is the top of the intrusion that is being viewed and suggests that the volcanic sequence behaved as a barrier, hindering the upward movement of the granite magma after it had penetrated the more ductile Skiddaw Group which forms the sub-volcanic basement. The ascending intrusion has produced a broad dome within the Borrowdale Volcanic Group.

Metasomatic alteration associated with the granite intrusion has produced greisens at its margins. At this locality (NY 1886 0008) quartz-sericite greisens are present along joints in the granite. Elsewhere along the contact this metasomatic alteration is more extensive and some of the greisens contain topaz as well as quartz and sericite.

The volcanic rocks at the contact with the granite are

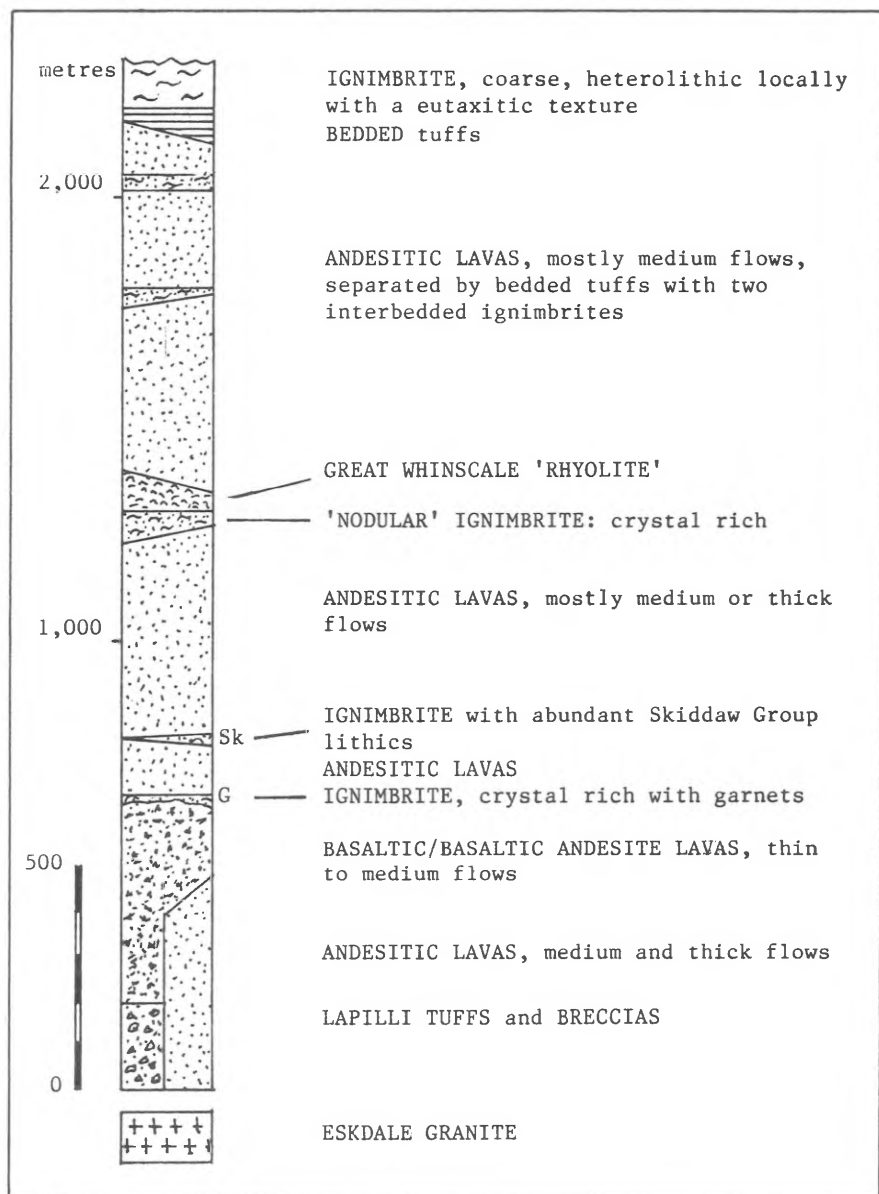


Fig. 2 GENERALISED SUCCESSION OF THE LOWER PART OF THE BORROWDALE VOLCANIC GROUP BETWEEN DEVOKE WATER AND HARTER FELL.

basaltic andesite lavas with thin intercalated bedded tuffs. They have been hornfelsed by the intrusion which gives the rocks a dark, purple-brown hue. This distinctive colouration is produced by the growth of microcrystalline biotite from the primary mafic minerals and is a characteristic feature of the highest grade zone of the contact metamorphic aureole. In the outer zone of the aureole the volcanic rocks have no diagnostic colouration and the mafic minerals are replaced by fibrous amphibole. The interbeds of tuff are a valuable aid to mapping as they allow dip and strike to be determined accurately in the lava dominated sequence. Thinly bedded tuff interbeds within the lava sequence are exposed at NY 188 001 and SD 189 999.

Within any succession it is important to identify distinctive marker horizons so that the stratigraphic level is known and structures can be recognised. In the two kilometre sequence of lavas that forms the lower part of the Borrowdale Volcanic Group such marker horizons are provided by thin, lithologically distinctive units of tuff. The lowest of these, which occurs approximately 600m above the base of the succession (Figure 2), is a crystal-rich tuff that contains abundant garnet. It is exposed on Tarn Crag (SD 192 995) and has been mapped as far as Cockley Beck, 6km to the east. Fiamme (flattened fragments of pumice) a few centimetres in length are present within the tuff, indicating that the tuff is an ignimbrite, the product of a pyroclastic flow. About 150m of andesite lavas separate this garnet-bearing tuff from the succeeding marker unit, a lapilli tuff that contains abundant lithic fragments of arkosic sandstone, siltstone and mudstone derived from the sub-volcanic Skiddaw Group basement. This lithic tuff crops out in poorly exposed ground at SD 196 992. Continuing southwards towards Crook Crag a drift filled hollow (SD 196 991) obscures an ESE trending fault. On the south, downthrown, side of this fault, the most extensive marker beds in the lower part of the Borrowdale Volcanic Group in the south-west Lake District are well exposed. The lower of these two units is a nodular, crystal-rich tuff (ignimbrite) and is separated by a few metres of bedded tuffs from a higher unit, a flow-jointed lava named the Great Whinscale Rhyolite by Firman (1957) from the crags of that name (SD 198 989). Samples from this and other localities of the flow-jointed lava have been analysed by Mr. R. Sotiriou of Sheffield University revealing the composition to be dacite rather than rhyolite.

In the andesite lavas overlying the Great Whinscale Rhyolite on Crook Crag many of the morphological features if these flows are well displayed. A few metres of breccia are present at the base: the central part is massive or flow jointed and in places may be flow folded especially close to the upper autobrecciated part of the flows. A few metres of bedded tuffs separate individual lava flows which vary from several tens to a few hundred metres in thickness.

A fault on the west side of Crook Crag that downthrows eastwards juxtaposes (SD 195 986) the drift covered outcrops of the Great Whinscale Rhyolite and the lowest marker unit, the garnet-bearing tuff, indicating a displacement of circa 700m and illustrating the importance of these lithologically distinctive units when mapping the sequence of lavas.

Continuing southwards towards Broad Crag, across faulted ground, the outcrop of the Great Whinscale Rhyolite is found at SD 196 982 and can be followed along strike south-westwards to Highford Beck (SD 187 914) before it is lost beneath drift cover.

In the ill-exposed ground between Highford Beck and Rough Crag (SD 185 966) are numerous exposures of a pink weathering, acid rock. The outcrop pattern suggests these exposures are part of an extensive sheet that is inclined subparallel to the present-day topographic slope. When the 60° dip of the Borrowdale Group along with the 10° slope gradient are considered, the original disposition of the sheet must have been subvertical. Petrographic studies reveal vitroclastic textures indicating that the rock was fragmental and pyroclastic in origin, i.e. an ignimbrite. The outcrop pattern and discordant relationships with the sequence of lavas suggests that the rhyodacitic ignimbrite may be preserved within a fissure vent, possibly a feeder dyke for the Airey's Bridge Formation in the upper part of the Borrowdale Volcanic Group. The contact between the ignimbrite and the lavas is only exposed at SD 185 967 on the north side of Rough Crag, where a flow-foliation is developed in the ignimbrite close to its margin.

Near the base of Rough Crag andesitic ignimbrites and bedded tuffs are intercalated within the sequence of lavas. The highest ignimbrite is lithologically uniform, has a well developed eutaxitic texture and contains abundant lapilli in addition to the fiamme.

After examining the sequence on Rough Crag members made their way to Brown Rigg where the Society's excursion secretary proposed a vote of thanks to the leader.

ACKNOWLEDGEMENT

The leader would like to thank Dr.D.Millward for his assistance in preparing the excursion, especially for demonstrating the geology of the Eskdale Granite and its metamorphic aureole in the ground to the north of Great Whinscale. This report is published by permission of the Director of the British Geological Survey (NERC).

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FIELD EXCURSION TO SHAP WELLS DISTRICT

Leader: E.Skipsey

21st June, 1986.

A party of twenty four, comprising members of the Society, friends and Open University Students, assembled at the Shap pipe works before commencing a visit to the Shap Granite quarry. Problems of access permission delayed the start of the visit, despite prior arrangements, but these were finally resolved at the eleventh hour by the arrival of Mary Cockersole flourishing the required permit. Large blocks of granite awaiting despatch to Cornwall provided ideal classroom specimens for the party who first of all examined the mineralogical composition of the rock. The origins of the large pink feldspar megacrysts were discussed and their relationship with the dark granite enclaves was considered. Recent geochemical studies have suggested that these dark enclaves were remnants of a primitive fractionation of the plutonic body which had been caught up in the intrusion of the main phase. Late hydrothermal mineralisation and alteration were very evident, varying from the occurrence of minerals such as pyrite, chalcopyrite, molybdenite and tourmaline on joint surfaces to the bands or veins of altered granite where extensive kaolinisation of feldspars led to the disintegration of the rock.

The relationship of the granite to the surrounding country rock formed the topic for the remainder of the visits. The actual contact zone was studied at upper Blea Beck (562 101) where marginal facies of the granite interfingered with the andesitic country rock. Metamorphosed Ordovician andesites of the Borrowdale Volcanic Group were examined in more detail in the Blue Shap Quarry. Here the rock was found to be very hard and splintery with large irregular patches of mineralisation and alteration, resulting from the proximity of the granite. Amongst the distinctive minerals identified were large patches of green epidote and chlorite and clusters of garnets.

In contrast to the rocks of the Blue Quarry, the outcrops of the Silurian Coniston Grit examined in the A6 road cutting (554 055) showed no evidence of metamorphism and apparently were outside the aureole of the granite. Highly deformed structures were elucidated with the aid of a variety of sedimentary features.

Lunch was taken at Shap Wells Hotel where the massed phalanx of Scottish coaches almost barred access to the grounds. The party studied the unconformity formed by the basal Carboniferous gravels and sandstones on the truncated and steeply dipping Silurian rocks, exposed on Wasdale Beck near the hotel (578 095).

The uncertainties over the age of these unfossiliferous red beds above the unconformity was discussed and compared with other units like the Mell Fell Conglomerate. Since the granite had been emplaced at 395 Ma (end Silurian or early Devonian) and numerous clasts of the feldspar megacrysts were found incorporated in the gravels, it can be deduced that the granite had already been unroofed by the time of their formation and that they must be either latest Devonian or lowest Carboniferous in age.

The remainder of the afternoon was spent tracing the irregularities in the unconformity over the Silurian and Ordovician outcrops exposed in lower Blea Beck and on to the Ordovician ridge visible in the Shap Summit railway cutting (573 107). It became very apparent as the party trekked across rough country that the unconformity represented a very irregular land surface with a high ridge of the andesitic lavas upstanding between the Blue Quarry and the summit railway cutting. The lowest limestone horizon of the Carboniferous, seen resting directly upon the andesites at the top of the cutting, could be correlated by eye with the near horizontal limestone scar on the hillside east of the M6 motorway. This suggested that the basal red beds were occupying hollows in the early Carboniferous land surface and with these flights of speculation the meeting closed.

THE VOLCANICS OF UPPER ESKDALE

Leader: Dr.D.Millward

7th September, 1986.

Introduction

The volcanics of Upper Eskdale belong to the lower portion of the Borrowdale Volcanic Group. The area is currently being surveyed as part of a long-term project to re-map the areas covered by the four main sheets of the Lake District; the initial emphasis has been placed on the Keswick and Ambleside sheets.

The sequence of rocks in the area examined during the excursion is predominantly lava with a small proportion of pyroclastics. The lavas are andesitic in the lower part of the sequence, becoming basaltic higher up. An earlier account of the geology of the Borrowdale Volcanic Group categorised these basalts as andesites. Basalts are a common constituent of the early,

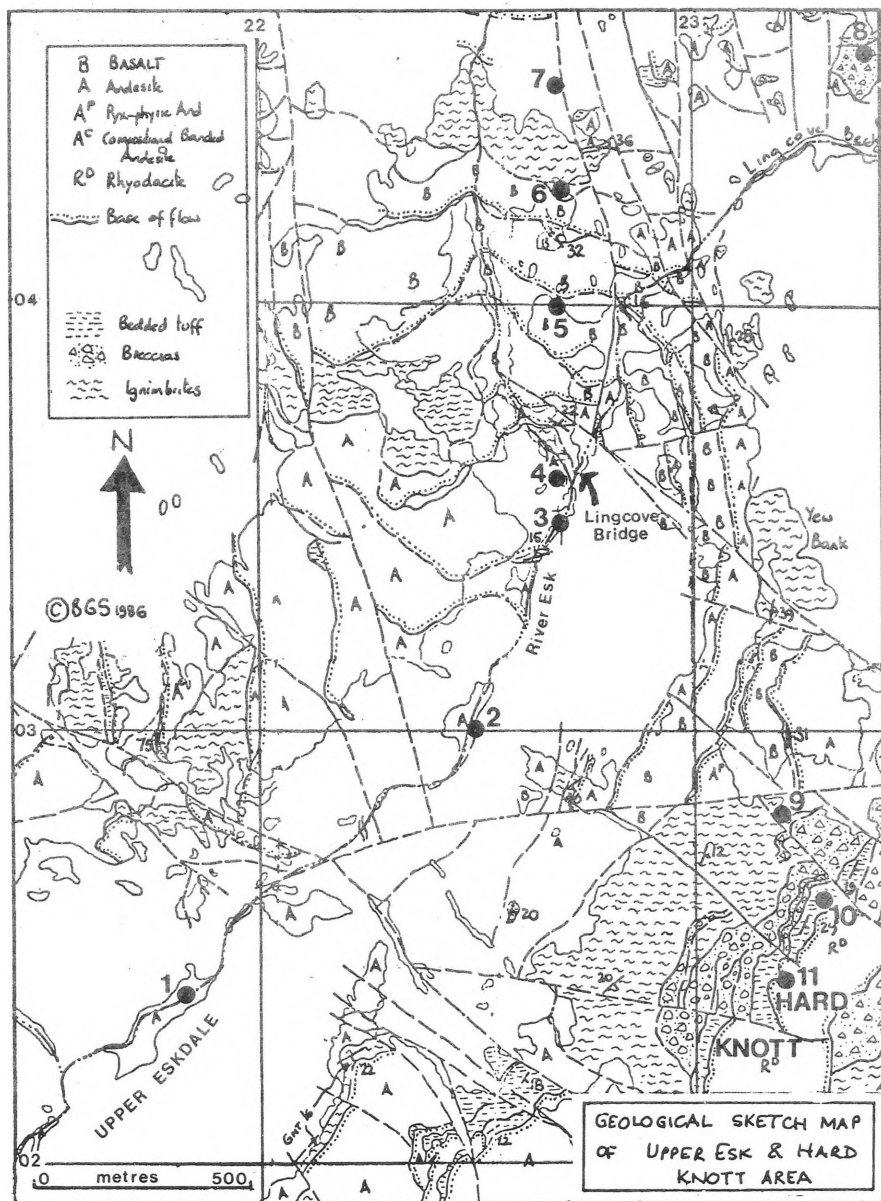


Fig. 1 GEOLOGICAL SKETCH MAP OF UPPER ESK AND HARD KNOTT AREA

constructional phase of volcanic development in the destructive plate-margin environment.

The Eskdale Granite is exposed nearby to the south; its upper contact dips at a shallow angle below the lavas of Upper Eskdale. Thus its presence at depth can be inferred. There is also geophysical evidence for the presence of the granite; a gravity 'low' indicates the existence of a batholith beneath the valley. Additionally, there is strong petrographical evidence which can be studied in detail, namely:

- (1) Some thermal alteration of the andesites giving a purple-brown appearance due to recrystallised biotite in the groundmass and at times a hornfelsed appearance; some secondary hornblende is commonly present.
- (2) Veinlets of hornblende are locally abundant throughout the area.
- (3) Many of the basalts are amphibolized, having a greenish tinge.

The metamorphism extends some 4km up the valley to Throstlegarth, but much less at right angles to the main trend of the valley.

Structurally, the volcanics form a north-east plunging anticline (i.e. up the valley). Pyroclastic horizons have aided the determination of the structure, notably the garnet-bearing ignimbrite and the quartz-filled nodule-bearing ignimbrite.

The Excursion

The excursion started at the west side of Hard Knott Pass (213 011). From here a path descends to the River Esk. The river was followed to Throstlegarth, then on to Lingcove, returning via Hard Knott summit. The localities visited and commented on below are indicated on the accompanying sketch map.

Locality 1. East bank of the River Esk, 300m beyond Catcove Beck (218 024). An outcrop of andesites showing evidence of metamorphism, i.e. a purple-brown hue with hornfelsed appearance.

Locality 2. East bank of the River Esk (225 030). An exposure of crystal-rich andesites, something of the order of 30% of the rock being white plagioclase feldspar crystals. The exposure is cut by a basalt dyke, probably, but not conclusively, of pre-granite age.

Locality 3. Immediately below a deep pool (227 035) is an exposure of some 6 to 8m of medium-grained laminated tuffs.

Locality 4. Above Lingcove Bridge (227 037). A substantial exposure of ignimbrite. The ignimbrites are overlain by tuffs

showing wavy laminations and shallow cross-laminations. Rapid changes between coarse and fine-grained horizons with reverse grading, are indicative of a primary pyroclastic deposit, probably airfall.

Locality 5. Throstlegarth (227 040). The fell rising to the north between the Esk and Lingcove consists of a series of basalt lavas. Examination shows well-etched spinose breccias together with massive lenticular bodies. There are examples of amygdaloidal basalts with hornblende and quartz amygdales appearing in the upper part of the flows. Quartz, being weather resistant, now stands out against the matrix. On higher ground, approaching Throstlehow Crag, the 'benches', coinciding with the tops of the lava flows, are particularly well seen.

Locality 6. Throstlehow Crag (227 043). The crag is composed of a massive eutaxitic-textured ignimbrite of andesitic composition.

Locality 7. From this point (227 045) looking towards the head of Eskdale an appreciation is obtained of the open folding of this area, compared with the much tighter folding to the south and east. The head of the valley is at the nose of a dipping anticline. Rhyodacitic lava flows and ignimbrites and bedded tuffs within the broad Scafell syncline form the crags of the Scafells, Esk Pike and Bowfell. At a high position the Airy's Bridge Formation can be located; this forms the basal unit of the upper Borrowdale Volcanic Group.

Locality 8. Pianet Knott (234 046). A fine example of a debris flow, varying from angular blocks to fine muds badly sorted, with various rock types represented.

Locality 9. Northern slope of Hard Knott (232 028). The rocks of this and the two following localities appear not to be related to the rocks seen so far. They are representative sections of a triangular area of some 2km^2 which currently cannot be related to the surrounding area with any degree of certainty. At locality 9 a thick sequence of ignimbrites, more acidic than those seen earlier is reminiscent of the Airy's Bridge Formation.

Locality 10. (233 026). Here there are boulder beds of quite spectacular appearance, possibly the result of infilling of a steep sided valley with debris of volcanic origin at some later stage.

Locality 11. Hard Knott summit (232 024). The summit and surrounding high ground consists of well exposed rhyodacite lavas. These too are more typical of the Airy's Bridge Formation.

THE CROSS FELL INLIER

Leader: Dr.R.C.Wright

29th March, 1987

On a bright frosty morning 10 members and friends of the Society assembled for a joint meeting with 28 members of the Open University Geological Society at the village of Murton (NY 728 217) near Appleby-in-Westmorland.

The excursion leader, Dr.Rodney Wright from the department of Continuing Education at the University of Liverpool, gave a short introduction to the geology of the area and explained its tectonic significance. The Cross Fell area lies at the western margin of the Alston Block and straddles the Pennine Fault Zone into the Vale of Eden basin. This zone has been the focus of differential basement movement during the last 400 Ma. Intrusion of the Weardale Granite at 390 Ma initiated the rise of the Alston Block and subsequent earth movements have periodically reactivated this line of weakness. Major movements occurred in late-Carboniferous and Tertiary times, but adjustments continue today as evidenced by the 1970 earthquake (Browning & Jacob, 1970).

As a departure from the norm, the party was issued with sketch topographical maps and asked to map the relationships between rock-types on Murton Pike before lunch! The first outcrops were of Skiddaw Group mudstones in Murton Beck (733 222) and at Thornarbour Scar (733 223). A slaty cleavage dominates the outcrops and occasional siltstone laminae distinguish the bedding. At 737 223 a 4cm thick sandstone bed is isoclinally folded and the slaty cleavage is seen to be axial planar to this fold. Graptolites are not known from these outcrops, but on microfossil evidence these rocks are correlated with the Murton Formation and in turn with the Lower Ordovician (Arenig) rocks of the Skiddaw Group of the Lake District. Trace fossils are known, however, from the rocks of Murton Pike. Thin, branching forms of the trace fossil Chondrites are locally common, but in addition several members of the party discovered pellet-filled burrow forms.

Further outcrops of Skiddaw Group (Murton Formation) mudstones were examined as the party traversed the southern slopes of Murton Pike via Low Trough (731 224) and High Trough (732 226). These two dramatic short valleys, carved into the flank of Murton Pike, are excellent examples of glacial meltwater channels, formed by englacial rivers where these locally flowed out of the melting ice-sheet to erode steep-sided channels in the adjacent bedrock.

The party paused at the eastern end of High Trough to view geological relationships on the fellsides to the south-east. On the opposite valley side, the Lower Carboniferous succession is

represented by approximately 75m of conglomerates and sandstones (Basement Beds), overlain by approximately 50m of sandstones and impure limestones (Orton Group), overlain by the Melmerby Scar Limestone (base of Alston Group, Asbian Stage of Dinantian). The Melmerby Scar Limestone outcrops to form Delfekirk Scar and can be traced into Gasdale to the major spring source of Murton beck (744 229), then back out of the valley to Murton Crag. The Carboniferous succession dips at approximately 10° to the east and unconformably overlies the Skiddaw Group. Abandoned mineral workings occur at White Mines (744 226) and traces of extensive surface exploration along the line of the Murton Fell North Vein could be seen crossing the fells beyond. Several members of the party visited the spoil heaps later in the morning to collect specimens of galena and barytes.

Beyond Delfekirk Scar the bulk of Roman Fell lies to the south of Swindale beck. Field mapping in this area has demonstrated thickness and facies variation in the Lower Carboniferous which are interpreted as evidence of differential basement movements across a hinge line during sedimentation (see also Burgess and Harrison, 1967).

The party now traversed across the hillside to the screes below the Melmerby Scar Limestone outcrop at Murton Crag (736 227). Examples of several coral groups and some brachiopods were found. At this point the leader stated that to save a further 150m of steep ascent, the party could accept his word that Skiddaw Group rocks formed the summit of Murton Pike (735 232) - one person went to confirm this. Consideration of the data plotted on to the field slips appeared paradoxical with Skiddaw Group mudstones occurring both below and above the Melmerby Scar Limestone of Murton Crag. Clearly these relationships could be explained in terms of a reverse fault which brought older rocks up from the west to overlie the limestone. The orientation of the fault plane was determined from the map as striking 163° and dipping 20° SW - at a shallower angle than is indicated on the Geological Survey Special Sheet, Cross Fell Inlier.

The party then descended the hillside and travelled to Dufton (690 250) for a lunch stop at The Stag Inn, enjoying en route a splendid view of the black crags of the Whin Sill standing out amongst the snows of High Cup.

The afternoon section of the excursion consisted of a circuit around Dufton Pike to demonstrate the variety of rock-types present in the Cross Fell Inlier. The inlier stretches for 25km from Roman Fell to Melmerby and is 1 to 3km wide. It includes the pre-Carboniferous rocks of the Alston Block (e.g. Skiddaw Group rocks in the upper part of Murton Beck), together with the upfaulted Lower Palaeozoic rocks within the Pennine Fault Zone. The latter include representatives of the Skiddaw, Borrowdale and Windermere Groups of the Lake District, and occur as a large-scale

fault breccia - the faults separating adjacent rock-types often being eroded by glacial meltwater. Hence the more resistant rocks, e.g. Borrowdale Volcanics, form many of the upstanding 'pikes' (Dufton Pike, Knock Pike), that give this area its unique topographical character.

From the north-west corner of Dufton village, the party followed the Pennine Way into Hurning Lane across drift-covered Permo-Triassic St. Bees Sandstone until, 250m north of Coatsike (689 259), a break-in-slope marks the line of the Outer Pennine Fault at the western margin of the Pennine Fault Zone. In the eroded track side at 691 265, grey, partly calcareous mudstones of the Upper Ordovician Dufton Shales (correlated with the Coniston Limestone Group) were located. No sooner had the leader remarked that this particular outcrop was not very fossiliferous, than eagle-eyed members of the Society located brachiopods (including *Oniella*) and fragments of trilobites and graptolites. In a further 250m, a stone wall at 691 268 containing blocks of pink porphyritic microgranite with phenocrysts of muscovite, quartz and feldspar, marked the adjacent outcrop of the Dufton Microgranite at 693 268. This minor intrusion is thought to have a dyke-like form and similar bodies, occurring for example at Shap Fell and at Brown Howe, Coniston, all appear to be late intrusions associated with the early Devonian emplacement of the Lake District granites.

The route continued over Cosca Hill to the ford over Rundale Beck (692 273) where a diversion was made following the footpath down the northern side of the beck to its junction with Swindale Beck (Knock). Adjacent to the footpath several erratic blocks of Shap Granite were located. Lake District ice advanced right across the Vale of Eden to the front of the Pennine escarpment, although there is no evidence that it overrode the escarpment in the Cross Fell-Dufton Fell area. In the vicinity of the stream junction, several faulted blocks of Silurian strata outcrop (see Burgess, Rickards & Strachan, 1970, Fig.3), but because of snow-melt it was not feasible to cross Swindale beck. A ridge on both banks of the stream is due to a dyke of lamprophyre with prominent biotite phenocrysts. Similar dykes occur over a wide radius around Shap and are thought to represent an early phase of the end-Silurian to Devonian igneous activity.

Returning to the Rundale ford, the party now followed the footpath along the northern flank of Dufton Pike, noting in passing examples of volcanic rock-types in the scree material derived from scattered outcrops of the Borrowdale Group high on the slope of the Pike. The view into Great Rundale drew comparison with the morning mapping exercise. The crags of Melmerby Scar Limestone 'vee' into the head of the valley above screes of Orton Group and Basement Bed sandstones and conglomerates; Brownber Hill is formed in Skiddaw Group rocks which are reverse faulted over the limestone of Rossgill Edge. At the head of Great Rundale is the site

of the Pack Mule Mines - an extensive series of levels which sought galena from a number of east-west trending veins. Within the last few years, attempts have been made to opencast work some of the old veins to extract the former gangue mineral, barytes.

The party now turned south to follow the mine track back to Dufton where the leader was thanked for a most interesting day and for sharing his enthusiasm for the area with everyone present.

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THE LOWER CARBONIFEROUS NEAR ORTON

Leader: A. Day

25th April, 1987.

The group met at Orton at 10.30 a.m. and proceeded by car along a minor road to Sproat Ghyll Farm. Here the party leader pointed out the relevant features and gave an account of the local geology.

Near Orton rocks of Lower Carboniferous age form two escarpments trending NW-SE. The lower of the two escarpments crosses the Tebay-Orton road just north of Tebay Bridge, the village of Orton being on the dip slope. The upper scarp is the more dominant feature forming Orton Scar north of the village. Regional dip between 5° and 10° NE brings much of the succession to the surface even if covered by thick drift deposits.

The lowest beds, the Basement Beds of Shap Conglomerate, were laid down in a fluvial environment on the eroded edges of the folded Bannisdale Slates. They are coarse basal conglomerates, fining upwards and followed by passage beds of sandstones and grits. The succession changes to predominantly shallow, lagoonal, marine sediments consisting of muddy, much dolomitised, limestones and shales. These pass up into marine limestones deposited in

warm, shallow, shelf seas. Regressive episodes of sandstone sedimentation within the limestones occur later in the sequence.

The Geological Survey made the original survey in the late 19th century. Garwood in his studies of the limestones of N.W. England established zones and marker bands on fossil content and correlated the limestones of Westmorland with those of Grange and Furness and the Askrigg Block in the early part of this century. Many workers since Garwood have made specialist studies in many parts of the area.

Looking west from Sproat Ghyll Farm, the eastern edge of the Shap Fells, consisting of folded Bannisdale Slates, slope down to the valley of Birk Beck. The wet marshy slopes in the foreground are on Shap Conglomerate and the ground to the north with its limestone scars rising to Bousefield Howe belong to the Lower Carboniferous.

At 600 075 just beyond the motorway bridges, by the roadside, an outcrop of grey-green Shap Conglomerate was examined. Pebbles of vein quartz and various fragments of volcanic rock were identified in the grey-green sandy matrix, the clasts being derived from Borrowdale Volcanic rocks to the west and north-west. The overall green colour indicates a more marine environment of deposition compared with the coarser red conglomerate below. Since the matrix supports the pebbles it is a paraconglomerate. Since clasts are of several rock types the conglomerate is a polymict. The beds dip eastwards at about 5° , the lime content increasing upwards.

The cars then proceeded via Scout Green and Greenholme and were parked at the roadside NE of Bridge End. The party walked across a field to the east side of Birk Beck (599 061). In the bed of the stream are steeply dipping Silurian Bannisdale Slates. There are large pebbles of locally derived Silurian mudstones and shales, the clasts being well rounded and of some considerable size, but with little matrix. The clasts are self-supporting so the bed is virtually an orthoconglomerate of one rock type, i.e. an oligomict. The bed appears to have been torrential river deposit, perhaps a piedmont fan into which a sandy matrix later filtered down.

At Tebay Bridge (619 057) on the north bank of the River Lune and east of the bridge the middle division of the Shap Conglomerate outcrops. The rock is a coarse red sandstone with abundant mud-flakes. The mud weathers out leaving elongated holes in the sandstone. It is a penecontemporaneous mud flake conglomerate. The division is fairly thick and was laid down by a substantial river system. At low water the mud and silt would be deposited and become hardened subaerially. Flooding would break up the hardened layer and the mud flakes would be incorporated in new layers of sand deposit.

At Raisgill Hall Bridge (634 058), the section on the north bank of the River Lune is difficult of access and was viewed from the south bank. Exposed are passage beds of shales and sandstones, cut by a fault, which link the Shap Conglomerate with overlying Chadian limestones.

Lunch was taken in Knott Lane (639 081) below the hill known as Knott.

After lunch the group walked along Knott Lane across the Michelinia grandis horizon and up the dip slope of the Ashgill Sandstone. At the end of the lane near the old kiln where Holkerian Ashfell Limestone outcrops, the members turned east tracing exposures of the thin posts of limestones in shales, the latter representing minor regressions. The limestones show false bedding and abundant chert and include the brachiopods Linoprotonia and Davidsonia carbonaria. At higher exposures in a small quarry these were well exposed, together with Chaetetis. Sedimentation details of the limestone deposition showed up very well. Ascending the hillside a possible small NE-SW fault was crossed and outcrops of the Potts Beck Limestone were examined. The limestone is local to the area, lying at the base of the Asbian and has interleaved sandstones and shales unlike the overlying Knipe Scar Limestone. It lies in the Lower Dibunophyllum Zone of Garwood, and higher beds yield the corals Palaeosmilina, Dibunophyllum and Axophyllum spp.

The top of the hill is covered with Knipe Scar Limestone of Asbian age. The limestones are equivalent to the Lower and Middle part of the Urswick Limestones around Grange and Ulverston and the upper part of the Great Scar Limestone of Ingleborough. The Bollandoceras (Berichoceras) hodderense stage is the upper part of the D1 zone of Garwood. The limestone is weathered to a typical pavement surface and the bed carries an open synclinal fold. The SW end of the fold carries NE-SW trending faults and the edges of the Knipe Scar Limestone hereabouts show gravity fall akin to camber. After examining the effects of the faults on the Potts Beck Limestone, the group returned to their cars and dispersed.

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OLD MINES OF THE ROUGHTON GILL VALLEY

Leaders: F. Lawton & M. Sanderson

17th May, 1987

20 members and friends met at Fellside Farm (NY 306 375), near Caldbeck, and walked south along the old mine road towards Roughton Gill Mine. The first part of the traverse was over tuffs of the High Ireby Formation, Upper Eycott Group, while further south rocks of the Binsey Formation, Lower Eycott Group, were exposed.

The first mining relics seen were in the Hay Gill area where the site of a smelter (301 362) built in 1794 was located, with its old flue running up the fellside to the east. The Dale Beck Level on the south side of the gill (307 360) was an adit driven in a porphyritic lava with large labradorite phenocrysts in a fine-grained green matrix while a dressing floor higher up the gill yielded several minerals.

Further south along the old mine road a long shallow gash with a fan of debris at its foot was pointed out on the eastern flank of Brae Fell (298 357). This was the remains of a 'hush' in lavas and tuffs of the Binsey Formation, an old mining technique used to expose veins by the sudden release of a large volume of water. The party continued to Red Gill Mine (285 348) where lunch was taken. The Dutch level at this location, thought to be Elizabethan in age, is famous for rare minerals and this was confirmed by finding the deep blue mineral Linarite ($\text{Pb,Cu(SO}_4\text{)(OH)}_2$) as well as commoner minerals such as galena, chalcopyrite and malachite. At the head of Red Gill it was noted that Skiddaw Slates are overthrust on to the younger Binsey Formation.

From Red Gill the party returned to the old mine road, passing Dry Smale Gill Mine and its dressing floor. Just before reaching Roughton Gill, the lines of the North and South Roughton Gill Veins were observed on the fellside (302 340). The main ores were galena, chalcopyrite and malachite, but mineralisation of these veins decreased towards the overthrust. The party then moved up the right side of the gill past the 90 fathom adit, worked in 1849, and the 45 fathom adit where a large quartz vein is visible on the right side and green malachite on rocks in the gill.

The final leg of the excursion was eastwards past a ruin, believed to be the Lainton Engine Shaft of 1866, to the Mexico Mine spoil tips (305 345). Here specimens of the green/yellow mineral pyromorphite were found with traces of malachite. The return route was past the bottom of the main spoil heap, where a granite crushing wheel 1.7m in diameter was seen, then back along the old mine road to Fellside.

GLACIAL, PERIGLACIAL AND OTHER FEATURES
IN DOVEDALE AND AT LITTLE HART CRAG.

Leader: Dr.R.Clark

13th June, 1987.

The group assembled at Cow Bridge near the outflow from Brotherswater. Dr. Clark described how the shallow lake was impounded on an older valley infill by a fan of debris from the Hartsop valley which held two of the several glaciers that developed locally in the short but severe Loch Lomond Stadial.

It was pointed out how the stream from Hartsop had, sometime in past centuries, been artificially channelled so that the fan could be cultivated as the Low Hartsop open fields, and the outflow from Brotherswater had been diverted into a walled channel on the west side of the valley, in places above the level of the alluvial flats, to improve the meadowland.

Above Brotherswater the inflow had also been channelled to improve the open fields of High Hartsop. On their enclosure in 1861 the river was diverted into a second artificial course: the original braided channels can still be traced across the valley floor.

As the party approached Hartsop Hall the leader pointed out the prominent cove on Caudale Moor and explained that although it held only a small glacier in the Lomond Stadial, there were several clearly-defined recessional moraines arranged in three groups. Also visible, high on the flank of Caudale Moor, is the set of abandoned quarries in cleaved water-lain tuffs and the complex of sledge tracks linking them to the Kirkstone road.

From the vicinity of Hartsop Hall it was also possible to pick out the synclinal bedding in tuffs outcropping in the cliffs on Black Brow. The route taken was to cross and re-cross the synclinal axis before returning to Hartsop Hall. On the south side of the valley massive boulders left by flood erosion of moraines have been incorporated into earthworks of a prehistoric site. There was some discussion on how such large boulders reached and were transported by the glacier.

Between the old settlement and the foot of Caiston Glen the party considered:

(i) the set of moraines at the northern foot of Kirkstone pass, trying to decide which of them might belong to the Lomond Stadial, and whether any might tell of ice activity at the end of the Late Devensian glaciation.

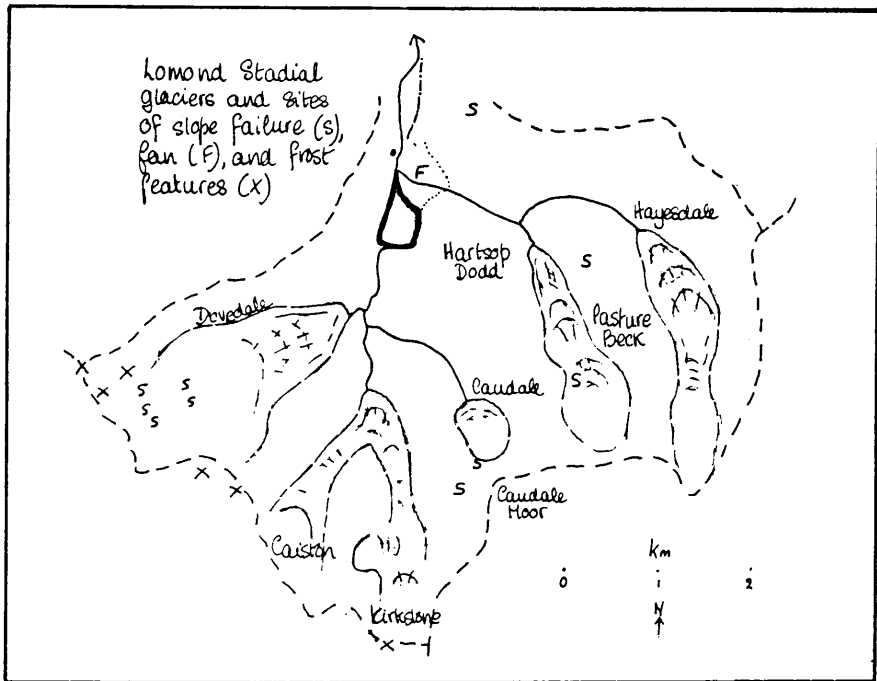


Fig.1 DOVEDALE AND HARTSOP AREA - SKETCH MAP

(ii) the slope failure scars high on Caudale Moor above the old quarries, whether due to simple instability, possibly association with valley-deepening by ice, or triggered by recent earth movements on the Ambleside lineament (certain similar features elsewhere in the Lake District are close to and parallel with lineaments).

Causton Glen, by which the group reached high ground at Scandale Pass, was a rather unfavourable site for growth of a Lomond Stadial glacier. There are small moraines at the foot of the glen adjacent to the Kirkstone moraines, but the party was non-committal about recognition of moraines further up the valley. A small undocumented mine part way up the glen was examined, and galena, pyrites and arsenopyrites found.

Steep scree-clad slopes on the west side of the glen give way as the pass is approached to more gentle slopes below Little Hart Crag and on them the rock debris, mainly of tuffs, is arranged in a series of fairly horizontal steep-fronted benches (ten in 300m in one transect) among which Scandale tarn and a number of lesser pools are enclosed. The benches were explained as periglacial in

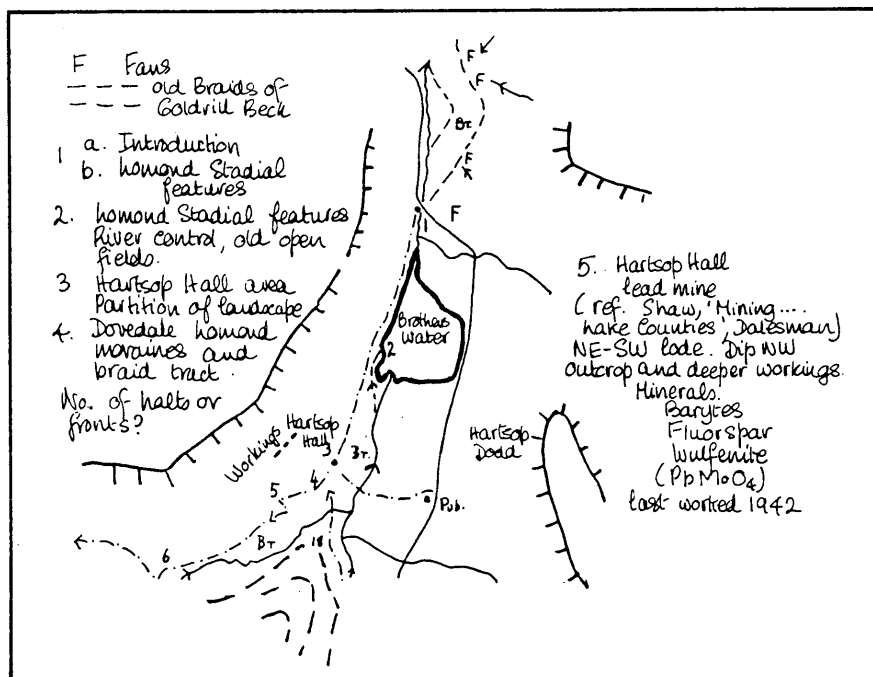


Fig.2(a) GLACIAL AND OTHER FEATURES OF BROTHERSWATER AND DOVEDALE

origin combining characteristics of large solifluction terraces and rock glaciers and probably formed in the Loch Lomond Stadial in an area generally swept clear of snow and enduring large temperature changes. Similar features are found in Houndshope Cove and on Dove Crag nearby.

Little Hart Crag is an isolated mass of rhyolitic lava on a thick pile of pyroclastic rock units. It is close to the synclinal axis and is the youngest of the volcanic rocks in the locality. Remarkably contorted flow-banding is very prominent in the weathered rock faces. The paths by which frost-detached debris passed the outcrop to the fringing talus and rubble slopes are also clearly evident.

The ridge crest from Little Hart Crag to Dove Crag holds good examples of close vertical cleavage in tuffs, periglacial weathering, and old peat banks once disputed between Ambleside and Hartsof. In the descent below the cliffs of Dove Crag into Dovedale some of the local rock-fall sites were passed, one notable for its long, narrow, bifurcated, and sharply-defined trail of broken rock. Though generally associated with severe periglacial

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Fig.2(b) GLACIAL AND OTHER FEATURES OF BROTHERSWATER AND DOVEDALE

conditions rock-falls still occur, one 'brand-new' example being on the cliffs of Seat Sandal only 3km to the west.

The descent into Dovedale led past the uppermost Lomond Stadial moraines, over the rock step, to moraines which mark the separation during retreat of the two feeders to the main glacier. A short diversion was made to the site of the lead smelter already described as ancient on a map of 1764. The leat, wheel pit, furnace and ore tip can be identified. Thence an easy walk on the valley floor past a set of recessional moraines took the party to the old Hartsop lead mine abandoned in about 1942. There the excursion ended, the leader being thanked for selecting a route which demonstrated a diversity of features; some of the members stayed a while to continue exploration of the old buildings and workings.

EXCURSION TO THE PENRITH SANDSTONE

Leader: Dr.F.J.Cockersole

6th September, 1987

This excursion was based on natural and quarry exposures of the Penrith Sandstone in the general area of Bowscar approximately 4km north of Penrith.

The members foregathered at the roadside on the crest of the westward facing escarpment of the Penrith Sandstone on the Bowscar to Lazonby road at MR 519 345. By way of introduction, Dr. Cockersole explained that the Penrith Sandstone originated in Lower Permian times as an aeolian sand-sea in an arid, sub-tropical environment at a latitude of between 10 and 30 degrees north of the equator. There was an inter-montane, largely fault-controlled, basin of deposition with marginal alluvial fans, composed of much-brecciated material and possibly playa lakes. Towards the centre of the basin there were extensive dune-fields and it was the remnants of these dune-bedded sand deposits that were to be examined during the excursion.

The first exposures visited were in the nearby disused Bowscar Quarries (520 344). Well-preserved, steeply dipping, thick foreset beds of sand-dunes that must have been 25-30 metres in height were pointed out. Large-scale dune cross-bedding, with

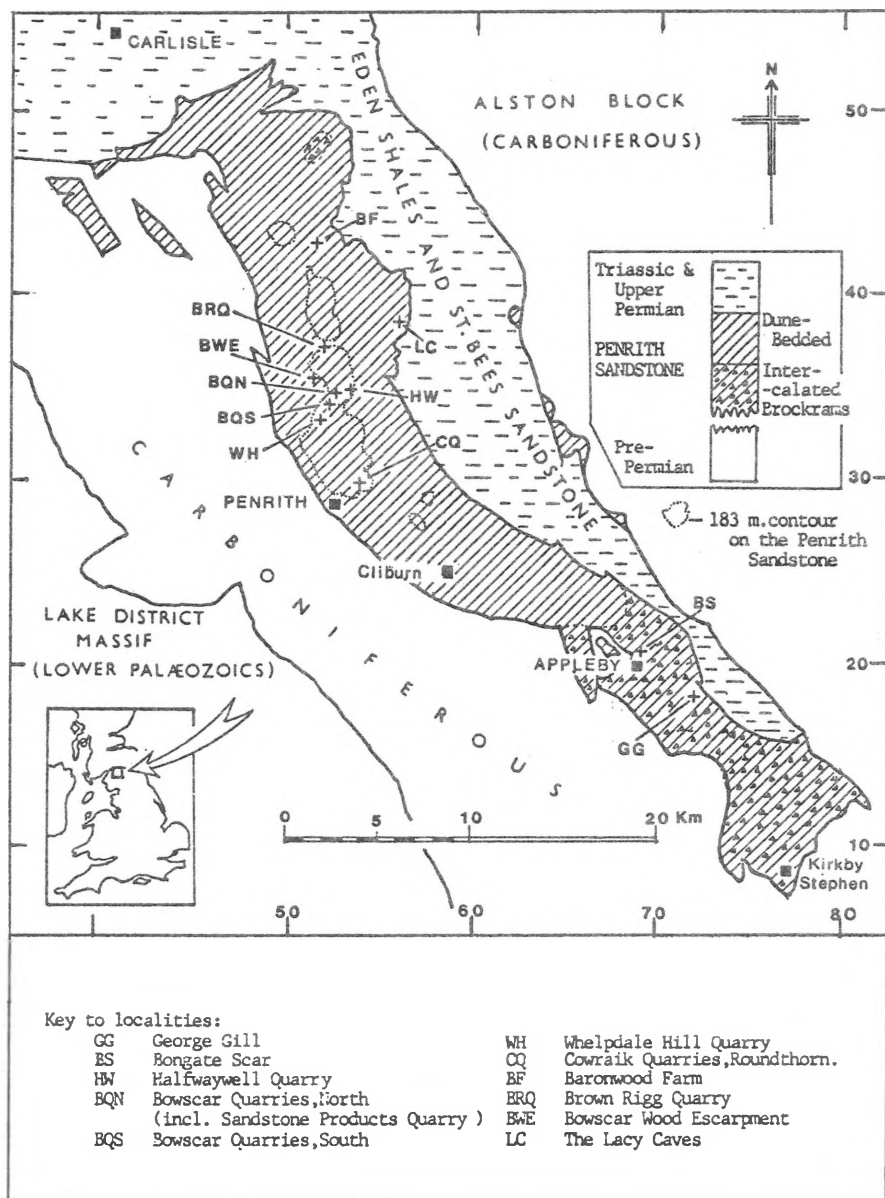


Fig.1 GEOLOGICAL AND LOCATION MAP OF PERMIAN AND TRIASSIC ROCKS IN THE VALE OF EDEN.

planar and wedge-planar sets of laminae, are characteristic of all exposures in the area. The leader showed how the cross-bedded foresets were truncated above by a gently-dipping, sharply defined bounding surface, perhaps representing a plane of aeolian erosion formed in front of the advancing superimposed dune. These features have been seen in America and elsewhere when contemporary dunes have been artificially sectioned.

The party next proceeded to a natural exposure on the edge of the escarpment at Bowscar Wood (512 314). From this vantage point an excellent overall view was obtained of the extent of the present outcrop of the Penrith Sandstone, from Barrock Fell in the north to Penrith Beacon in the south, and a general idea was gained of the basin of deposition between the Lake District mountains in the west and the Pennine escarpment to the east. In this locality, also, the previously noted features of fossilized dune remnants were identified. At one point the leader tried to persuade the sceptics in the party that certain peculiar impressions on an exposed foreset might be reptilian footprints, which have been found elsewhere in the Penrith Sandstone.

The next step was to inspect a series of abandoned shallow quarry pits and excavations in a general area centred on MR 523 347. These exposures allow many readings to be made of the dips and the dip directions of the foresets representing the lee-faces of a number of dunes. Dr. Cockersole explained that from such data the palaeowind direction could be deduced. After making allowance for subsequent continental drift and rotation, it turns out that, in Permian times, the territory must have been in a north-easterly Trade Wind belt, north of the equator, in an environment very like the Sahara Desert today. In addition to the palaeowind direction, measurements provided evidence of the morphology of the dunes that were formed. It seems that in the centre of this particular basin, the dune-field consisted of crescentic, transverse dunes of the barchan type, perhaps packed closely together so that continuous sinuous crest lines were formed.

Finally the party made its way to Halfwaywell on the Penrith to Lazonby road, at MR 534 355, where, with the permission of the Quarry Manager, a visit was made to the only remaining working quarry in the Penrith Sandstone. It appears that a single dune structure is in the process of excavation yielding high quality blocks and slabs of building stone. It was explained that the quality of the stone, here and in other localities where it has been quarried in the past, is due to the unusual degree of secondary cementation of the rock with authigenic quartz. In thin section, the Penrith Sandstone is seen to be composed of very characteristic, large, well-rounded quartz grains known as 'wind grains'. These show that the material had been transported some distance and well-sorted in the process, and was possibly derived

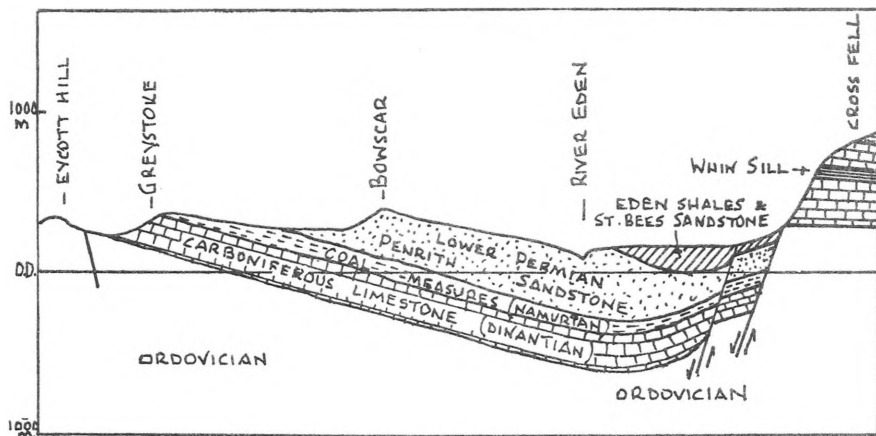


Fig. 2 SKETCH CROSS-SECTION, E - W ACROSS THE VALE OF EDEN
(vertical scale considerably exaggerated).

from the Namurian Millstone Grit deposits of Yorkshire. The grains also have a thin coating of iron salts, giving the rock its attractive pinky-red colour, and outside this coating the secondary quartz has been deposited in the form of euhedral crystals optically continuous with the grains themselves and locking them firmly together. The post-depositional diagenetic processes giving rise to these and other features were discussed.

The latter part of the excursion was enlivened by the sound of rapid and repeated gunfire rather too close for comfort. Thinking that this might be local youths indulging in war-games or shooting rats in the disused quarries, the party thought it prudent to return to the cars by a more circuitous route, only to discover that the disturbance was occasioned by a meet of a large number of clay-pigeon enthusiasts blasting off in a field with several butts in operation.

The President, Tom Shipp, thanked the leader for a day full of interest, not least because the Penrith Sandstone is a formation not often visited by the Society.

LECTURE REPORTS

THE EVOLUTION OF NORTHERN ENGLAND DURING THE PERMIAN PERIOD

A lecture given on the 20th September, 1986,
at the Derwent Centre, Cockermouth, by
Dr.D.B.Smith, President of the Yorkshire Geological Society.

In early Permian times Britain lay near the centre of the super-continent of Laurasia in equatorial latitudes, resulting in day temperatures of 55-60°C which produced high evaporation rates. The Hercynian orogeny left northern and western Britain as regions of high relief with many intermontane areas with internal drainage. The Vale of Eden was typical of these intermontane valley basins with outwash fans around the flanks and thick deposits of aeolian sandstones occupying the centre of the basin. Flash floods shifted enormous quantities of coarse debris from the surrounding highland to form the marginal fans which were later cut by alluvial streams that transported sand and pebbles up to 8km into the basin. A sand sea accumulated in the basin where the sand was transported by wind to form sinuous dunes at right angles to the direction of the prevailing winds while the finer sediments had been removed by deflation. The mid-Vale landscape must have resembled that of Death Valley in California today.

The early Permian land surface on the eastern side of northern England was very different, for here a peneplained pediment resulted from some 30 million years of erosion during which nearly 1,000m of Carboniferous rocks had been removed by deflation. The oldest Permian deposits in this eastern region are the yellow sands lying in the Carboniferous basement in longitudinal parallel ridges, each 1 to 2km wide and up to 60m high, separated by belts where sand is thin or absent. The first thin marine sediments, known as the Marl Slate, deposited over these sands marked the flooding of the region by the Zechstein Sea in Upper Permian times. The dune structures were preserved, perhaps due to the rapidity of the flooding. The Irish Sea basins were also flooded at this time to form the Bakevillia Sea, but the speaker concentrated upon the eastern area in what is known as the Southern North Sea Basin. Here four cycles of marine sedimentation (EZ1 to EZ4) can be recognised and are illustrated in Figure 1.

The first cycle (EZ1) is a lenticular carbonate formation, up to 70m thick with oolites and many species of invertebrates in a fine-grained dolomitic limestone. This limestone shows much evidence of widespread submarine slumping, perhaps triggered by

THE GEOCHEMICAL EVOLUTION AND GEOTHERMAL POTENTIAL OF
U.K. GRANITES WITH PARTICULAR REFERENCE TO THE LAKE DISTRICT

A lecture given on the 5th November, 1986
at West Cumbria College, Workington by
Professor G.C.Brown of The Open University

Most geothermal developments have been based on underground steam fields associated with volcanism; most geothermal sites are located on presently active 'plate' margins. The principle is to drill boreholes to intersect an aquifer, perhaps at 2km depth: the steam produced drives turbines connected to alternators and the condensed water is re-injected.

Though a survey for oil in the Paris Basin was largely unsuccessful, hot water was found - not hot enough for power station use - but a zone of domestic heating has been coupled up via a heat-exchanger. Hence technology is well developed already to exploit both high temperature steam fields and somewhat lower temperature sedimentary formations containing hot water in aquifers.

Surface heat flow measurements (with a mean approaching 60 milliwatts per square metre) over the U.K. have been contoured to produce a heat flow map now available from the B.G.S. Warmer areas than average occur in the East Highlands, Lake District, East Midlands, Worcester and Devon/Cornwall. Some of these are areas where there is underlying radiothermal granite. Different granites contain greater or lesser abundances of the radioactive isotopes of uranium, thorium and potassium, chiefly in micas and feldspars, which generate heat as they decay. Over the outcrop of the Carnmenellis Granite heat flow readings were around 140mW m^{-2} , whereas its surrounding sediments showed only half that heat flow.

The 'hot-dry-rock' concept of exploitation is to drill down into the granite two boreholes, an injection well ('I') and a production well ('P'). Small charges are exploded at the base of each well to produce enough cracking to facilitate the passage of water which is then pumped down until the cracks expand and a hydraulic connection between the two wells is established. An early attempt, following drilling down to 2½km depth in Cornwall, failed however: the injected water did not come up. Probably pre-existing fracture patterns had been misinterpreted, and there

may have been some kaolinised granite below. A further attempt at the same depth in 1986 has proved much more successful. If the project is to become economically viable for power generation, then boreholes to a depth of 5km will need to be considered by the Central Electricity Generating Board.

Should Cornish exploitation become successful, where else might be tried? Radioactive element concentrations give some indication. From a map showing uranium, thorium and potassium contents of granites in Northern England and Scotland, possible areas with high contents might be the Cairngorms, Weardale, Shap and the Lake District. Two heat flow holes have been drilled in the Lake District on the strength of these radioelement data, and four in the eastern Highlands. The shape of the granite also needs to be known in order to calculate crustal temperatures, hence a gravity survey was done first.

Depths to the Shap Granite surface based on the interpretation of the negative gravity anomaly indicate that the granite extends towards Haweswater. Drilling was done near the top of Shap Fell and temperature increase with depth was about 24°C/km and surface heat flow was 77mW m⁻²; rather disappointing results from a geothermal point of view. A sample from 100m depth was of normal pink granite: from 200m to at least 230m was grey granite - not a 'xenolith' of country rock, but igneous material. On plots of Si, Th, Zr, U, Rb or Zn, each against a borehole depth, perhaps most significant was the grey granite's lower silica percentage of 65-68%, whereas the pink granite contains 70% silica. Probably the grey granite is a precursor magma pre-dating the present pink granite magma: the first crystals would be of higher mafic content. In places a dark crust may have formed: later, lighter coloured melt may have burst through it. The older stopping concept, leaving 'xenoliths', is in question for the Shap Granite inclusions, and the small, very dark patches (which also occur in other granites), may well be fragments of earlier crystallised margin, not pieces of altered country rock.

The only accessible outcrop of Skiddaw Granite at Grainsgill is complicated by mineralisation, so permission was obtained to make a temporary track to take a drill rig up the Caldew Valley: the position of the drill site was also constrained by gravity contours. The top 40m of core showed much-altered granite (like the Grainsgill exposure, containing greenish sericite), and to that depth, plots of mineral concentration/depth were completely irregular. Between 40 and 100m, however, was clean white granite, and below 100m a grey granite of rather lower silica content.

Even for altered granite samples, ratios of a certain element to the relatively immobile elements titanium and zirconium can indicate magmatic fractionation related to depth. For Skiddaw Granite, the Na₂O/TiO₂, K₂O/TiO₂ and SiO₂/TiO₂ ratios show departures from magmatic trends where hydrothermal processes have

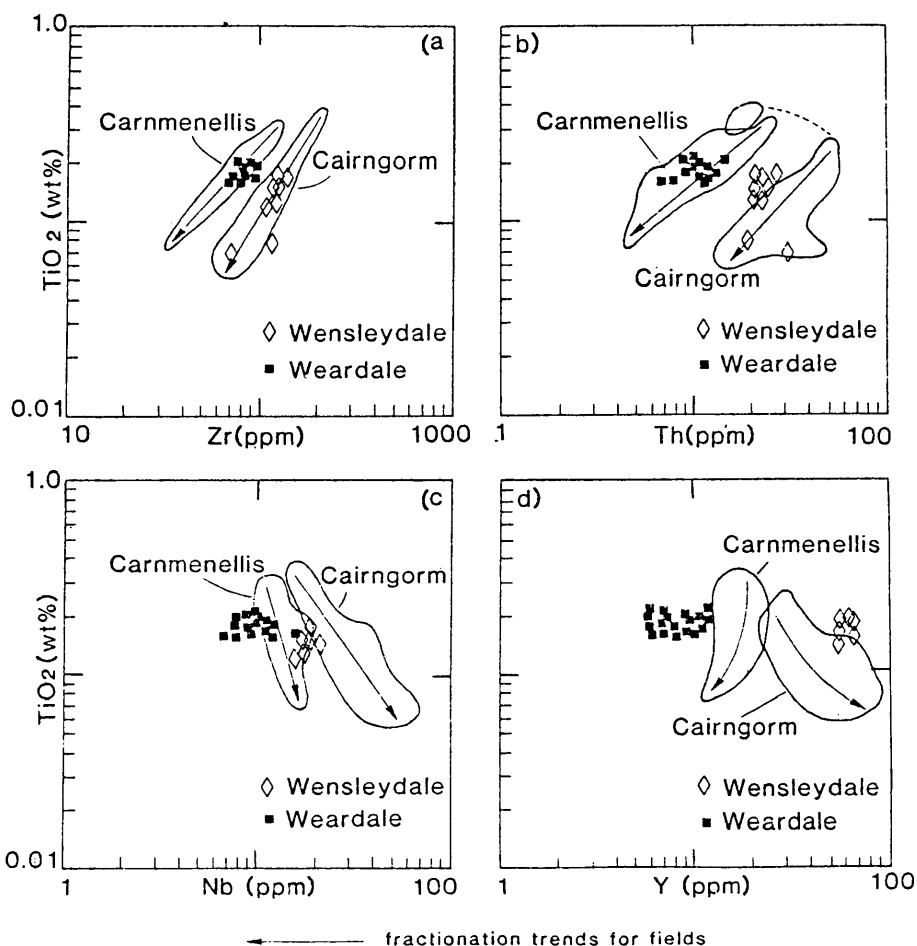


Fig.1 FRACTIONATION SEQUENCES OPERATING IN THE MAGMATIC EVOLUTION OF CARNMENELLIS AND CAIRNGORM PROVINCE GRANITES

been involved; for example, a lot of sodium has been removed. Plots of $\text{TiO}_2/\text{ZrO}_2$, BaO/TiO_2 and ZnO/ZrO_2 showed mobilisation of Ba and Zn compared with zirconium, again due to hydrothermal processes. Zinc removal may be important in the genesis of mineral veins.

The Caldey borehole had a temperature gradient of $36^\circ\text{C}/\text{km}$ and at the surface the heat flow was 10mW m^{-2} . This is the highest U.K. heat flow yet measured outside Cornwall and could be of

geothermal interest in the longer term. In comparison the Rookhope borehole into the Weardale Granite shows 95mW m^{-2} and Raydale (Wensleydale Granite) 65mW m^{-2} .

For differing depths of rock types in the same crustal heat flow province, heat flow 'Q' is proportional to surface heat generation from radioactive sources, 'A'. The proportionality constant differs in different heat flow provinces and until recently it was thought that the whole of the U.K. was one such province. However, the new data show that at least two provinces (perhaps north and south of the Iapetus suture) must be involved. For example, the Cairngorm Granite gave $Q = 76\text{mW m}^{-2}$ and $A = 7.3\mu\text{W m}^{-3}$ whereas Carnmenellis gave $Q = 108\text{mW m}^{-2}$ and $A = 4.0\mu\text{W m}^{-3}$ so there is a paradox unless they belong to different heat flow provinces.

Ti and Zr contents show that clearly defined but different fractionation sequences operated during the magmatic evolution of Cairngorm and Carnmenellis - the two U.K. granites which have been studied in most detail from a radiothermal viewpoint. The data for Weardale (Figure 1a) and, indeed, for Skiddaw show many similarities with those of Carnmenellis, whereas Wensleydale and Shap are most similar to Cairngorm. Having defined fractionation trends using Ti and Zr it is possible to find out what happens to radioelements during fractionation. For example (Figure 1b), thorium decreases with magmatic evolution (towards lower Ti values) in both types of granite, though the more mafic rocks in the Cairngorm pluton may evolve to increasing Th values, hence the tentative 'dog-leg' trend shown. High field strength elements such as Nb and Y (Figures 1c and d) - these are elements with large cation charges) are more strongly fractionated (towards increasing values with magmatic evolution) in the Cairngorm-Wensleydale-Shap type magmas than they are in the Carnmenellis-Weardale-Skiddaw type. This important observation, which also affects uranium, is due to the fact that these elements (Nb, Y, U etc.) form anion complexes early in the crystallization history of the Cairngorm type magmas and these complexes do not become concentrated in crystalline minerals until late in the crystallization process. What this means is that uranium is much more strongly concentrated towards the roof in Cairngorm type intrusions than those of the Carnmenellis type.

Putting all this geochemical evidence together, Figure 2a shows contours of heat production overlain on the uranium-thorium fractionation trends for both Cairngorm and Carnmenellis. U and Th both increase with fractionation in Cairngorm and so, therefore, does heat production. The strong decrease in thorium towards the roof of Carnmenellis is probably compensated by a slight increase in uranium such that heat production is almost constant with fractionation. Thus Figure 2b shows how heat production will vary beneath the outcrop at Cairngorm (strongly depleted with depth) and

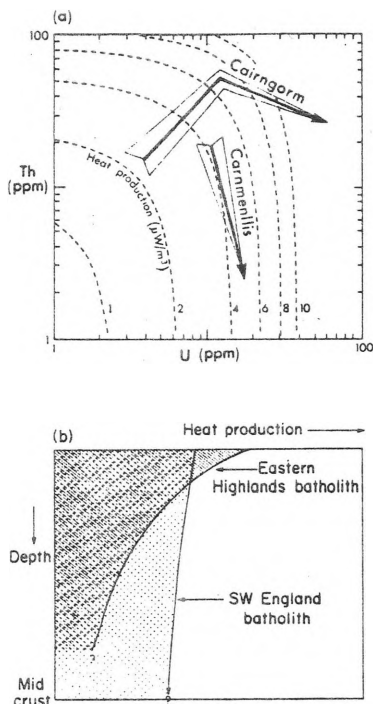


Fig. 2. (a) Proposed fractionation paths in U,Th space for the Cairngorm and Carnmenellis Granites, representing the Eastern Highlands and SW England batholiths, respectively (after Webb *et al.* 1985). U,Th space is contoured for heat production assuming a constant potassium content of 4% in granites. Arrow heads indicate the direction of fractionation. More evolved products of a fractionation series are volumetrically less important than less-evolved representatives, therefore the width of the bands reflects the greater volume of less evolved rock expected at depth within a granite batholith. (b) Schematic representation of conjectural heat production/depth profiles for the Eastern Highlands and SW England batholiths, based on the fractionation paths in (a) and geothermal models for the two areas (see text for references). For each curve the area of ornament represents the contribution to surface heat flow from heat production within the batholith.

at Carnmenellis (only weakly depleted at depth). The conclusion is that geochemical parameters, such as variations of elements like Nb, Y and U with fractionation in available surface samples can be used to determine which type of granite we are dealing with. Granites of the Carnmenellis-Weardale-Skiddaw type have the higher hot-dry-rock geothermal potential because their heat production is volumetrically much more significant than granites of the Cairngorm-Wensleydale-Shap type. We now understand, much more fully, the reasons for the heat production - heat flow paradox described earlier.

The conclusion for geothermal energy in the U.K. is that sub-surface temperatures of 100°C at, say, 3km depth, particularly where there is a cover of suitable sedimentary rocks with low thermal conductivity (e.g. mud rocks, shales etc.), could provide a hot water supply following the Paris Basin model. Steam supply for power

production would need 200°C, at perhaps 6km depth in granite. A number of granites are now known, from gravity and seismic readings, to underlie well-populated or industrial areas in the Midlands and Southern England. Figure 3 is a Heat Flow map of the U.K. and illustrates these variations.

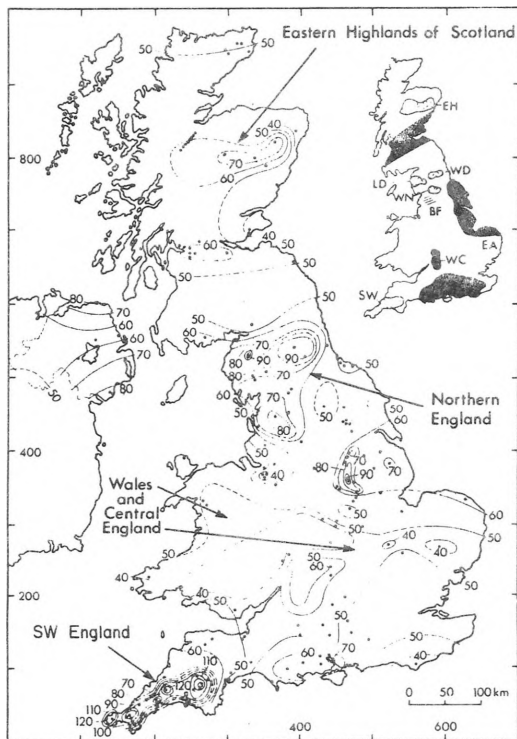


Fig. 3. Heat Flow map based on the Geothermal Map of the UK (BGS 1986). Dots indicate the locations of heat flow measurements. Inset shows granite batholiths, sedimentary basins and other areas referred to in text: EH, Eastern Highlands batholith; WD, Weardale batholith; LD, Lake District batholith; WN, Wensleydale batholith; SW, SW England (Cornubian) batholith; WS, Wessex basin; WC, Worcester basin; YL, East Yorkshire and Lincolnshire basin; MV, Midland Valley of Scotland; BF, Bowland Forest Area; EA, East Anglia.

At question time it was established that the Cheviot Granite had not been investigated geothermally: it is not a typical subduction-related granite. The hot-dry-rock technique has been pioneered at Los Alamos in the U.S.A., but the granites of S.W. England may not become a geothermal power source until well into the next century. The London Basin is unlikely, but the Hampshire basin is likely as a hot water source.

The term 'Lake District Batholith' was not relevant to the geothermal question as only its cupolas were investigated. Some parameters to guide future exploration are obtainable now from ordinary surface samples. Eskdale would be interesting to drill, there being little alteration.

In geothermal exploitation there can indeed be problems from minerals mobilising in cycling water: pumps were blocked in the

Paris Basin: some separation (though mainly gases) is done in Italy: geothermal hot water cannot be supplied direct to houses because of the potential pollution problem; heat exchangers are used. The pressures involved in geothermal stations are not a problem. If water was not re-cycled, the water table might be altered and the production aquifers might become exhausted.

Thanks to Professor Brown were expressed by the President.

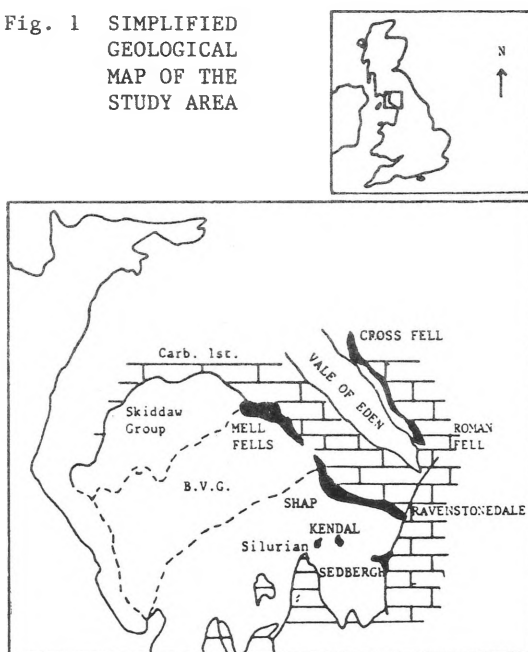
FACIES VARIATIONS WITHIN THE BASAL LOWER CARBONIFEROUS CLASTIC ROCKS IN EAST CUMBRIA

A lecture given on 3rd December, 1986, at
Derwent Centre, Cockermouth by
Dr.R.N.Kimber of Robertson Research International

The basal section of the Lower Carboniferous succession surrounding the Vale of Eden consists of a dominantly clastic sequence of variable thickness which unconformably overlies the Lower Palaeozoic basement and which in turn is overlain by the lowest Carboniferous Limestones. To the south of the study area in North Yorkshire, these limestones of Arundian - Holkerian age rest directly upon the Lower Palaeozoic basement.

The clastic rocks are exposed in five main areas - Shap, Mell Fell (Ullswater), Cross Fell, Sedbergh and Ravenstonedale

Fig. 1 SIMPLIFIED
GEOLOGICAL
MAP OF THE
STUDY AREA



which are shown on Figure 1. They are representative of an alluvial fan. Fluvial deposition and facies analysis, in association with palaeocurrent and clast provenance studies, provides 'a powerful tool' in reconstructing the regional palaeogeography. The facies terminology used follows the braided-fluvial facies scheme of Miall (1977, 1985) which incorporated the contained sediment structures of each lithofacies to erect a sub-facies. This sub-facies classification is summarised in Table 1 (following page) and applies to each area.

Table 1. LITHOFACIES AND SUB-FACIES DIVISIONS ERECTED ON CONTAINED SEDIMENT STRUCTURES.

CONGLOMERATE FACIES 'G'	'Gm'	clast supported conglomerates
	'Gms'	matrix supported conglomerates
	'Gp'	planar cross-bedded conglomerates
	'Gt'	trough cross-bedded conglomerates
SANDSTONES 'S'	'Sp'	planar cross-bedded sandstones
	'Sh'	horizontally laminated sandstones
	'St'	trough cross-bedded sandstones
	'Sr'	ripple cross-bedded sandstones
MUDSTONES 'F'	'Fl'	laminated mudstones
	'Fm'	massive mudstones

Shap Red Beds

The succession exposed between Shap Wells and Scout Green and varying in thickness between 5m and 130m comprises three lithofacies - conglomerates, sandstones and mudstones - which form a fining-up sequence. The conglomerate lithofacies at the base is characterised by boulder-cobble conglomerates (facies Gm) that are massive to horizontally stratified, locally imbricated and organised into fining-upward units up to 4m thick. Trough- and planar-cross-bedded conglomerates (facies Gt and Gp) also occur, as grouped or individual sets interbedded with facies Gm and overlying it, and which are in turn transitional to trough-cross-bedded sandstones (facies St). The sequence is capped by mudstones (facies Fl/Fm), up to 1m thick, which contain rare incipient calcrete nodules.

These sequences are interpreted as the aggradation of channel bar complexes (cf. Vos & Tankard, 1981) with the dominance of facies Gm indicating deposition within a braided-fluvial environment (Rust, 1984). This facies represents accumulations of gravel as longitudinal bars, the characteristic fining-up trend being a reflection of downstream clast-grading to the bar form. Facies Gt and St represent infill of minor channels and scour depressions on the bar surface during the waning flow stage as the flow is diverted onto the bar surface and away from the main channel tract. The silty mudstone member reflects accumulation of fine-grained sediment in an overbank area and records the abandonment of the active channel complex as the flow is diverted elsewhere. These facies relationships are closely comparable with those present in the modern River Donjek, Yukon (Williams & Rust, 1969).

In a northerly direction sandstone lithofacies predominate over conglomerate and occupy the main part of the fining-upwards sequences, up to 11m thick and characterised by thick (up to 6m)

festoon co-sets of facies St with interbedded sets of facies Sp sandstones. Facies St is gradationally overlain by horizontally laminated sandstones (facies Sh) which in turn is overlain by current-rippled silty sandstones (facies St) and silty mudstones (facies Fl/Fm). This sandstone-dominated part of the overall fining-upwards sequence is interpreted as the deposits of sandy bed-load channels, facies closely comparable with those in present-day South Saskatchewan River, Canada (Cant, 1978). This northward change from conglomerate to sandstone lithofacies, associated with consistent N to NNE palaeocurrents, reflects the progressive evolution from a granular bed-load channel system into a sandy bed-load regime, and can be equated with a reduction in source area relief and the superposition of fine-grained sediments upon coarse over a period of time.

Mell Fell Conglomerate

The Mell Fell Conglomerate (of the order of 250m thick) which outcrops to the west and north-west of Ullswater also exhibits a large scale fining-up sequence. Facies Gm is dominant in the south and south-west, but in a general NE direction exhibits a decrease in clast size (80cm to 8cm), increase in abundance of cross-stratification and cross-bedding and the development of fining-upward sequences until facies Gt is dominant in the north. Significantly the latter preserves finer-grained, stratified pebble conglomerate units, trough-cross-bedded conglomerate and pebbly sandstone (facies Gt and St) and cross-bedded sandstone sets (facies Sp) and intercalations. Thin mudstone drapes are also evident in places.

The dominance of facies Gm towards the south is interpreted as reflecting the dominance of longitudinal gravel bar deposits within a braided fluvial regime, supported by similar fining-up sequences to those described at Shap. The NE variation within facies Gm, particularly the striking decrease in maximum clast size and increase in sandstone content, is interpreted as proximal to relatively more distal variations within a fluvial braidplain. As such this NE depositional trend is associated with a down-stream decrease in channel gradient accompanied by decrease in clast and grain size, these variables being principally a function of lowering of source area relief.

Cross Fell clastic rocks

These rocks also exhibit an overall upward-fining sequence, represented by four lithological groups: Polygenetic Conglomerates, Quartz Conglomerates, Red Sandstones and Green Sandstones. The Polygenetic Conglomerate contains matrix-supported cobble/boulder conglomerate (facies Gms) with interbedded clast-supported pebble-conglomerate (facies Gm) and minor silty mudstone (facies Fl/Fm) intervals. The group is poorly represented with local distribution, with very varied thicknesses ranging from absent to

70m (Arthurton & Wadge, 1981). It is interpreted as the deposits of locally distributed alluvial fans, facies Gms, representing debris flow sedimentation.

The Quartz Conglomerates, characterised by clast-supported massive to imbricated cobble conglomerates (facies Gm), are very similar to the facies Gm described for the Shap Red Bed sections. Sandstone lithofacies within the Red Sandstone (and also the Roman Fell Sandstone, laterally equivalent in the south of the Cross Fell area) comprise an interbedded sequence of facies Sc and Sp, while the Green Sandstone forms an argillaceous top member up to 24m thick and characterised by facies Sh muddy sandstones interbedded with cross-bedded sandstones (facies Sp and Sc). The group is overlain by Carboniferous Limestones of the Orton Group.

The overall fining-upwards sequence, up to 120m thick, reflects the downstream change from proximal (Quartz Conglomerate) to medial (Red Sandstones) and distal muddy (Green Sandstones) parts of a braidplain system with a consistent NE trend. In this context the Cross Fell clastic rocks can be considered as a Donjek to S.Saskatchewan transition in terms of the vertical braided-fluvial profiles of Miall (1985).

Sedbergh clastic rocks

The Sedbergh clastic rocks, which outcrop west of the Askrigg Block in the south of the study area, may be up to 270m thick (Dakyns et al., 1891). The facies developed are closely comparable to the boulder conglomerates (facies Gm) of the Mell Fell Conglomerate, with massive units containing clasts up to 65cm across, interbedded with imbricated units. Palaeoflow direction for these imbricated horizons was towards the NW. Towards the top of the section conglomerates are crudely cross-stratified (facies Gm/Gt) and intercalated with sandstone. Facies Gm within this succession is interpreted as deposits of longitudinal gravel bars which accumulated in a proximal-fluvial environment. Facies relationships are consistent with Scott type braided sequences of Miall (1985) and probably accumulated within relatively high gradient incised channels on an alluvial fan surface.

Pinskey Gill Beds, Ravenstonedale

The Pinskey Gill Beds, up to 29m thick, comprise an overall upward coarsening sequence of silty sandstones, shales and limestones with a diverse faunal assemblage and unconformably overlie the Lower Palaeozoic basement, forming a transition into the Stone Gill Limestone above. They are the facies equivalent to deposits that stratigraphically overlie the Shap Red Beds.

Palaeocurrents and Clast Provenance

Throughout the study region palaeocurrents measured from conglomerate imbrication and cross-bedding, and particularly from trough cross-bedded sandstones, are consistently towards the north

and north-east direction.

Analysis of clast types, both from the conglomerate maximum particle size fraction and sandstone/conglomerate matrix petrography demonstrate derivation from Lake District source rocks, particularly the Skiddaw Group, Borrowdale Volcanic Group, Coniston Limestone Group, Silurian Coniston Grits and various igneous rocks. The latter particularly include minette dyke rock clasts, derived from igneous dykes intruded into the Silurian cover over a large area of the Lake District and probably associated with intrusion of the Shap Granite (Moseley, 1978). These clasts are especially abundant in the distal braidplain facies of the Mell Fell Conglomerate and provide evidence for progressive erosion of the Silurian rocks during deposition of the basal Carboniferous clastics. Indeed, evidence that Silurian rocks, particularly the Coniston Grits, did extend further north than their present outcrop limit is provided by the abundant greywacke clasts in the locally derived coarse proximal boulder conglomerate facies of the Mell Fell Conglomerate. Within the Mell Fell Conglomerate, the upward transition into progressively finer and more distal facies of the braidplain correlates with an increase in variety of clast types, particularly Borrowdale Volcanic, Upper Ordovician limestone (possibly Coniston Limestone), Eycott Volcanic and minette rocks. This is seen as the result of downstream increase in fluvial dispersion of the braidplain with channels able to 'tap' a larger area of the eroded source terrain (Figure 3, Kimber and Johnson, 1986).

Elsewhere, the abundance of Silurian greywacke clasts within the Shap Red Beds and Sedbergh clastics suggests that high ground to the south, i.e. in the region of the Howgill Fells and the Askrigg Block, exposed Silurian greywacke lithologies. The Shap Red Beds also contain locally derived altered Borrowdale Volcanic and Silurian Brathay Flags clasts, these being associated with the metamorphic aureole of the Shap Granite. Indeed, granite and characteristic pink feldspar clasts from the Shap Granite are also locally present within the Shap Red Beds.

The proximal braidplain deposits of the Quartz Conglomerates Group (Cross Fell clastic rocks) contain an abundance of rounded vein quartz which contrasts markedly with the complete absence of such clasts within the alluvial fan deposits of the Polygenetic Conglomerate, which contains locally derived slate lithologies (Murton Formation) and notably decomposed granite which closely resembles weathered Weardale Granite of the Alston Block. The rapid increase in vein quartz is a reflection of the greater textural maturity of the Quartz Conglomerates, the vein quartz being mostly derived from the quartz-veined Skiddaw Slates. The dominant northeast palaeocurrents suggest the likely source terrain was located in the northern Lake District, although derivation from the Murton Formation of the Cross Fell Inlier may also have been possible.

Depositional Model and Palaeogeography

Integration of palaeocurrent data and clast compositions with facies distributions from each area suggest that the succession buried beneath the Vale of Eden represents the proximal to distal parts of a braidplain system (Figure 2). Ongoing denudation of high ground promoted decreasing sediment supply, decreasing channel gradient in progressively distal areas away from source, and this was accompanied by a change in channel bedload and downstream fining of clast and grain size. In terms of Miall's (1985)

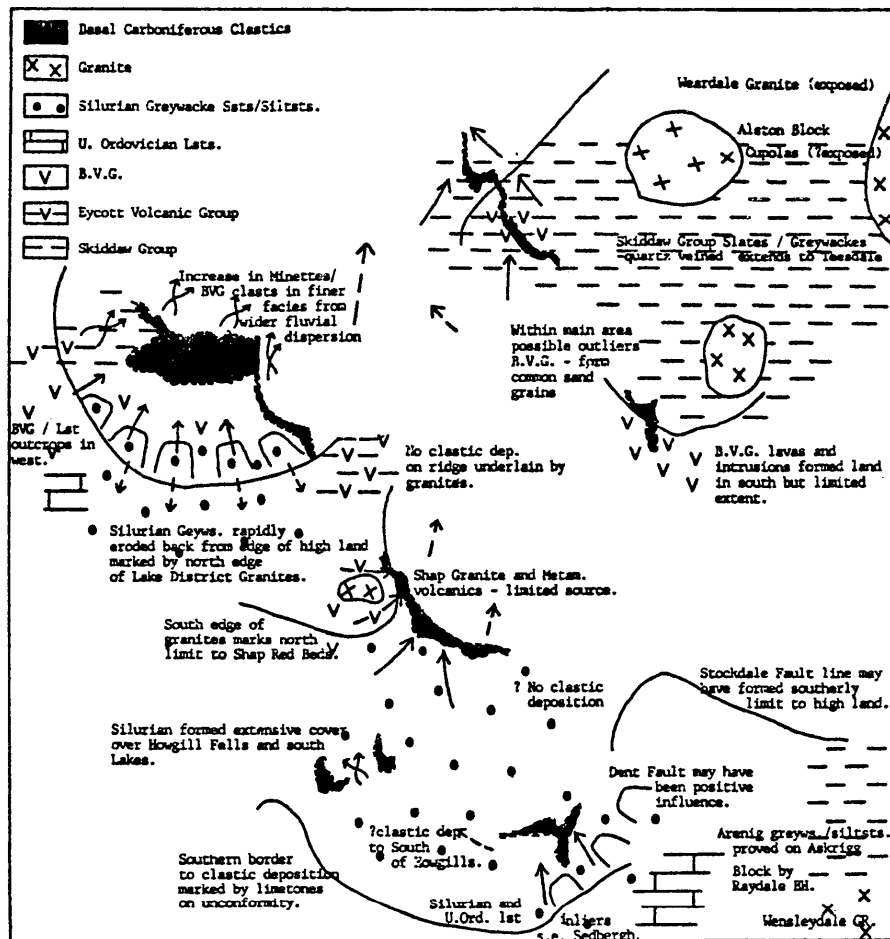


Fig. 2 SUMMARY OF CLAST PROVENANCE AND MAIN PALAEOGEOGRAPHICAL ELEMENTS, VALE OF EDEN REGION.

braided river profiles, the Vale of Eden succession represents a 'Scott-Donjek-South Saskatchewan' transition.

Principal high ground coincided mainly with areas underlain by deep-seated Caledonide granite plutons, i.e. the Lake District Massif, the Alston and Askrigg Blocks, with the area south of Shap and Ravenstonedale (Figure 2) also probably a region of high ground and non-clastic deposition. Indeed, Bott (1974) provides evidence that the Lake District granites may be responsible both for the present elevation and for the past tendency for the region to be uplifted in relation to its surroundings. Alluvial fans accumulated along the margins (e.g. Polygenetic Conglomerate along the western edge of the Alston Block) and in front (e.g. proximal Mell Fell Conglomerate facies) of principal high ground, these being transitional to more extensive fluvial braidplain sedimentation established towards the north and north-east. Towards the south of the region probable alluvial fans, represented by the Sedbergh clastic rocks accumulated north and west of the Askrigg Block. Clastic deposits may also have continued south of Shap, particularly as facies distribution within the Shap Red Beds predict that 'up-palaeoslope' (i.e. towards the south) a transition from 'Donjek' type to 'Scott' type deposits would be expected.

The Pinsky Gill Beds, exposed at Ravenstonedale and seen to overlie the Shap Red Beds at Shap, represent lagoonal-tidal flat deposition, most probably associated with the dominantly east-west marine transgression along the Stainmore Trough during the Lower Carboniferous (Johnson and Marshall, 1971).

Subsequent discussion dealt with the topics of palaeoslope and the 'marine incursion', the influence of climatic factors on the formation of calcretes and the Green Sandstones.

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In addition to the lectures reported the following were also given:

- Mr. E. Skipsey, 'Energy Potential of the Solway Basin'
on 12th March, 1986 at West Cumbria College, Whitehaven.
- Dr. S. K. Monro, 'Putting Geology to Work'
on 8th October, 1986 at West Cumbria College, Whitehaven.
- Mr. T. Shipp, 'Rocks into Sediments'
on 4th March, 1987, at West Cumbria College, Workington.
- Dr. J. R. Coffey, 'Aspects of Engineering Geology'
on 4th November, 1987 at West Cumbria College, Whitehaven.
- Mr. E. Lawrence, 'Opencast Coal'
on 13th January, 1988 at West Cumbria College, Workington.

ROCKS, RELIEF AND GLACIATION IN THE LAKE DISTRICT

A lecture given on 7th January, 1987
at West Cumbria College, Workington by
Dr.R.A.Smith of North Cheshire College, Warrington

Within the past 15 or 20 years a considerable body of data has accumulated which enables us to reconstruct environmental events during the final phases of the Quaternary. The quality of this data is, however, highly variable. The fullest record of events exists in lowland situations. In an area like the Lake District on the other hand, glacial activity was predominantly erosional in its effects and has consequently removed most of the earlier evidence of the terrestrial record. Hence reconstructions have to be based primarily on the morphological evidence of relict glacial land forms.

We now have a fairly good picture of the last 115,000 years of Quaternary time - the period of the Devensian. Reconstructions of average July temperatures over lowland Britain for this period based on coleoptera assemblages indicate wide oscillations. The early Devensian was dominated by continental anti-cyclonic conditions. Whether glaciers existed in the Lake District during this phase is a matter of conjecture. As yet there is no unequivocal evidence in the terrestrial record which indicates glaciation at that time. At the very least we must assume severe permafrost. Undoubtedly temperatures were low enough to permit glacier development, but it is questionable whether precipitation was high enough to generate and sustain glaciers. In the late Devensian there was a significant climatic shift to a more oceanic regime. Many sources of data suggest strong cyclonic activity over western and northern Britain and steep west-east climatic gradients.

The significant feature of the late Devensian was the growth and expansion of an ice sheet to cover two thirds of Britain; beginning around 30,000 years BP and lasting until about 13,000 BP. Boulton et al. (1977) suggested a model for this ice sheet from which it can be suggested that the surface of the ice dome over the Lake District at its maximum (about 18,000 BP) was around 1600m - i.e. just over 600m above the tops of the highest mountains. In round terms it took approximately 15,000 years to build up, but only 5,000 years to waste away. At the maximum phase the surface temperature on the ice cap was about -18°C , with basal temperatures

beneath the ice between -6°C and -4°C . Estimated velocities in the ice are low - around 10m/year. It seems reasonable to postulate, therefore, that with sub-melting point temperatures of this nature and low ice velocities, such conditions around the maximum phase would not be conducive to high rates of erosion. Ice could have been largely protective. Erosion was thus primarily achieved during the build up phase and probably more particularly during the rapid ablation phase. For more than half the Devensian phase ice was largely confined to the corries, high snow fields and major glacial troughs. In the final 5,000 years ablation rates were high, glaciers were of the temperate type, moving relatively quickly. Locally there could have been striking variations in accumulation rates, in ablation, and hence in erosional intensity. The evidence of the landforms bears this out.

Lakes and Tarns

A count of lakes and tarns in Cumbria from large scale O.S. maps reveals a total of 1006. 775 (77%) are natural features. 627 lie in glacially eroded rock basins, the majority of which (58) are small ice-scour lakes on summits, ridge tops, mountain ledges or cols. Only 28 are corrie tarns. 19 can be classified as piedmont (ribbon) lakes on the floors of the main glacial troughs.

The lakes and tarns show a strong relationship to the bedrock geology - 344 (45%) lie on the Borrowdale Volcanic Group, 270 (35.3%) on the Silurian, yet only 21 (2.7%) on the Skiddaw Group. The areas of the three outcrops are broadly similar. The major lakes basins in the west and south-west of the district are in general terms the most perfectly eroded deep rock basins; they are deep for their size, have simple basin forms and contain no islands. They represent valley troughs where glacial erosion was both effective and efficient. They also lie at lower altitudes than the other major basins. This suggests that ice may have been moving quickly and had free egress down the westerly and south-westerly troughs. Ice was able to sweep the trough floors free of obstructions. The relatively low altitudes suggest high accumulation rates of snow and the ability of glaciers to be sustained at heights near to sea level.

The distribution of the lakes and tarns, apart from the correlation with the bedrock also shows a high concentration south of the main east-west divide, particularly in the area due south of the high ground of the central high fells. Much of the topography of this area is identical to the 'knock and lochan' landscapes of the Hebrides and Western Scotland.

Corries

The morphology of these landforms in Cumbria is well documented (Clough, 1977). There is strong geological control evident in their distribution, with a preponderance on the

Borrowdale Volcanic outcrop. In general terms, however, corries are relatively poorly developed in the Lake District. Only 28 of the 199 corries distinguished in Clough's analysis contain tarns. The fitting of logarithmic curves of the type suggested by Haynes (1968) confirms this trend. No corries produce k values greater than 1.5 ($k = 2$ is a well developed shape). The majority of the k values fall below 1.0.

Glacial Troughs

The walls of the major troughs north of the main divide, and more particularly in the east of the district, are far more intact than those in the west and south. In the east, troughs of an 'Alpine' type exist - self contained dendritic networks with few examples of diffluence. An examination of where diffluent tongues managed to cross divides shows a preponderance in the west and south. The main east-west divide has been crossed in several places. All this accords with active ice movement streaming southwards from the knot of the central fells.

Much of the valley network is adjusted to the underlying structure - parts of every system show alignment along faults, strike directions or other lineations. In total probably more than 60% of the system shows structural control.

Two broad themes are evident. First, glacial erosion varied a great deal in its intensity from one part of the Lake District to another. There is a noticeable west-east gradient in intensity. In the west and the south-west the combination of glaciers moving down relatively steep gradients within short distances, debouching ice on to the West Cumbrian plain and into Morecambe Bay, and an oceanic climate producing not only high snow accumulations but also high ablation rates, produced erosion of high intensity.

This is evidenced by deeply scoured troughs, deep lake basins, diffluent ice scouring of interfluves producing 'knockan' ('hows' in Cumbria) and numerous small ice-scour lakes. In contrast to the east, particularly north of the main divide, glacier systems were largely confined within the valley troughs. Valley gradients are lower and valley floors higher above present sea level. Snow accumulation could have been significantly reduced by the rain-shadow effect.

The second theme demonstrates the strong geological control of the present topography. The response of the major rock groups to glacier scouring and quarrying varies widely. The classic landforms of corries, lake basins, and over-deepened troughs are best developed in the igneous outcrops.

It is probable that the adjustment of the landscape to the underlying geological structure has been a long process; one which has been proceeding ever since the Lower Palaeozoic materials were revealed by sub-aerial erosion. Much of the present valley

pattern must have been established long before the Quaternary. Devensian ice moved across the geological and topographical grain in the south and south-west of the district. Structural lines must have been exploited here by earlier erosional activity.

The effects of the late Devensian ice sheets and glaciers must not be over-stated. It was a phase of relatively short duration and around its maximum the ice may have been largely protective. The amount of erosion actually achieved need not have been high. It can be demonstrated that in the nearby Yorkshire dales, in Kingsmere for example, the amount of valley floor lowering is only about 13 metres. The fact that a large percentage of Lakeland valleys are aligned along structurally weak lines could suggest that these were etched to considerable depths by stream action pre-glacially. Lake District corries remain enigmatic features. Of the ones that exist today few are well developed. We have no good evidence of how old they are. It is difficult to know whether they could have been protected from glacial erosion when the Devensian ice sheet was at its maximum - it is tempting to argue that some well developed basins in west and central Lakeland may even have been partly destroyed by Devensian ice, especially when it is remembered that some of the most perfect forms lie in the east where the intensity of erosion was certainly lower.

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THE LAKES AND TARNS OF CUMBRIA

A lecture, given on 16th September, 1987 at
Derwent Centre, Cockermouth by
Dr.R.A.Smith of North Cheshire College, Warrington

A count of the lakes and tarns of Cumbria using 1:25,000 and 1:10,000 scale Ordnance Survey maps reveals a total of 1006. Of these, just over three-quarters appear to be natural features and form the subject of this lecture.

A possible classification suggests they fall into 14 types (Table 1). Whilst the majority owe their origin to glacial activity in the Pleistocene period, a considerable number have other origins (types F - M).

A significant group (L) lie on peat, notably in Pennine Cumbria, but also on other flat summit areas. These are clearly post-glacial in age and date from after 7500 BP. Their size and origin relate to the way deep peat on flat summits erodes. Small pools emerge where breaks in the vegetation cover occur, and wave action leads to erosion and undermining of the banks - a process that becomes more effective as the area of open water enlarges.

Many mountain tarns owe their origin to landslipping and rock fall. Instability of slopes was common as the Devensian ice sheets wasted away around 13,000 BP and was probably further boosted by the cold climates of the Loch Lomond Stadial (11,000 - 10,400 BP). Sand Tarn on Great Boar Fell or the Yoredale sequence is a good example. Damming by prolonged rockfall can be invoked for Greendale Tarn (Wasdale) and also for Goat's Water (Coniston).

The process of deltaic deposition causing the separation of major ribbon lakes as best exemplified by Bassenthwaite Lake and Derwentwater appears too simplistic. Considerable boulder clay plastered over rocky knolls in the isthmus area between the two basins casts doubts on the extent of this process. Alluvial damming of Brotherswater on the other hand is clearer.

Five different glacial landsystems can be distinguished within Cumbria, each characterised by lake and tarn basins of distinct type.

First, around the Devensian maximum (18,000 BP) ice was able to move as a sheet, scouring and abrading the landscape up to the highest summit levels, across ridges and plateaux. Under such conditions numerous 'ice-scour lakes' were produced, on summits, on

Table 1. A CLASSIFICATION OF LAKE/TARN BASINS IN CUMBRIA

	No. in Cumbria	Type Examples
<u>LAKES FORMED BY GLACIAL ACTIVITY</u>		
<u>GLACIAL ROCK BASINS</u>		
A. Ice-scour lakes (on shattered and mature surfaces) (i) on summits and ridges (ii) on ledges (iii) in cols	A. 580	Seathwaite Fell Tarns, Eel Tarn, Beacon Tarn (i) Lank Rigg, Illgill Head (ii) Broadcrag Tarn (iii) Red Tarn (Wrynose), Beckhead Tarns
B. Cirques	B. 28	Blea Water, Angle Tarn
C. Valley rock basins formed below the snow-line by glacial corrasion (Piedmont lakes)	C. 19	Wastwater, Ennerdale
<u>DRIFT BASINS</u>		
D. Lakes in kettles in drift filled valleys	D. 51	Tosh Tarn, Woodhow Tarn
E. Lakes in kettles in pitted outwash plains (simple and compound types)	E. 42	Barfield Tarn, Tarns Dub
<u>LAKES DUE TO FLUVIATILE ACTION</u>		
F. Fluvatile dams - deposits of deltas dividing an original lake into two	F. 2	Derwentwater, Bassenthwaite (?)
G. Oxbows or isolated loops of meanders	G. 1	River Ehen
H. Lakes in depressions formed on flood plains by uneven aggradation	H. 6	Allan Tarn, Out Duba Tarn
<u>LAKES FORMED BY LANDSLIDES</u>		
J. Lakes held by rock slides	J. 2	Sand Tarn
K. Lakes held by scree dams formed by prolonged rock fall	K. 1/2	Greendale Tarn, Goat's Water (?)
<u>LAKES FORMED BY ORGANIC ACCUMULATION</u>		
L. Closed phytogenic basins (ponds on peat bogs)	L. 42	Little Rundale Tarn, Seamore Tarn
<u>SOLUTION LAKES</u>		
M. Tecto-Karsatic lakes, formed by solution in tectonically determined basins	M. 1	Argles Tarn
<u>LAKES PRODUCED BY HUMAN ACTIVITY</u>		
N. Dams	N.) 231	Wet Sleddale Dam, Gurnal Duba
O. Excavations	O.)	Tilberthwaite Quarries

ledges, and in cols where ice was transgressing watersheds. Second is a distinct group of cirque or corrie lakes. In general few are well developed forms.

The major ribbon or piedmont lakes lying in the floors of the major glaciated troughs form the third group. They are largely the product of block removal, particularly where ice was well confined by steep trough walls.

They occupy true trough basins. Their shape, size and depth are good indexes of the efficiency and intensity of glacial erosion. It is these lake basins that give 'radial symmetry' to the district, rather than the drainage lines. The pattern of the lake basins helps our understanding of the movement of Devensian ice.

The fourth and fifth groups of lakes and tarns lie in the low-lands, peripheral to the central core of Lakeland fells. A complex landform assemblage is developed at the fell-lowland margin, where erosional and depositional forms exist, complicated by meltwater activity. On the more distant till plains of the Solway and West Cumbria, kettle hole features and lakes produced by down-wasting ice in situ occur.

CALDERA VOLCANOES - PAST AND FUTURE

A lecture given on 7th October, 1987 at
West Cumbria College, Workington by
Dr.R.Macdonald of the University of Lancaster

Calderas range in diameter from 1km to tens of kms. The well known eruption of Mt.St.Helens in May, 1980, left a 2km caldera, At the other end of the spectrum, the Yellowstone volcano complex erupted some 600,000 years ago to form an elliptical caldera with a 70km long axis. The scale of the eruption is also marked by the volume of pumice and ash ejected, 1km^3 and $1,000\text{km}^3$ respectively.

Eruptions close in scale to that at Yellowstone probably occur about 10 times every million years; crudely speaking, each order of magnitude decrease in size is probably accompanied by an order of magnitude increase in probability of occurrence.

Many major caldera-forming eruptions, recognised by the associated ash flow tuffs, have been identified throughout the geological column, back to Archean times. They will undoubtedly occur again in the near future, geologically speaking. The hazards presented by such eruptions are poorly understood. However, in an eruption on the Yellowstone scale, all animals and plants within an area of about $30,000\text{km}^2$ would be killed by ash flows. Ash particles in the atmosphere can be transported across enormous distances, and can cover areas of 10^6km^2 . The potential effects on agriculture in, for example, the United States, are obvious. Even more worrying, injection of dust into the atmosphere may affect the Earth's climate by blanketing our solar radiation. Some models have likened the possible effects to nuclear winters.

There is clearly a great incentive to predict such major caldera eruptions. The most violent tend to occur in silica-rich magmas (dacite-rhyolite) within continental crust. No one tectonic setting has a monopoly, however; active continental margins, rift valleys and areas of lithospheric attenuation, such as the Basin and Range Province, all have examples of major caldera systems. A possible indication of a future caldera eruption might be the leakage of high silica magmas up an arcuate zone which could be the site of a developing ring fracture, e.g. the Mono Craters, California. Active rhyolitic dome fields may be sites of expanding magma chambers which could be potential sites of caldera formation. Geophysical studies of such fields are warranted. Even in existing caldera volcanoes, little is known about the warning signs of imminent ash flow eruption and further caldera collapse. The infrequency of such eruptions has left a poor observational base.

SOME ASPECTS OF THE GEOLOGY AND GEOGRAPHY OF SVALBARD

A lecture given on 2nd December, 1987, at Derwent Centre, Cockermouth, by the Society's President, Mr.T.Shipp

This year (1987) it was my good fortune to join the British Schools Exploring Society's Expedition to Svalbard as Deputy Chief Leader. Svalbard is a group of islands with a total land area approximately the same as that of Scotland. The group lies between 74°N and 81°N latitudes, and between 10°E and 35°E longitudes. This puts the archipelago within 1000km of the North Pole, and in this location it should be well and truly locked in polar ice. However, the northernmost extension of the warm Gulf Stream divides in the North Atlantic, one branch turning east around the North Cape of Norway into the Barents Sea, the other continuing north along the west coast of Spitsbergen, the largest of the Svalbard islands. This results in an anticlockwise circulation of surface water in the ocean gulf between Svalbard and Greenland, and whilst the east coast of Greenland is locked in sea ice for most if not all of the year, Svalbard, and more particularly Spitsbergen, can expect to be free of sea ice during the summer months.

The maximum encroachment of sea ice appears to occur in March, whilst in August there is usually no sea ice to be seen, only occasional small bergs that have broken from the snouts of land-based glaciers.

At about $78\frac{1}{2}^{\circ}\text{N}$, the location of the Expedition, the sun is constantly above the horizon between 19th April and 23rd August. The sun describes an elliptical path in the sky, rising at mid-summer to a maximum of 34° above the horizon, and declining to a minimum of 12° above the horizon at midnight.

The British Schools Exploring Society was founded in 1932 by Surgeon Commander Murray Levick, R.N., who had been a medical officer on the ill-fated expedition led by Scott to the South Pole. The Society set out to give boys an opportunity to experience living in the wilderness for a few weeks, undertaking a variety of adventurous and scientific projects. For much of its history the Society was firmly associated with boys' public schools and activities in Arctic or Subarctic regions. During the past few years the Society has widened its scope, accepting youngsters, girls as well as boys, from all walks of life, and extending its activities into hot, as well as cold climates.

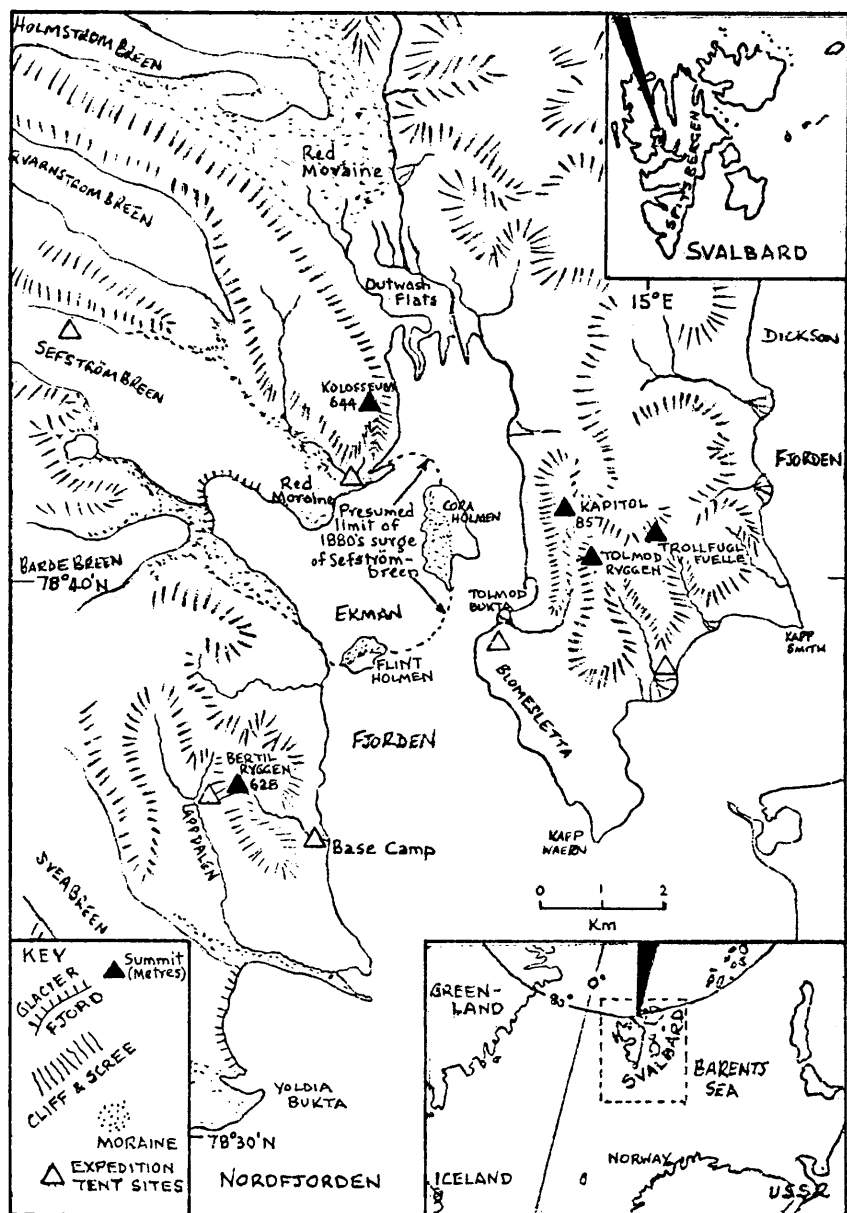


Fig.1 SKETCH MAP OF PART OF SPITSBERGEN, SVALBARD

During 1987 the Society organised two Expeditions, each one taking about 60 youngsters and 20 leaders, to Papua New Guinea and to Svalbard.

The Chief Leader of the Svalbard Expedition was Commander Chris Furze, a Royal Naval Engineer who had previously led Joint Services Expeditions to overwinter on Elephant Island and on Brabant Island in the Antarctic. I was his understudy, to take over the organisation in case of need. My only claims to Arctic experience were a visit to Iceland (1983) and a previous B.S.E.S. Expedition (1984) to Arctic Norway, although it was felt that my general mountaineering experience, particularly in rescue work, would be useful.

In the event, I took charge of the advance party, arriving five days before the main Expedition in order to organise stores and transport. During the Expedition itself, I helped to look after a group of young people whose main task was to undertake a bird census along the eastern side of Ekmanfjord extending towards Dicksonfjord. I also had the task of making a systematic collection of rock specimens from the Carboniferous for an analysis to be made, back in England, of their microspore content.

The recorded history of Svalbard starts with its discovery in 1596 by the Dutch navigator Willem van Barendzoon (after whom the Barents Sea is named). The large schools of whales led to whaling activities, principally by Dutch and English operators, which nearly wiped out the Greenland Whale. The Dutch, who had a summer settlement of about 200 workers at Smeerenburg ('Blubbervtown') in the northwest, named the islands Spitsbergen ('Spiky Mountains'). The English adventurers, for political reasons, preferred to call the large western island 'Greneland'. The present name of the archipelago, Svalbard, is derived from an obscure reference to a 'Cold Coast' in Icelandic records dating from the 12th century.

As the whaling declined, the slaughter of living creatures continued on land where, during the 18th and 19th centuries, Russian trappers made inroads into the natural population of polar bears, arctic foxes, reindeer and seal. Today, trapping is a very minor activity, rigorously controlled. The Expedition visited one trapper living on the eastern side of Dicksonfjord, Dr. Harald Solheim, a 'retired' microbiologist.

Coal deposits had been discovered on the islands, and mining commenced in earnest at the beginning of the 20th century. The principal settlement, Longyearbyen, is named after an American mining engineer who founded the principal mines in 1906.

The competition by various countries, particularly Holland, Britain and Denmark/Norway, for the natural resources of Svalbard meant that the fate of the islands could not be left to chance, so after lengthy discussions a Treaty was established in 1920 recognising the sovereignty of Norway. This Treaty was ratified

in 1925, with the signatory countries entitled to rights of mineral extraction. At the present time coal is exploited by the Norwegian Store Norsk Spitsbergen Kulkompanie (S.N.S.K.) at Longyearbyen and Sveagruva, with a production of about 400,000 tonnes per annum. The Russians also have two mining settlements, at Pyramiden and Barentsburg, producing about the same annual tonnage of coal. The total (winter) population of Svalbard is about 4,000. The coal is exported, as ice-conditions in the fjord permit, during the summer months.

Communications with the outside world have improved with the opening of an all-weather airport in 1975. Increasingly, in addition to mining and other commercial traffic, scientific expeditions and tourism are being catered for. The Sysselman's (Governor's) Expeditions Officer reported more than 130 assorted groups entering and leaving via Longyearbyen in 1986. Each group must be self-contained, bringing its own equipment and food, and must have means of fending off inquisitive (and potentially dangerous) Polar Bears. The B.S.E.S. Expedition imported over 15 tonnes of food and equipment, including three Gemini rubber dinghies. We were, however, able to buy petrol and paraffin locally, and to charter local coasting vessels to ferry stores and people to and from the Expedition area, about 40km to the north.

It was very important to make the Sysselman aware of the Expedition's plans, for there was some apprehension on the part of the Norwegian authorities about the influx of such a large number of 'untried' youngsters. The Administration seems happy to welcome expeditions from abroad, provided that they cause no trouble and leave no permanent mark on the landscape.

In the event, even with 88 people out in the wilds for more than six weeks, apart from a few cuts, scrapes, burns and mosquito bites, the worst injury suffered was a sprained ankle. One of the main problems in a wilderness area is the disposal of garbage. All burnable rubbish was incinerated, helped by the plentiful driftwood along the shores of the fjords. Cans were squashed and, along with bottles, sunk in deep water. Loo pits were dug, sometimes with difficulty as the soil was usually waterlogged or permafrosted (or both). These pits were carefully covered after use, as it takes many years for organic wastes to decay in the Arctic.

Geological development of Svalbard

The oldest rock sequence in the archipelago, dating from Precambrian to Silurian (Downtonian Stage), is known as the Hecla Hoek Formation. It is located principally on the western coastal strip, and in the north east, and, apart from erratic boulders, was not encountered during the Expedition.

Caledonian folding, mostly of Mid to Upper Silurian age, in these ancient rocks shows a N-S trend. Other effects of

Caledonian disturbance, found in northern Svalbard, include the emplacement of granites of two main types, (i) red, non-foliated granite, and (ii) grey, strongly foliated granite. These granites may be further differentiated as 'in situ', showing a transition from Hecla Hoek metasediments through gneiss, to granite, and 'intruded' granite.

The Caledonian disturbance resulted in uplift, folding, faulting and erosion on a massive scale, resulting in a series of conglomerates fining upwards, valley fill and deltaic deposits of late Silurian to early Devonian age. The prevailing red colour of these deposits suggests an arid climate at the time, and these deposits are known locally as the Red Bay Formation, overlain by the finer-grained Wood Bay Formation. Following a break in the depositional sequence during the Middle Devonian, the climate appears to have become more humid, resulting in fine-grained clastic sediments of the Grey Hoek Formation and the Wijdefjord Formation. These four formations may be thought of as the Svalbardian equivalent of the Old Red Sandstone of Scotland.

Uplift, downwarping, folding and faulting have resulted in these Devonian rocks being preserved in the N-S graben which runs through the central axis of Spitsbergen. The older Hecla Hoek rocks are found on the flanking horsts.

Following a further break in deposition, resulting in a plane of unconformity clearly seen at the top of the red beds in N.W. Ekmanfjord and in Holmstromdalen, the climate during the Lower Carboniferous became humid and subtropical. A series of sediments described as Culm Measures was deposited; sandstones, shales and thin coals (exploited by the Russians at Pyramidene). These Culm Measures pass upwards into Middle Carboniferous red sandstones with gypsum/anhydrite evaporites, showing increasing aridity of climate during their deposition. These Lower to Middle Carboniferous rocks occur to the east of the area covered by the Expedition, mainly in the Millefjorden region.

Marine deposition ensued during the Upper Carboniferous, extending conformably through into the Permian. Fossils are common, typically the brachiopod Spirifer and the rugose coral Cyathophyllum.

The onset of the Permian is marked by the limestones becoming conspicuously cherty, and merging upwards into black shales containing fusulinids, reptiles, fish, ammonoids, bivalves, sponges, coprolites, and some coals. As with the Permian further south in Europe, there is a markedly arid environment indicated by the occurrence of dolomitic and gypsiferous beds. Following the slight effects of Variscan folding, Triassic black shales and sandy marls with prolific marine invertebrate and vertebrate fossils were deposited. These rocks were encountered on the west side of Ekmanfjord, at the Expedition Base Camp, between Sveabreen and

Sefstrømbreen.

Jurassic and Cretaceous formations, mainly sandstones and shales, but with some coals, occur extensively to the south of Isfjord. The coals are exploited at Longyearbyen, Barentsburg and Sveagruva. Around Longyearbyen, the boundary between Cretaceous and Tertiary is marked by a resistant sandstone which has developed some spectacular erosion gullies.

There are also some early Cretaceous dolerite intrusions to be found invading the sedimentary rocks at various levels around Ekmanfjord. In places, these form impressive lines of cliffs, bringing back memories of High Cup Nick. One intrusion, near the summit of Gaborgnuten, looked very like a classical laccolith, though the majority had simple sill-like forms, sometimes showing transgressive changes of level.

Rocks of Tertiary age, again coal-bearing clastic sediments, are extensive south of Isfjord. Some folding took place during the late Tertiary, principally affecting the western side of Svalbard.

During the Quaternary the whole Svalbard region was uplifted by up to 1,000 metres, and there is some limited volcanic activity in the Woodfjorden area, some of it being post-glacial as shown by the presence of small volcanic cones in a glaciated terrain.

Severe erosion has produced the present dissected plateau topography, with the relatively flat-lying Upper Palaeozoic, Mesozoic and Tertiary strata giving an 'open book' aspect to the geology of much of the region.

Glaciation, formerly much more extensive, has produced the classic sculpted valleys and fjords, picking out and accentuating the N-S and E-W trending faults and folds.

During the 1987 B.S.E.S. Expedition a large number of features of geological interest was seen, and many were investigated. I shall concentrate on two very different aspects; the lithology of the Upper Carboniferous into the Permian, and the historical surge of the Sefstrøm Glacier.

The Expedition was based on the Ekmanfjord area with major glaciers spilling down from the west and a relatively ice-free peninsula in the east between Ekmanfjord and Dicksonfjord. The geological map shows a 'basement' of Devonian, with Upper Carboniferous and Permian above a plane of unconformity rising gently to the north west. The Upper Carboniferous is intruded by Late Mesozoic dolerite. To the west of the fjord, which appears to be fault-controlled, Tertiary rocks occur, whilst a fault through Lappdalen repeats the Upper Palaeozoic sequence further west. Outside the Expedition area, on the west coast of Spitsbergen, the Hecla Hoek Formation is to be found.

My group of 9 youngsters were conducting a seabird survey with

co-leader Mark Evans. Such geology as we did was incidental to the ornithology programme. My main task was to collect samples at 5 metre vertical intervals through the 250 metres of Upper Carboniferous. Location of the lower boundary was not difficult as it formed a clear unconformity above the Wood Bay Series of the Old Red Sandstone. The transition from Carboniferous to Permian could be found by tracing a persistent 2 metre thickness of bituminous limestone containing masses of fusilinids. According to the sketch map, the task would seem to be relatively easy, but I had not reckoned with the awkwardness of the terrain and the intensity of the frost shattering, so I was reduced to collecting from the bases of the cliffs and from shore sections on the east of the peninsula at Kapp Smith. Collection was 'blind' in the sense that the spores (if present) were too small to be seen.

Higher in the sequence there were extensive Permian gypsum beds over 200 metres thick. These showed interesting features including spheroidal weathering, pseudomorphs, and intense frost shattering.

In 1892, Professor De Geer examined the Sefstrøm Glacier and found the snout recessed back into the head of Ekmanfjord, much as it is at the present day.

By 1896 the glacier had surged 6.5km east, practically filling the northern part of Ekmanfjord with chaotically crevassed ice. The ice front lay across Flintholmen and Coraholmen. The moraine deposited by this surge still has a very fresh appearance. Much of it is still ice-cored; mudflows and slumps occur, so care is necessary in walking over it. The prevailing red colour is a reflection of the Old Red Sandstone rocks traversed by the glacier.

The Expedition found evidence that a similar surge had occurred quite recently in the neighbouring Holmstrøm Glacier, but there is no known documentary evidence for this. G.W.Lamplugh, in a paper to the Yorkshire Geological Society in 1910, reports on a visit he made to the area with De Greer. He described and illustrated the continued presence of surge-ice over Cora Island.

Two groups of youngsters in the 1987 Expedition were involved in investigating and surveying parts of the Sefstrøm moraines.

In conclusion, what were my overriding impressions of seven and a half weeks spent in the Arctic? Firstly, it is not a dull place - there is so much to see and do, with 24 hours of summer daylight to do it in. Secondly, there is a tremendous variety in the terrain and a surprising amount of seabird, insect and plant life. Thirdly, an Expedition such as this will not be a happy experience if the participants do not pull their weight and co-operate with one another. I am pleased to report that this Expedition, although not without its worries and hard work, was for me a very happy experience.

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OBITUARY - John J. Martin, B.A.

Conversations with John were always refreshingly interesting and illuminating, such as those enjoyed by C.G.S. and Y.G.S. members visiting some of the old hematite mines in July, 1983. He was the author of notes in Volume 4, part 3, pp. 316-317 of the Society's Proceedings on the development of the West Cumbrian iron industry.

Much of his earlier career was in local industrial chemistry; the latter part with the North West Water Authority. Local industrial history was one of his interests, as were church and community responsibilities and the study of music. Late in his career a study of entomology led to the award of a degree.

However, he was best known for research in industrial archaeology, particularly on the West Cumbrian coastal salt industry. He was a member of the Friends of Whitehaven Museum, Cumberland and Westmorland Antiquarian and Archaeological Society and Cumbria Industrial History Society for all of which he wrote articles or pamphlets, as he did for Allerdale District Council.

John Martin joined our Geological Society early in 1975 with his wife, to whom we extend our sympathy. John died in April, 1987; he will be long remembered.

S.H.G.

ANNUAL DINNERS - 1986 and 1987

The 1986 Annual Dinner was held on 19th April at Mockerkin Hall Hotel when members and friends enjoyed a very pleasant evening. The guests of honour were Dr. and Mrs. Angus Lunn of the Department of Continuing Education, Newcastle University.

The 1987 Annual Dinner was held on 4th April at Mockerkin Hall Hotel when the twenty-fifth anniversary of the Society was celebrated. The guests of honour on this special occasion were Dr. and Mrs. Peter Allen of the British Geological Survey, and Mr. and Mrs. Walter Annis, representing the Westmorland geological Society.

During the evening the President presented the Charles Edmonds Prize to Dr. Allen in recognition of his work as leader of the B.G.S. Lake District survey team from 1984 to 1986. The prize was set up as a memorial to the Society's first president and is awarded in recognition of original work, either amateur or professional, which furthers geological knowledge of some part of the six northern counties of England. The prize has only been awarded on six previous occasions and the awarding panel considered that the work of the B.G.S. team in the Lake District merited this public acknowledgement.

CUMBERLAND GEOLOGICAL SOCIETY

Income and Expenditure Account

Year Ended 31st December 1980

<u>INCOME</u>				<u>EXPENDITURE</u>			
	1986	1985			1986	1985	
	£	£	£		£	£	£
Subscriptions:				Cost of Publications	772.80	-	
arrears for 1985	11.50		8	Cost of Lectures & Excursions			
1986	404.50		472	Lecturers Expenses	144.37		117
advance for 1987	17.50		87	Hire of Rooms	54.20		29
				Hire of Films	-		-
	433.50		567		971.37		140
Sales of Publications	283.21		141	Subs to Other Societies	7.50		17
Royalties from 'Lake District'	136.03		153	Library Books	8.47		5
				Annual Dinner Expenses	292.50		236
Inland Revenue refund	84.59		84	Admin. & General Expenses			
Other Income:-				Printing	183.92		107
Donations	5.33		4	Stats. & Mats.	46.35		12
Bank Interest rec.	206.10		225	Bank Charges	-		-
Annual Dinner	301.00		301	Telephone Calls	17.05		6
Refund on Room Hire	20.00			Postage Charges	163.01		113
				Travel (Petrol)	27.45		28
	532.43		530	Miscellaneous			10
					448.28		277
Total Income for 1986	1469.76		1480	Total Expenditure for 1986	1728.12		731
Surplus/(Deficit) for year	(258.36)		749				
Balance forward from 1985	3090.54		2341				
Balance forward as Revenue	2832.18		3090				
<u>THE CHARLES EDMONDS MEMORIAL FUND INCOME</u>				<u>EXPENDITURE</u>			
	£	£	£		£	£	£
Year's interest on 3½% War Stock	5.10		5	None			
Bank Interest received	4.37		5				
Increase in fund 1986	9.47		10				
Balance forward from 1985	59.42		49				
Balance forward to 1987	68.89		59				
<u>BALANCE SHEET: 31 December 1986</u>							
Capital Employed				Surplus (Deficit) year 1986	(258.36)		749
Assets:-				Accumulated Funds	4280.65		3531
Equipment at Nominal Value							
Stock of Publications	1203.33		1266				
Deposit A/C at Bank	2403.62		2442				
Annual Dinner A/C at Bank	413.60		491				
Current A/C at Bank	9.26		155				
Cash in Hand	5.70		3				
Cheques in Hand	-		-				
Publications Sec. Cash	4.28		10				
in hand							
	4039.79		4307				
Less Current Liabilities							
Creditors (uncleared chqs)	-		-				
Subs in Advance	17.50		87				
TOTAL NETT ASSETS	4022.29		4280		4022.29		4280

REPORT OF THE HONORARY AUDITOR:

To the members of the Cumberland Geological Society
I certify that I have examined the accounts, bank statements, receipts and other financial documents of the Cumberland Geological Society. In my opinion the accounts give a true and fair view of the state of the Society's affairs as at 31st December 1986

J.F. Yearseley (Honorary Auditor)

Brook House,
Dean, Workington.

CUMBERLAND GEOLOGICAL SOCIETY
Income and Expenditure Account Year Ended 31st December 1987

<u>INCOME</u>				<u>EXPENDITURE</u>			
	£	1987	1986		£	1987	1986
	£	£	£		£	£	£
Subscriptions:				Cost of Publications	117.00		773
arrears for 1986	22.98		11	Cost of Lectures & Excursions			
1987	480.75		405	Lecturers Expenses	127.13		144
advance for 1988	75.50		17	Hire of Rooms	29.00		54
		579.23	433	Hire of Films	-		
Sales of Publications	159.29		283			273.13	971
Royalties from 'Lake District'	121.37		136	Subs to Other Societies		27.50	8
				Library Books		-	8
Inland Revenue refund	69.55		85	Annual Dinner Expenses		317.20	293
Other Income:-				Admin. & General Expenses			
Donations	8.05			Printing	117.97		189
Bank Interest rec.	169.23		206	Stats. & Mats.	23.55		47
Annual Dinner	277.00		301	Bank Charges	-		-
Miscellaneous	58.03		20	Telephone Calls	6.55		17
		512.31	532	Postage Charges	156.74		168
				Travel (Petrol)	20.00		27
Total Income for 1987		1441.75	1469	Miscellaneous	60.00		-
Surplus/(Deficit) for year	439.11	(258)				384.81	448
Balance forward from 1986	2832.18		3090	Total Expenditure for 1987		1002.64	1723
Balance forward as Revenue	3271.20		2832				
<u>THE CHARLES EDMONDS MEMORIAL FUND INCOME</u>				<u>EXPENDITURE</u>			
	£		£		£		£
Balance at 1.1.87	68.89		59	Prize presented to Dr.P.Allen	55.00		
Year's interest on 3½% War Stock	2.55		5	Balance at 31.12.87	48.92		69
Bank Interest received	1.77		5			103.92	69
Sale of War Stock	30.71		-				
		103.92	69				
<u>BALANCE SHEET: 31 December 1987</u>							
Capital Employed				Surplus (Deficit) year 1987	439.11	(258)	
Assets:-				Accumulated Funds 1986	4022.29	4280	
Equipment at Nominal Value							
Stock of Publications	1261.99		1203				
Deposit A/C at Bank	2307.20		2404				
Annual Dinner A/C at Bank	386.70		414				
Current A/C at Bank	76.62		9				
Cash in Hand	77		6				
Cheques in Hand	-		-				
Publications Sec. Cash in hand	3.62		4				
	4536.90		4040				
Less Current Liabilities							
Creditors (uncleared chqs)	-		-				
Subs in Advance	75.50		18				
						4461.40	4022
TOTAL NETT ASSETS		4461.40	4022				

REPORT OF THE HONORARY AUDITOR: To the members of the Cumberland Geological Society
I certify that I have examined the accounts, bank statements, receipts and other financial documents of the Cumberland Geological Society. In my opinion the accounts give a true and fair view of the state of the Society's affairs as at 31st December 1987

J.F. Yearsley (Honorary Auditor)

Brook House,
Dean, Workington.

THE 26th ANNUAL GENERAL MEETING of the Society was held at the Royal British Legion Club, Workington, on 18th February, 1987, with the President, Dr.F.J.Cockersole, in the chair. The accounts for the year ended 31st December, 1986, were presented and accepted and the Officers and Council elected for the following year, as detailed below. The President particularly thanked Derek Leviston for his services as Secretary over the past three years and offered Tom Shipp his best wishes as the new President. Mr.Shipp responded by expressing the Society's thanks for Jim Cockersole's leadership during his Presidency.

THE 27th ANNUAL GENERAL MEETING of the Society was held at the Royal British Legion Club, Workington, on 10th February, 1988, with the President, Mr.T.Shipp, in the chair. The accounts for the year ended 31st December, 1987, were presented and accepted and the following Officers and Council were elected. The President thanked the Officers for their efforts, particularly Mr.S.H.Gate who was retiring from his post as Editor due to ill-health. The Membership Secretary reported that membership remained almost static with a total of 204 at the end of the year.

AN EXTRA-ORDINARY GENERAL MEETING held immediately before the A.G.M. on 10th February, 1988, approved the following rule changes:

1. The reference to subscriptions in Rules 6, 12 and 19 shall be changed from a specific amount to -
 "...an amount as determined from time to time by the Council".
2. Charles Edmonds Fund.
 Rule 36(a). This shall be amended to read -
 "The fund, raised by public subscription and vested in three Trustees who shall be the President, Senior Vice-President and General Secretary of the Cumberland Geological Society".
 Rule 36(c). the words "...consist of a book suitably inscribed and shall..." be deleted.

<u>OFFICERS ELECTED FOR:</u>	1987	1988
President	T.Shipp	T.Shipp
Senior Vice-President	Dr.F.J.Cockersole	Dr.F.J.Cockersole
Vice-President	I.Gray	I.Gray
General Secretary	K.W.Bond	K.W.Bond
Hon.Treasurer	F.T.B.Lawton	F.T.B.Lawton
Membership Secretary	B.D.Allen	B.D.Allen
Excursion Secretary	M.B.Dodd	M.B.Dodd
Publications Secretary	T.P.Loftus	T.P.Loftus
Editor	S.H.Gate	E.Skipsey
Librarian	M.F.Burton	M.F.Burton
Council Members	M.Sanderson	M.Sanderson
	E.Skipsey	J.D.Hinde
	J.D.Hinde	G.E.Curzon
	G.E.Curzon	Mrs.M.Fox
Hon.Auditor	J.F.Yearsley	J.F.Yearsley

