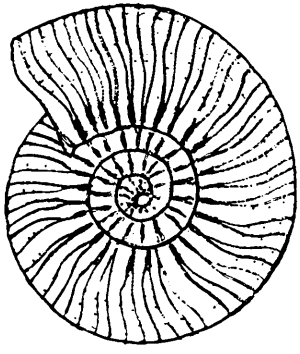
THE CUMBERLAND GEOLOGICAL SOCIETY



PROCEEDINGS

Volume 4 **1984-85** **Part 4**

THE CUMBERLAND GEOLOGICAL SOCIETY

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PROCEEDINGS
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EDITOR'S NOTE

I would like to thank all who have contributed articles, given lectures, forwarded constructive comments, and made reports of excursions.

For the whole of the typing, art-work and layout the Society in general, and the Editor in particular, are indebted to Mr. J. D. Hinde.

S.H.G.

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THE USE OF AERIAL PHOTOGRAPHY IN LAKE DISTRICT GEOLOGY

F. Moseley D.Sc.

ABSTRACT

Aerial photographs are of well established importance to the preparation of geological maps and to the general understanding of geology in all parts of the world. Their value in relation to the main Lake District geological divisions of Skiddaw Slates, Borrowdale Volcanics, Silurian sediments, Carboniferous Limestone and Quaternary landforms and sediments is reviewed. Aerial photographs always add to geological knowledge, in most cases their contribution is of great importance but in others it is limited.

Remote sensing today is becoming a subject for specialists with more methods introduced each year, most of them requiring equipment and materials which are too expensive for amateurs. Of all the methods in use, the study of stereo-air photographs is one of the oldest and it is still one of the best when it comes to geological interpretation. It is also the least expensive, and most people would be able to afford a pocket stereoscope and one or two stereopairs to study a problem which interests them.

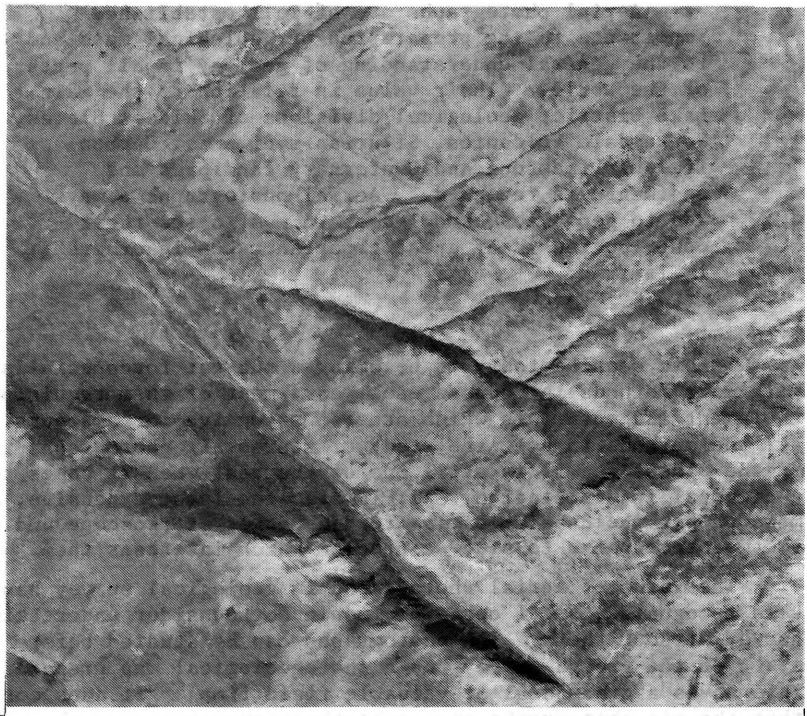
The value of aerial photographs in geological survey has long been recognised, and I certainly would not consider undertaking a survey without them. The photographs can be studied before the start of the ground survey and a photogeological map prepared. This saves a great deal of valuable field time. It does not mean that the air photographs tell all; there are occasions when they are of little value, as in certain types of lowland farming country, but on other occasions it is hard to see how a reasonable map could be made without them. It is always necessary, however, to follow photogeology with a ground survey, when the photogeological map will be checked and revised, and other information added. In this article I hope to show some of the advantages of

using aerial photographs in the Lake District and will contrast areas where they yield a great deal of information with others where they are not so useful. I have chosen to take examples from each of the well known Lake District geological units of Skiddaw Slates, Borrowdale Volcanics, Silurian sediments, Carboniferous Limestone and glacial drift.

SKIDDAW SLATES

The major outcrops of the Skiddaw Slates show them to be of a soft, uniform lithology, with complex small scale structures. Rocks and structures of this type are unlikely to be good for photogeological interpretation, indeed it is hard enough to pick out structures from a range of 1 metre. There is no doubt that aerial photographs of most of the Skiddaw Slate outcrops are

FIG. 1A



AERIAL PHOTOGRAPH AND PRELIMINARY PHOTOGEOLOGICAL MAP OF PART OF THE SKIDDAW SLATE OUTCROP NEAR BUTTERMERE (NY 1718). This photograph does not permit proper interpretation of geology and would be of minimum assistance to the ground survey.

geologically disappointing. Figure 1 is typical, structural lines are visible as gullies, and in almost all cases they represent fractures, either faults or joints. The line of crags X - X may also be a structure line, but neither bedding nor cleavage can be seen. These outcrops are known from ground survey to be folded in a complex polyphase manner. Areas shown as Z reveal little in the way of geology or exposure. Much of the ground between Buttermere and Keswick is rather like this, but there are other areas where some bedding and cleavage lineations can be seen on the air photographs, for example in harder units such as the Loweswater Flags.

BORROWDALE VOLCANICS

These rocks consist of alternating harder and softer layers (lava and tuff or coarse and bedded tuff) which are readily picked

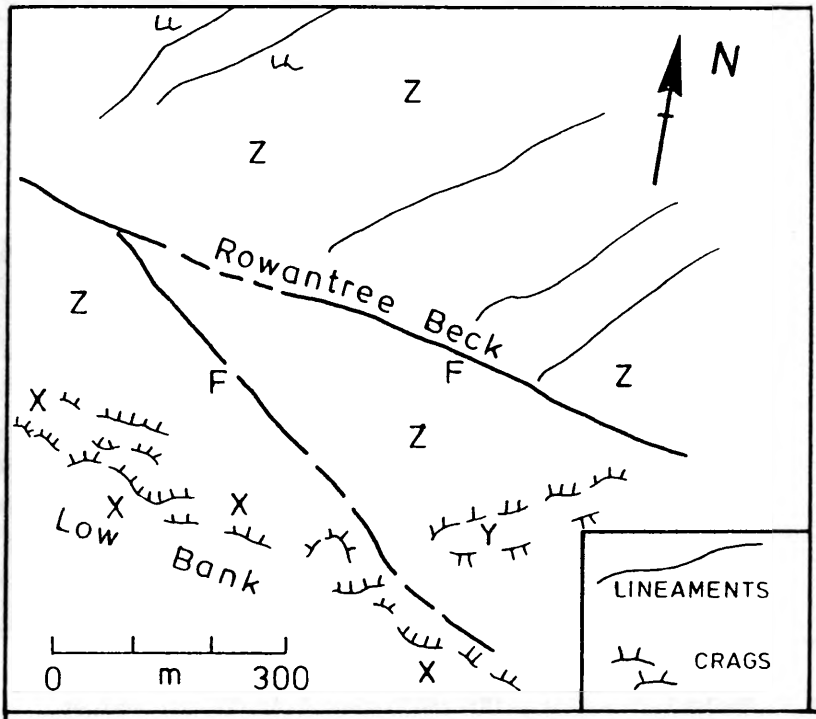
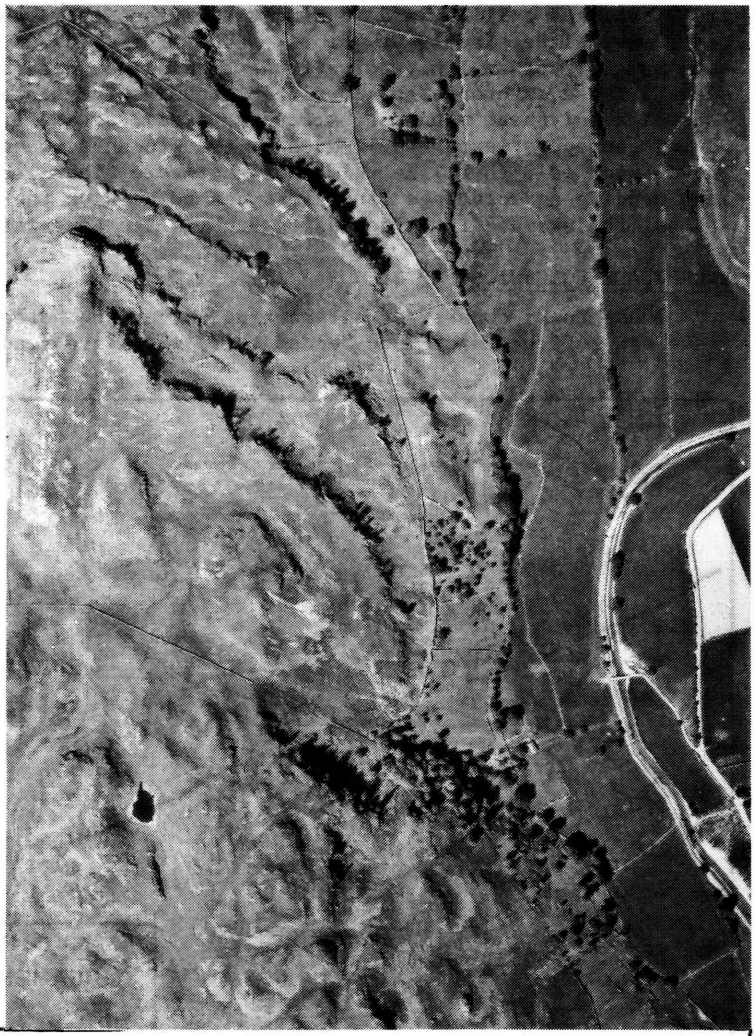


FIG. 1B

F = possible faults or master joints (gullies), X = crags (relation to geology not clear), Y = low ridge, Z = ground which is largely unexposed (grass, juncus etc.).

FIGURE

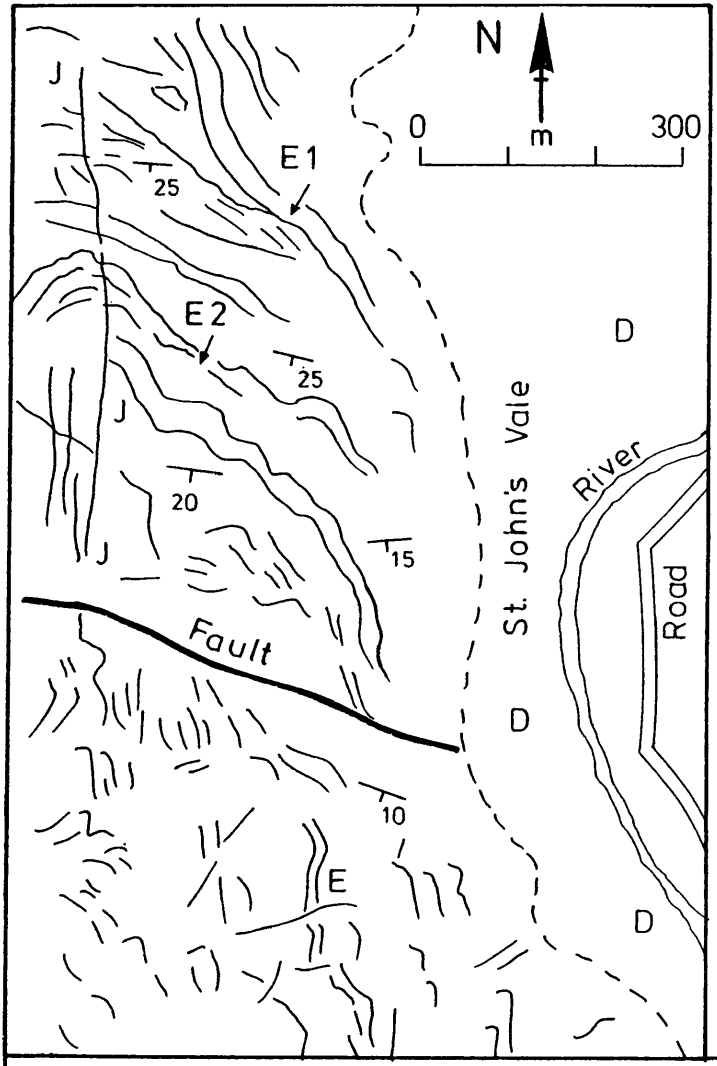
2A



AERIAL PHOTOGRAPH AND OUTLINE PHOTOGEOLOGICAL MAP OF PART OF HIGH RIGG AND ST. JOHN'S VALE (NY 310215).

Good interpretation of geological structures is possible. Strong lineaments are formed by bedding, jointing and faulting and the relationship of escarpments to topography shows the rocks to be dipping uniformly to the south.

FIGURE 2B

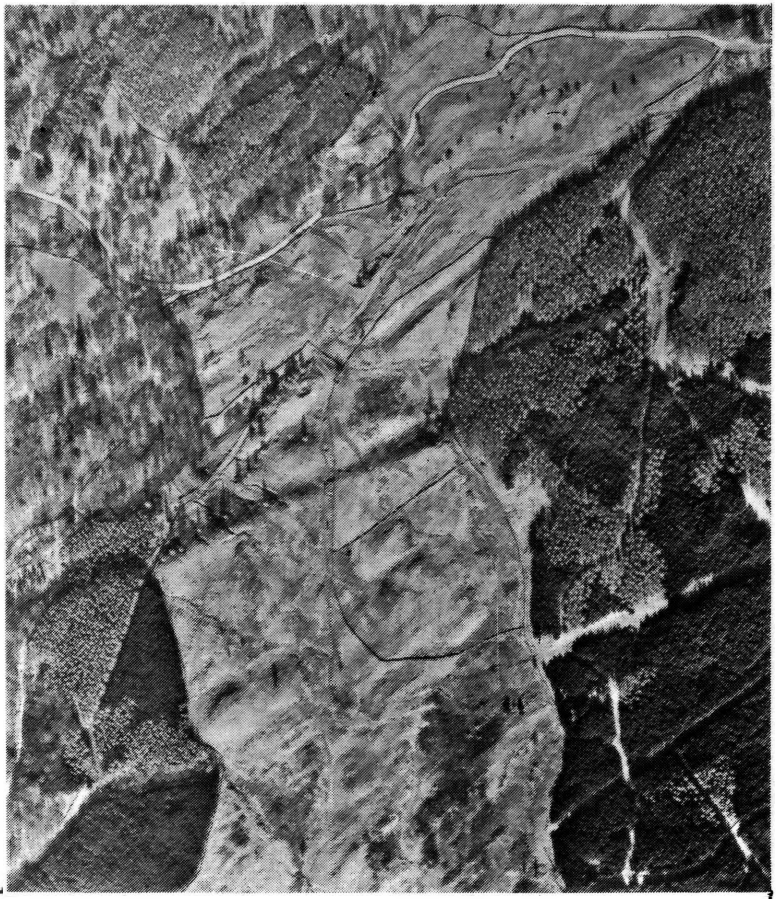


This and the other photographs in this article are at a disadvantage in two respects: (a) they are not in stereo and the visible detail is therefore much reduced, (b) there is always a loss of definition when original photographs are printed.

E = escarpment (bedding of lavas and tuffs), J = joints, D = drift.

FIGURE

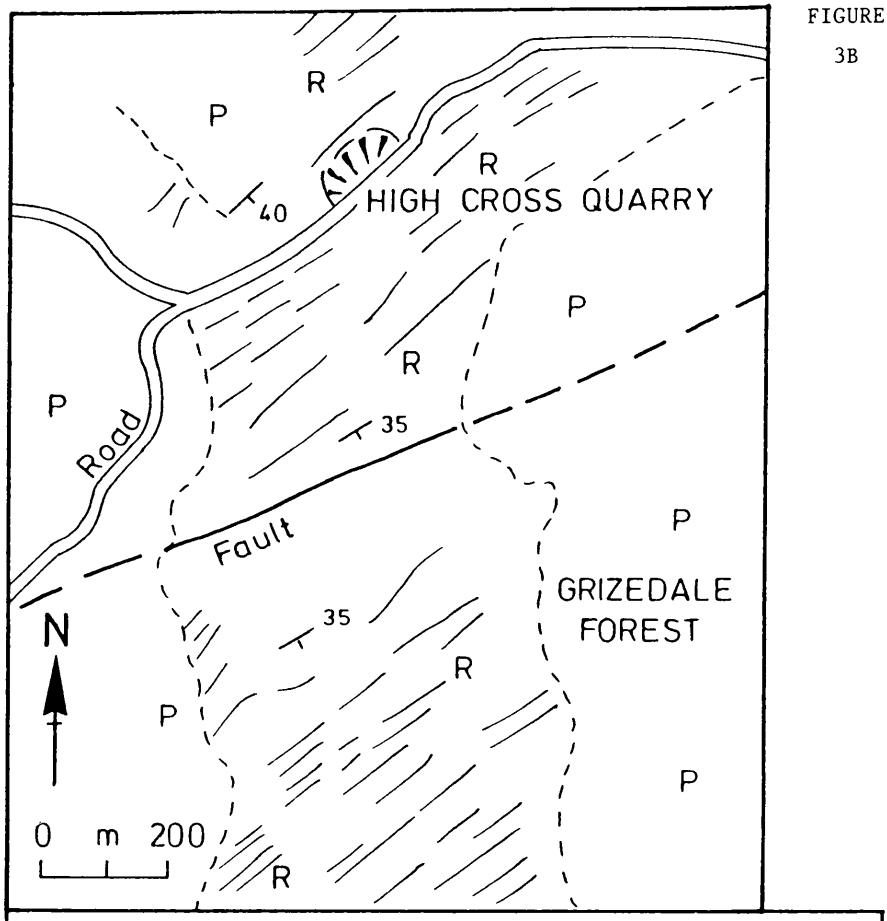
3A



PART OF THE SILURIAN OUTCROP (COLDWELL FORMATION) OF THE SOUTHERN LAKE DISTRICT BETWEEN CONISTON AND HAWKSHEAD (SD 3398).

out by weathering and show up well on aerial photographs. Patterns of jointing and cleavage are also easily seen (Moseley 1981, Figure 7). It is not, however, easy to identify lithologies. Figure 2B is an outline photogeological map of part of High Rigg and St. John's Vale (Moseley 1972, Figure 4 and Plate 1) on which the escarpments formed by harder rock are picked out. Examination of original photographs with a stereoscope makes it possible to plot much more information than is shown on Figure 2B, other details of bedding and joints can then be recorded, and

FIGURE 3B



R = small ridges with orientation controlled by bedding of harder greywacke units, P = forest.

using a stereometer it is possible to measure the dip with reasonable accuracy. Note also how some rock layers wedge out as at E1. However, determination of lithology is difficult from air photographs alone, and in this case lavas cannot be distinguished from more massive tuff beds. For example, most of the escarpments are andesite lavas separated by thin layers of tuff which form benches, but there are exceptions, and the escarpment at E2 is made of hard coarse tuff.

I hope it will be appreciated that a detailed photogeological

map of Fig. 2A would save a great deal of valuable field time. The photographs make it possible accurately to relate position for one thing, not easy on open fellsides, and without them each escarpment would have to be tediously plotted by topographical survey (plane table or whatever). In addition to the saving of field time it is often the case that features clearly visible on air photographs are not easily seen on the ground, where one may be surrounded by a confusing array of crags. 'Not able to see the wood for the trees' as it were. For example, on High Spy (NY 2416) there are distinctive N - S lineaments which turn out to be prominent master joints (Moseley 1981, Figure 7). They have never been recorded by surveys of this region which have not used air photographs. The same is true of the Yewdale Breccia outcrop of Coniston (SD 2897) where the whole mountainside is crossed by similar lineaments which are N - S joints. No



FIGURE 4A

CARBONIFEROUS LIMESTONE OF UNDERBARROW WEST OF KENDAL (SD 4992). Stereophotograph showing a west facing escarpment with the limestones resting unconformably on Silurian rocks at the

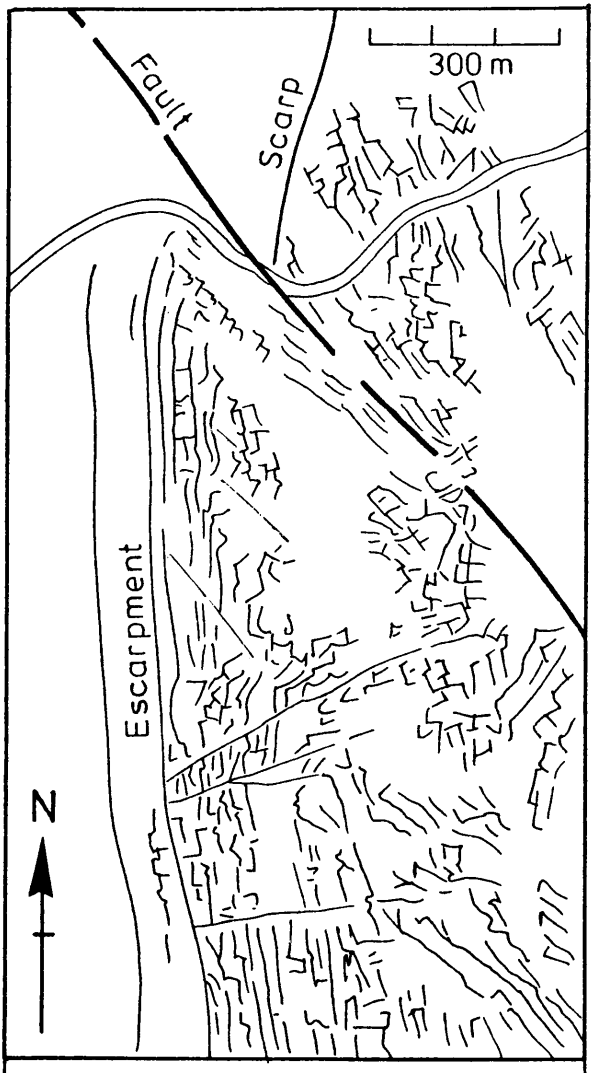


FIGURE 4B

bottom of the wood. The escarpment is delineated by joints and bedding, as are the small scars to the east of it. Other joints are parallel to the fault (Moseley and Ahmed, 1967).

ground survey has recorded them (Moseley 1983).

SILURIAN SEDIMENTARY ROCKS

Most of the Silurian outcrops of the southern Lake District have good topographical expression. Thin but hard sandstone bands stand out as small ridges, separated from each other by softer mudstones which weather out as hollows. This is so for all the main formations, for example the Coniston Grits have thick greywacke units and thin mudstone interbeds, whereas the situation is the reverse for the Bannisdale Slates. These features are readily seen on air photographs. Uniformly dipping and folded strata can be plotted and faults usually make cross cutting depressions.

Figure 3 is an area along the Coniston-Hawkshead road in outcrops of the Coldwell Formation. The greywacke units which on the ground are seen to be 1 to 5

FIGURE 5A

ONE OF THE YORE-DALE LIMESTONES ON CROGLIN FELL

(NY 595487) and Moseley 1981, Figure 50).

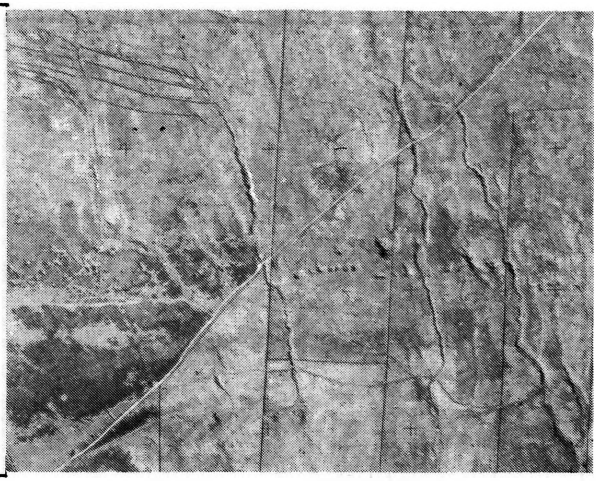
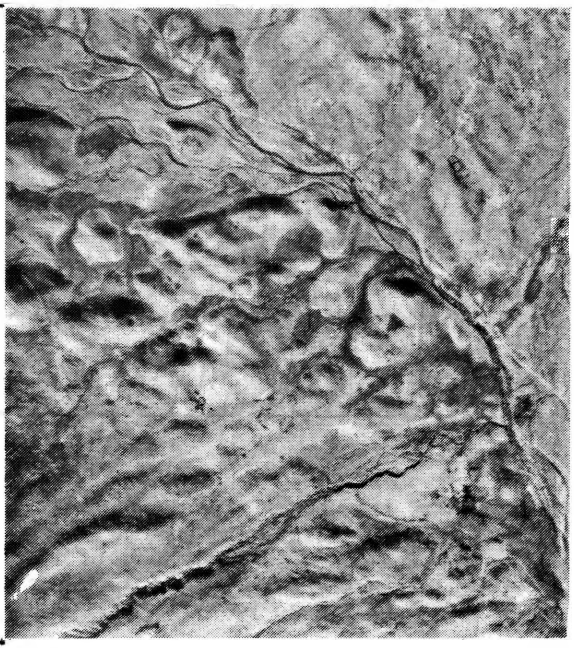


FIGURE 6A

HUMMOCKY MORAINE IN MICKLEDEN LANGDALE. (NY 2707).

The outline of each hummock is easily plotted on the air photographs.



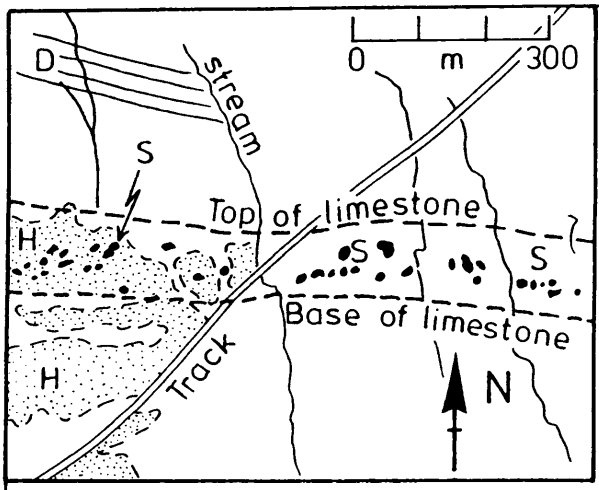


FIGURE 5B

Numerous swallow holes follow the limestone outcrop. Sandstones and shales outcrop above and below the Limestone and down-wash from them has filled or partially filled most of the swallows making location difficult during ground survey.

S = Swallow holes H = Heather D = Drainage ditches (peat on shale)

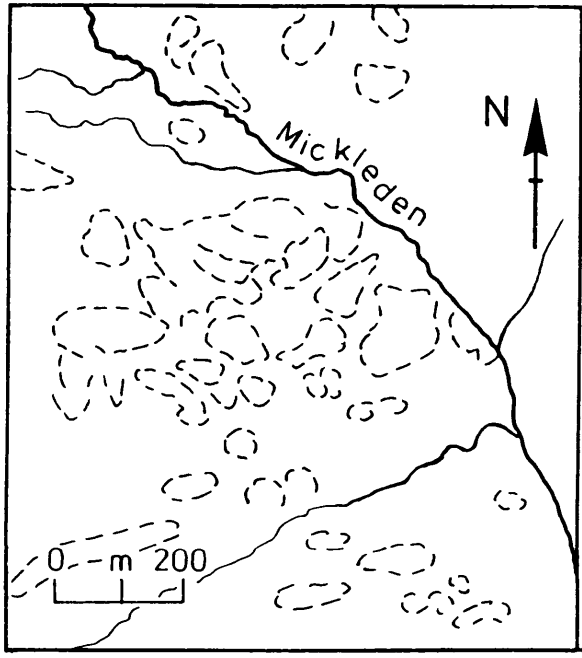


FIGURE 6B

Form lines are shown on morainic hummocks.



FIGURE 7A

MEATHOP MOSS (SD 4587). A number of mosses at the head of Morecambe Bay indicate former extent of the estuaries and inlets. The photograph was taken before construction of the new road.

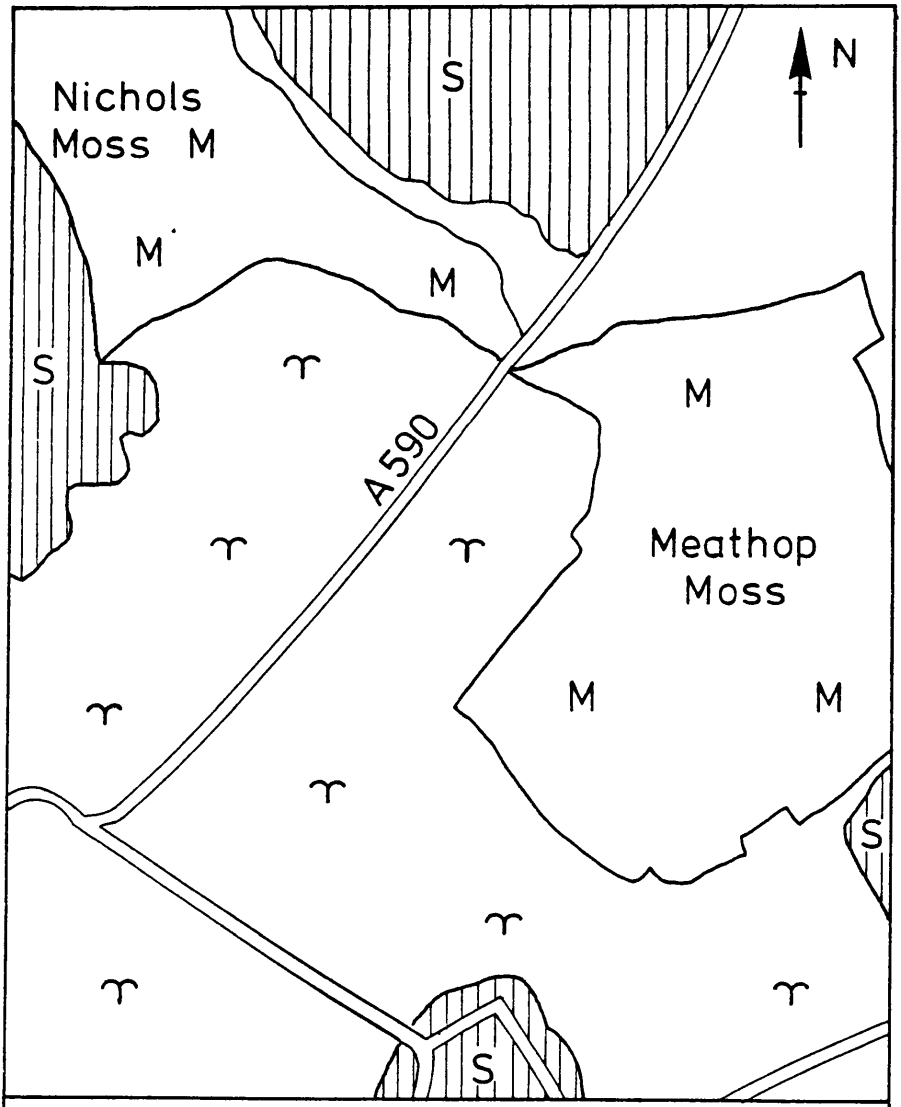


FIGURE 7B

Reclaimed moss (alluvium and peat) can go unrecognised during road construction.
S = solid formation.

metres thick, make distinctive features which can be traced east to west. An important fault also makes a distinctive feature and can be traced well beyond the limits of Figure 3 (Soper and Moseley 1978, Figure 28). Figure 3 also shows how small scale geological features are concealed by forest. It is one good reason why there is no recent geological map of the Grizedale Forest area.

Other published examples of southern Lake District photo-geological maps showing similar features will be found in Moseley 1981, Figures 8 and 9 (Bannisdale Slates) and 1983, Figure 3 (Coniston Grits and Bannisdale Slates).

CARBONIFEROUS LIMESTONE

Structural interpretation of the Carboniferous Limestone of the Lake District region is relatively straightforward since the rocks are generally well exposed and low dipping, there are extensive limestone pavements, and many outcrops are bounded by escarpments. The geology is easily seen on the ground and on aerial photographs, but the latter do have a number of advantages over ground surveys. The clints and grykes of the limestone pavements show up perfectly from above, and since the grykes are weathered-out joints, it makes statistical analysis of joint orientations and their relation to other structures an easy matter (Moseley and Ahmed, 1967). Aerial photographs of course do not help in the determination of a faunal succession, in the collection of faunal assemblages, or in studies such as sedimentology, but a glance at Figure 4 will reveal how easily structures can be determined. Figure 5 illustrates another aspect which is of importance to highway engineering. The Pennine area east of the Lake District has widespread outcrops of Yoredale rocks, alternations of sandstone, shale and limestone. The limestones are dotted with swallow holes, not easy to locate by ground survey since they are usually filled or partially filled by downwash from sandstone and shale outcrops above. However, they remain active and can be hazardous to road construction, witness the piece of expensive heavy plant which subsided into one during the construction of the M6 across Shap. Such swallows are easily identified on aerial photographs, an obvious advantage to motorway engineers.

QUATERNARY

There is no doubt that major erosional features of glacial origin such as U shaped valleys, corries and hanging valleys make spectacular viewing with stereoscope and stereopair. Some of the best Lakeland examples are: (1) Bleaberry Tarn and Sour Milk Ghyll, (2) Helvellyn with Striding Edge and Red Tarn, and (3) Blea Water to High Street, but there are many others. For elementary teaching purposes stereopairs showing these landforms are well worth acquiring together with a pocket stereoscope.

Less spectacular but equally important to Quaternary studies are the deposits. Figure 6 is an illustration of the well known moraine at Mickleden, Langdale. This moraine is obvious on the ground, but a proper ground survey would require the mapping of all the hummocks, a time consuming task, but a task easily accomplished by using stereo photographs. There are many other types of glacial and post-glacial deposit which can be interpreted from aerial photographs, some of them of considerable economic importance. For example, kettle holes eventually become post-glacial swamps filled with peat. Many of these areas are drained and reclaimed for farming and may be difficult to map out by ground survey, but they are easy to see on air photographs. Unrecorded peat of kettle holes has caused trouble in the past, especially in road construction. For example, the M6 link road to Kidsgrove in Staffordshire crossed an unnoticed kettle hole with 40 feet of peat. It all had to be removed before the road could be built at considerable cost for the company.

ACKNOWLEDGEMENT

The author wishes to thank the Director of the Ordnance Survey for permission to use the photographs.

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LAKE DISTRICT HIGHLANDS AND ISLANDS DURING THE UPPER PALAEOZOIC.

R.N. Kimber B.Sc. and G.A.L.Johnson D.Sc.

SUMMARY

The history of the unroofing of the English Lake District during the Upper Palaeozoic has been discussed since the early years of the century and particularly the presence of Devonian and Permian uplands and the possible development of persistent islands over the centre during the Carboniferous. From the outcrop pattern of the Lower Carboniferous rocks it is accepted that an island or islands were present over the centre until the Asbian. When the effects of Permian and Mesozoic to Recent erosion are taken into consideration, the presence of high topography over the centre during the Carboniferous becomes likely, and the development of persistent island masses during the period of marine transgression is equally probable. New work on the Mell Fell and Carboniferous basement conglomerates gives evidence from clast content of the gradual unroofing process and significantly shows that the Silurian succession extended northwards over the Borrowdale Volcanic Group in the centre of the Lake District at least until the Carboniferous. The Silurian (Ludlow) age of the greywacke clasts in the Mell Fell Conglomerate of Little Mell Fell is confirmed by the new discovery of a single well-preserved specimen of Saetograptus varians (Wood). The centre of the Lake District is believed to have been an emergent upland throughout the Upper Palaeozoic, forming islands during the Carboniferous transgression and persisting as high topography into early Mesozoic times.

INTRODUCTION

The Carboniferous Period in Britain starts with a major marine transgression from south-west to north-east over an irregular surface of erosion or peneplain left by the long interval of Devonian erosion. The sea made its way into the lowlands and

initially the higher ground stood out of the sea to form an archipelago. These islands were successively covered by the sea as can be proved by the age of the lowest Carboniferous rocks that overlie the upstanding basement masses. Thus the Alston Block was finally submerged during the Asbian, the Askrigg Block was covered during the Holkerian and the Southern Uplands of Scotland were at least partly submerged by the Brigantian (Johnson, 1982, 1984). The Lake District was another region of high ground that formed an island at the beginning of the Carboniferous, at least until the Asbian. The core of Lower Palaeozoic age is surrounded by a rim of carbonates of mainly Holkerian age and these beds thin and onlap onto the centre on all sides. There is no evidence from the central part of the Lake District for any cover of Carboniferous rocks. The region has been uplifted and subject to erosion for long periods of post-Lower Palaeozoic times owing mainly to positive buoyancy imparted by the large underlying Caledonian age granite batholith (Bott, 1967, 1974).

Two processes affected the uplifted centres or blocks during the Carboniferous. Positive buoyancy was imparted by the underlying granite batholiths, and negative crustal downwarping was caused by regional subsidence (Johnson, 1982). Subsiding basins were separated from rising blocks by active fault belts during the early Carboniferous. Later, conditions approaching equilibrium between block and basin allowed more uniform downwarping of the whole region (ibid.). At this point the blocks became submerged and the islands of the archipelago were successively eliminated.

Discussion of whether the Lake District was an island during the Carboniferous goes back to the late years of the last century (Ward, 1879). Current views were reviewed by Garwood (1913, p. 522) who put forward two opinions. One, that the Lower Carboniferous sediments were deposited against an island of Lower Palaeozoic rocks which were covered by successively younger Carboniferous strata towards the centre which may have remained emergent. The second view, that Ward, Garwood and Marr (1916) strongly supported, suggests that the Lower Carboniferous sequence was laid down on an almost even surface of Lower Palaeozoic rocks over the whole of the Lake District and that it was subsequently elevated into a dome that has been denuded to form the present ring of Carboniferous rocks. Later work tended to show that neither of these possibilities was completely correct. The early Carboniferous island was well established, but it was believed to have been totally submerged during the Asbian (D_1) late in the Lower Carboniferous. Thus Earle (1922) studied the faulting and radial dip of the Carboniferous in the northern part of the Lake District to produce evidence that the Asbian enveloped the whole of the Lake District; but he noted that the dip is hardly sufficient to carry the Asbian over the present summit of Carrock Fell. In agreement with Earle's conclusions, Mitchell (1978) states that the south and east of the Lake District were of moderate relief during early

Carboniferous times and describes the progressive onlap of the Carboniferous stages onto the pre-Carboniferous land surface. In his diagram (ibid. p. 169, Fig. 58) he shows the Lake District covered by late Asbian deposits and no emergent island. Although this model conforms with that found over the adjacent Alston Block there are striking differences between the two regions. The Alston Block is still roofed with Carboniferous deposits whereas the Lake District was largely denuded of Carboniferous before the overlying Permian was laid down. The onlap of the Permian over the Carboniferous and onto the Lower Palaeozoic core is particularly clear between Egremont and Millom on the south-west side of the Lake District, with the small faulted outlier of Wilton Fell (Egremont) proving the Carboniferous cover was once more extensive. To what extent the core of the Lake District has been modified by uplift and long periods of erosion between Carboniferous times and the present is difficult to quantify, but equally it is difficult to be sure that the topography was not sufficient to maintain emergence through Carboniferous times, producing islands of more permanence than the Alston Block.

Any evidence of Carboniferous age emergence of the core of the Lake District has long been lost through erosion, and evidence of past geography of the centre can only be inferred from study of sedimentary rocks which crop out around the margins at the present day. These sedimentary rocks include conglomerates of probable Devonian to Carboniferous age, exposed at Ullswater (Mell Fell Conglomerate) and Shap, and also the basal Permian Brockram breccias. Sedimentology and provenance studies of these clastic rocks, described in the following paragraphs, provides a chronology of the unroofing of the north-east side of the Lake District.

DEVONIAN TO CARBONIFEROUS CONGLOMERATES

The timing of deposition of these clastic rocks is very difficult to resolve, but in this paper all clastic rocks that underlie the Carboniferous Limestone and lie unconformably on the Lower Palaeozoic succession in the study area, are considered to have an age that spans the Devonian to Carboniferous boundary. The conglomerates and sandstones are devoid of fossils, with only the Pinskey Gill beds, marginal to the conglomerates at Shap, being of known Tournasian age and thus the earliest dated Carboniferous rocks in the north of England (Johnson and Marshall, 1971).

Capewell (1955) separates the Mell Fell Conglomerates from the other clastic rocks exposed at Shap and Caldbeck, which he considers to be Carboniferous in age. This is based on an apparent strong angular discordance between different conglomerates exposed at Dalemain Weir, which also contain different clast compositions. In fact, clast compositions in all the conglomerate sequences described below are strikingly similar and it is suggested they provide evidence for contemporaneous erosion of the

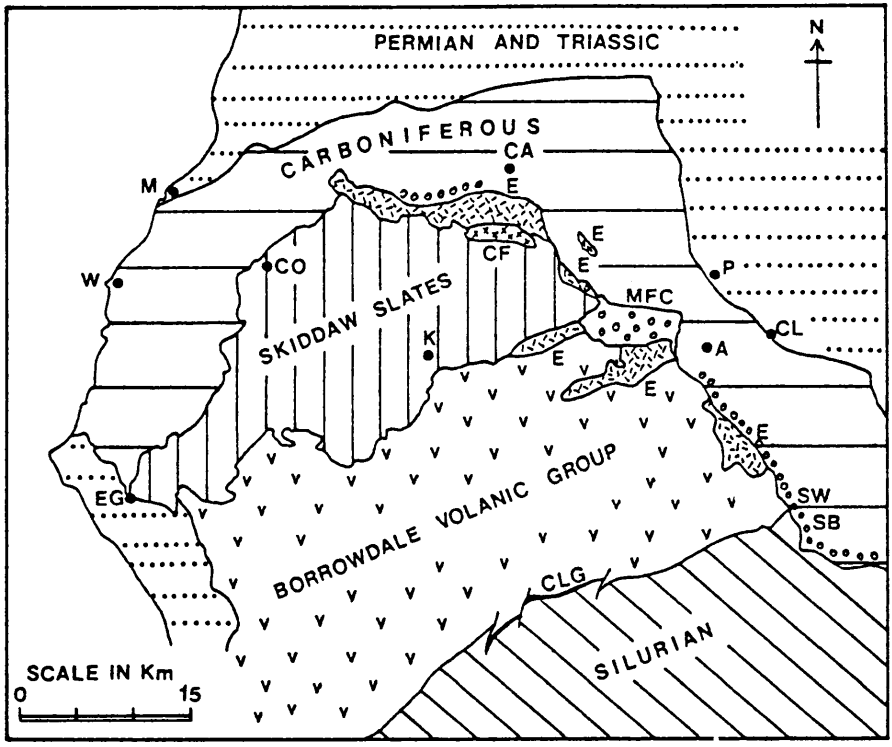


FIG. 1 OUTLINE GEOLOGICAL MAP OF THE ENGLISH LAKE DISTRICT SHOWING THE FORMATIONS AND LOCALITIES MENTIONED IN THE TEXT.
A - Askham, CA - Caldbeck, CF - Carrock Fell Complex, CL - Cliburn, CLG - Coniston Limestone Group, CO - Cockermouth, E - Eycott Volcanic Group Lavas, EG - Egremont, K - Keswick, M - Maryport, MFC - Mell Fell Conglomerate, P - Penrith, SB - Shepherd's Bridge, SW - Shap Wells, W - Workington.

Lake District. The variation in clast composition is related to the type and extent of the source rock terrain and also strongly associated with the position of deposition relative to distance away from source. Further evidence for contemporaneous deposition of the clastic rocks is shown by the regional depositional trends which support a strong north and north-east transport direction.

Mell Fell Conglomerate

The Mell Fell Conglomerate is found in the region of Great Mell Fell and the ground at the foot of Ullswater (Fig. 1). It has been studied by a succession of workers including particularly Oldham (1900), who recognised that it was formed of fan detritus

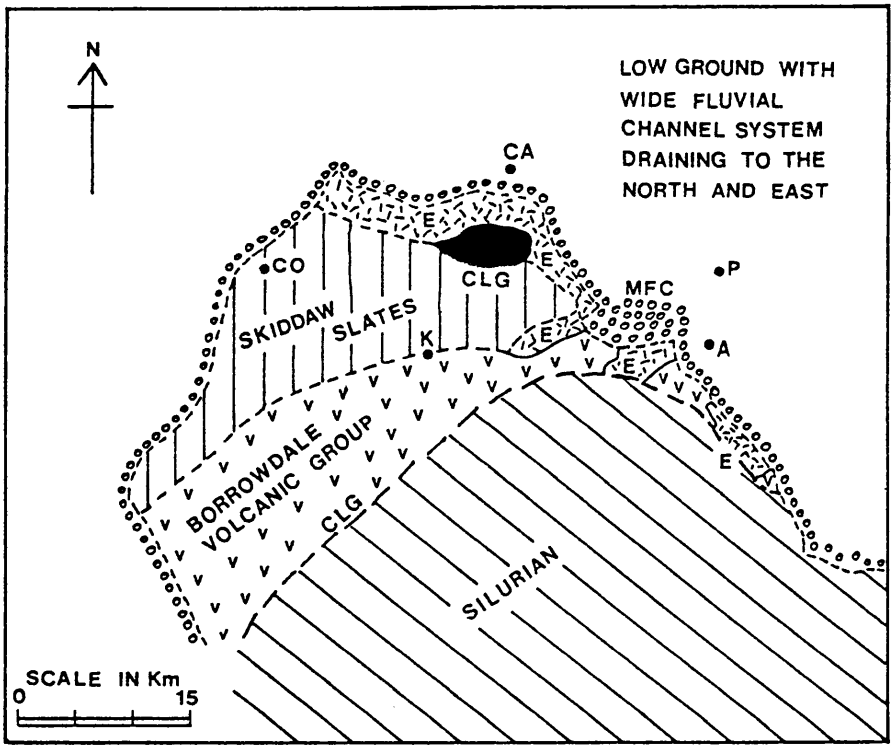


FIG. 2 TENTATIVE GEOLOGICAL RECONSTRUCTION OF THE BASIC OUTCROP PATTERN IN THE LAKE DISTRICT UPLANDS DURING THE FORMATION OF THE DEVONIAN - CARBONIFEROUS CONGLOMERATES. Key to the symbols is given in the legend to Figure 1.

under arid climatic conditions, Green (1918), who analysed the clast content and deduced the probable source area, and Capewell (1955), who made a detailed study of the lithology and mineralogy of the deposits. The most recent account is by Wadge (1978).

The Mell Fell Conglomerate exhibits a marked south-west to north-east depositional trend. Consensus of opinion about the thickness suggests the total stratigraphic thickness to be about 275 m and this is supported by one of us (R.N.K.) who has recently completed a detailed survey of the sequence. Massive to crudely imbricated boulder conglomerates, containing clasts up to 80 cm across, are present in the south and west of the outcrop area. Clast compositions are mainly greywacke sandstones (up to 92% at Waterfoot Beck, NY 429 245) which are comparable with Silurian lithologies (Figure 3), particularly the Ludlow age Coniston Grits

as has been recognised for more thsn a century (Ward, 1879, Postlethwaite, 1897). These are exposed today in the south of the Lake District, especially in the Howgill Fells. Supporting this, a specimen of the graptolite Monograptus colonus, typically from the nilssoni zone (Lower Ludlow), was found in a greywacke clast on Great Mell Fell by Capewell (1955, p.26). More recently a single well-preserved graptolite was found in a greywacke clast near the Hause, Little Mell Fell (NY 427 327) by Miss K.V.J. Miller of Trevelyan College, Durham. The specimen was kindly examined by Dr.R.B. Rickards who finds it to be Saetograptus varians (Wood) again typical of the lowest Ludlow nilssoni zone, but it does range up rarely into the tumescens zone. The Upper Silurian age of the abundant greywacke clasts in the Mell Fell Conglomerate is thus founded on both lithological and biostratigraphical grounds. The large size of these clasts indicates that the coarse conglomerates were deposited close to source in a 'proximal' position. They are interpreted as stacked longitudinal bars deposited within channels on an alluvial fan surface.

In a north and north-easterly direction, maximum clast size decreases sharply and cobble - pebble conglomerates in the central part of the area (Dacre Beck, NY 457 263 - 460 264) are arranged as well-bedded units interbedded with sheet and trough-cross-bedded pebbly sandstones. Similar cobble conglomerates, containing clasts up to 0.45 m across are exposed at the junction of Setterah Sike and Heltondale Beck (NY 3507 5206), 5 km south of the main Mell Fell Conglomerate outcrop area, and considered to be equivalent to the conglomerates, described above, exposed around Dacre. In the northern part of the area, outcrops at Holghyll, (NY 429 272) and borehole data from Dalemain (Dalemain borehole, courtesy of B.G.S.) show that thick pebbly sandstones form trough-cross-bedded festoon cosets, fining up from conglomerates below.

Clast compositions in the finer grained sediments are distinctly more varied than clast compositions in the proximal boulder conglomerates (Figure 3). Generally volcanic rock clasts are more abundant than greywacke sandstone clasts and in some localities account for 75% of clast compositions (e.g. Holghyll Gorge, NY 429 272). Quartz felsites, flow-textured ignimbrites and andesites were derived from the Borrowdale Volcanic Group. Porphyritic volcanic rock clasts, containing decomposed feldspars, were probably derived from the Eycott Group. Rare bioclastic limestone clasts, which contain Favosites coral fragments, were derived from similar limestones of the Ordovician Coniston Limestone Group (Caradoc). Minette clasts originated from the alkaline feldspar and biotite-rich dyke rocks which intruded the Silurian greywackes and which were probably associated with intrusion of the Shap Granite (Moseley, 1978).

These finer grained clastic rocks from the central and northern part of the outcrop area are interpreted as the genetically

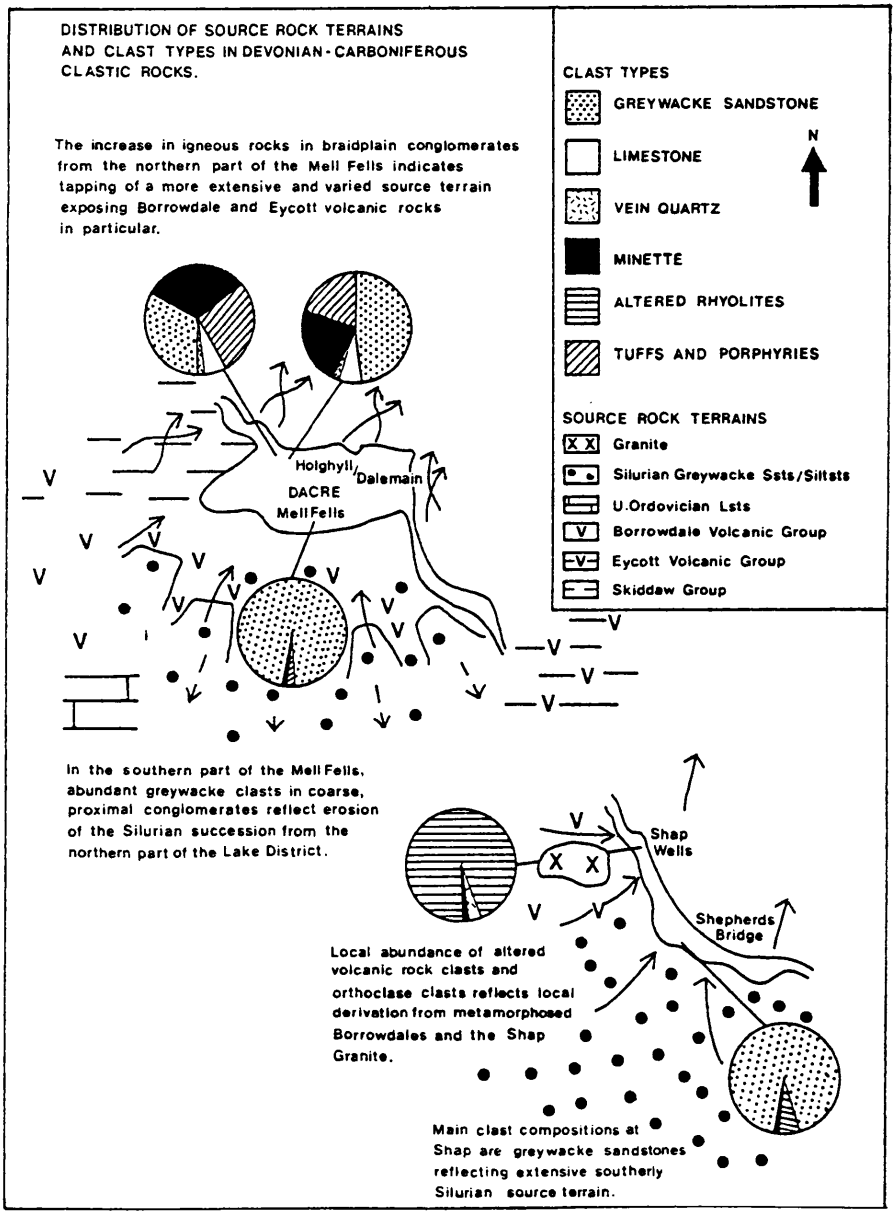


FIG. 3. DISTRIBUTION OF SOURCE ROCK TERRAINS AND CLAST TYPES IN THE DEVONIAN - CARBONIFEROUS CLASTIC ROCKS.

related components of a braidplain system. Conglomerate units interbedded with cross-bedded sandstones in the central part of the area were deposited as longitudinal 'gravel' bars within a coarse braided fluvial system. They thus represent the more proximal equivalents of the pebbly, cross-bedded sandstones found further north. The latter were deposited within probably wide but shallow braided river channels which 'combed' the distal part of the braidplain.

The Mell Fell Conglomerate therefore exhibits proximal to distal relationships related to the down-slope transition from proximal alluvial fan to a wide braided-fluvial channel system, which itself shows broad proximal to distal changes. A similar model was developed for the Devonian Van Horne Sandstone, Texas, by McGowan and Groat (1971). In this way, the vertical and lateral changes in lithologies reflect erosion of the source area and retreat of the highest parts of the Lake District (cf. Heward, 1978).

It is suggested that the change from predominantly Silurian greywacke clasts, present in the proximal boulder conglomerates, to the abundant volcanic rock clasts in the braidplain deposits, can be largely accounted for by the increase in the fluvial dispersion created within the braidplain system. The large Silurian greywacke clasts, which were deposited close to source, reflect erosion of the Silurian greywacke which was probably restricted to the highest parts of the source area. Erosion of this source terrain accompanied by contemporaneous erosion of the minette dykes uncovered the older Ordovician rocks beneath. At the same time, braided rivers in front of the alluvial fans were able to 'tap' a wider source area, eroding and transporting more varied clast compositions (Figure 3). The result was a dissected source terrain largely removing the Silurian succession from the northern part of the Lake District.

The geographical significance of the large quantities of Silurian greywacke clasts in the Mell Fell Conglomerate was recognised by Green (1918) and Capewell (1955). To produce the source area at the time of conglomerate deposition, probably during the Devonian, the Silurian succession must have continued northwards over the Coniston Limestone Group and the Borrowdale Volcanic Group to form high ground immediately to the south and west of the Mell Fell Conglomerate outcrop (Fig. 2). A map of the Conglomerate outcrop showing the derivation of clasts from contemporary outcrops has been produced by Wadge (1978, Fig. 57b). Northwards the Coniston Limestone Group would lie in front of the Silurian sequence, and north again a thinning succession of the Borrowdale Volcanic Group appears to have been present. The Eycott Volcanic Group probably surrounded the Skiddaw Slates much as they do today (Figures 1 and 2). If the full Lake District succession was present in the catchment area, the total thickness of strata

between the top of the Skiddaw Slates and the Coniston Grits would be approaching the order of 11,500 m; more than sufficient to form an impressive mountain range.

However, there is no necessity to involve this great thickness of Llandeilo to Ludlow rocks in the region to the south and west of the Mell Fells. Two well documented periods of earth movements and erosion have disrupted the succession of strata and significantly reduced the vertical thickness. The pre-Borrowdale Volcanic Group folding and erosion affected the Skiddaw Slates and the Eycott Volcanic group. A pre-Borrowdale anticline developed of similar position and trend to the later Skiddaw anticline lying to the north and west of the Mell Fells and there was much pre-Borrowdale denudation (Wadge, 1972). At the end of Borrowdale extrusion further folding and uplift led to a second phase of erosion that is particularly pronounced in the north and the south of the Lake District (Moseley, 1978). On this erosion surface the Bala age Coniston Limestone Group was laid down and was followed by the Silurian sequence. The total thickness of post-Skiddaw Slate to Coniston Grit strata laid down to the west of the Mell Fells may have been reduced by earth movements and denudation to half of the possible figure quoted above, but at 5,750 m this would have produced the required high mountains and the source of the Mell Fell detritus fans.

Shap Conglomerates

Clastic rocks of probable Devonian to Carboniferous age are exposed south of Shap, on the south-eastern side of the Lake District. Conglomerates and sandstones form fining-upward sequences and were deposited by valley-confined braided rivers flowing in a north to north-north-easterly direction (Fig. 3). Clast compositions, analysed from conglomerate units deposited as longitudinal bars, are very similar to clast types described for the Mell Fell Conglomerate.

Palaeocurrents deduced from associated trough-cross-bedded sandstones support a strong southerly provenance for the conglomerates. Clasts in these units are mainly greywacke sandstones (up to 95% at Shepherd's Bridge, NY 589 076), identical to the Silurian greywacke clasts found in the coarse boulder conglomerates in the Mell Fell Conglomerate. However, the fact that the clast size is much finer, cobble to pebble range, indicates that these conglomerates were deposited by braided rivers transporting clasts further away from source. Indeed, conglomerate sequences at Shap are comparable with 'proximal' braidplain conglomerate sequences present in the Mell Fell Conglomerate, although the latter contain abundant volcanic clasts. The inference from this strongly suggests that the Silurian source terrain in the south part of the Lake District must have been more extensive than that further north where the Borrowdale Volcanics were also exposed. However, more local derivation of clasts is inferred in conglomerates exposed

along Wasdale Beck, Shap Wells (NY 578 096). Palaeocurrents from this section indicate a south-south-west to south-west provenance (Fig. 3). Clasts are mainly altered acidic volcanic rocks (92%), with a quartz granulose 'hornfels' groundmass. Lithologies include devitrified rhyodacites, spherulitic rhyolites and ignimbrites with minettes; the latter clasts are the same as those present in the Mell Fell Conglomerate. The association of these clasts suggests that they have been derived from the Borrowdale Volcanics which, according to Firman (1978), have undergone metasomatism along fissures, associated with intrusion of the Shap Granite. The local transport direction would support clast derivation from the Shap Granite area; indeed, abundant orthoclase granules along this section proves that the Shap Granite was supplying clastic material during their time of deposition.

Caldbeck Conglomerates

North and west of the Mell Fell Conglomerate outcrop, Devonian to Carboniferous age conglomerates are poorly exposed. Along the northern boundary of the Lake District, exposures south of Caldbeck contain abundant Eycott Volcanic rock clasts (Figs. 1 & 2). This Conglomerate is exposed near to the Carrock Fell Igneous Complex, but according to Eastwood et al. (1968) no pebbles of that Complex are present. They conclude that the rocks of the Complex were not available for erosion at the time of conglomerate deposition.

PERMIAN BASEMENT BRECCIA

Continental deposits of presumed Lower Permian age form an outer ring round most of the Lake District. This Penrith Sandstone and breccia lies almost everywhere on reddened Carboniferous rocks, except in the west where they overlap onto the Lower palaeozoic (Fig. 1). Breccias are widely developed at the base of the Permian and are called Brockrams around Kirkby Stephen at the south end of the Vale of Eden where they are particularly well developed. Here the breccias are mainly composed of boulder, cobble and pebble sized clasts of Carboniferous Limestone, often much dolomitized, and they pass laterally into water-lain sands towards the west and north. The breccias formed as alluvial fans derived from eroding Carboniferous Limestone on the flanks of the Permian uplands of the Lake District and the Howgill Fells to the south. They are restricted to the vicinity of the high ground and they do not extend north of a line between Dufton and Crackenthorpe in the Vale of Eden (Versey, 1939, p. 227).

Slightly west of this Dufton line and only 11 km east of the Mell Fell Conglomerate outcrop, a breccia at the base of the Permian has been recorded by Versey (1939, p. 284) at Trough Gill, Cliburn (NY 6587 5239). The area about Trough Gill was planted with conifers in the late 1950's and over the past 25 years the exposures have deteriorated to such an extent that the breccias are

now obscured and only the overlying Penrith Sandstone is visible in a shallow choked gorge. However, Professor Versey's account of the breccia is detailed and shows that it is quite distinct from the brockram breccias of the south and east. The Cliburn breccia is formed of pebble-sized clasts of lava and tuffs with little Carboniferous material. The fragments of extrusive rocks include vesicular porphyrites and more acid lavas with tuffs which are referred to the Eycott Volcanic Group by Versey (1939, p. 284). The possibility that some of the material was derived from the not too distant Mell Fell Conglomerate is considered by Versey, but he concludes that the clasts in the Cliburn breccia were mainly derived directly from the Lake District uplands to the west.

A time gap of about 30 my separates the highest Carboniferous rocks from the overlying Lower Permian breccias and during this period the Lake District was uplifted to produce radial dips in the surrounding Carboniferous. There followed a long interval of erosion when hundreds of metres of Carboniferous strata were stripped from the flanks of the Lake District and from the floor of the Vale of Eden. During the Lower Permian, uplands, even mountains, were once again present over the Lake District (Arthurton et al. 1978, p. 189). The Eycott Volcanic Group of the Caldbeck Fells, and possibly associated exposures, again suffered sub-aerial erosion to produce the distal detritus at Cliburn. If our interpretation of the dominant Lower Palaeozoic clasts in the Cliburn breccia is correct, most of the Carboniferous cover to the west must have been removed by Lower Permian times or, owing to continuously emergent topography, Carboniferous sediments were not widely deposited here, possibly both factors being involved.

PERMANENCE OF HIGH GROUND AND ISLANDS

The evidence discussed in the previous paragraphs supports the proposition that the Lake District was an emergent upland from the Devonian, through the Carboniferous and into the Permian. Products of erosion of the mountains began with the Devonian Mell Fell Conglomerate detritus fans dominated by coarse clasts of Silurian greywacke. With much of the Silurian succession overlying the Borrowdale Group in the core of the Lake District, high mountains would be present of quite sufficient size to produce the detritus fans. By the beginning of the period of Carboniferous deposition, probably after a long period of erosion, wide valleys with braided streams choked with fluviatile sediments had developed on the margins of the Lake District. Clasts from the basal Carboniferous conglomerates indicate that the Silurian greywackes were still present over the central region and high topography must have been maintained here. Evidence that the Carrock Complex had not been unroofed in early Carboniferous times supports the contention that thick Lower Palaeozoic cover extended over the Lake District at this time. Much Carboniferous and post-Carboniferous sub-aerial

erosion must have followed. The absence of Carboniferous outliers within the Lake District, except for one example near Egremont and a few others in the extreme south and east, again testifies in favour of a long period of deep erosion during post-Carboniferous times. Yet, in the Lower Permian, mountains were still present over the region. The simple explanation for this data is that the Lake District was rising almost continuously from the Devonian through to the Permian owing to inversion of the deep pre-Bala sedimentary basin. This, coupled with the thick pile of Lower Palaeozoic deposits in the centre of the region, maintained mountainous topography at least to the Permian. Rejuvenation of the mountain chain owing to uplift may have been a significant factor in the persistence of high topography.

Radial dips in the rim of Carboniferous rocks that surrounds the Lake District give evidence of post-Carboniferous uplift and additional later movements gave the same type of dip to the unconformably overlying Permo-Trias. The Carlisle basin to the north of the Lake District has a small and little known sequence of Lias (Lower Jurassic) at the top of the succession showing that basin subsidence, probably linked with uplift at the margins, persisted beyond the Triassic. In the north-east corner of the Lake District where the fells rise steeply above the rim of Carboniferous rocks, Earle (1922, p. 525) made the important observation that the dip of the D_1 (Asbian) limestones is hardly sufficient to carry them over the present summit of Carrock Fell. Add to this high ground the cover of country rocks that roofed the igneous complex during the Carboniferous, possibly including a substantial thickness of Ordovician Drygill Shales, and it is unlikely that the Asbian or later seas ever covered what is now Carrock Fell; it may well have formed an island of uplifted ground that was not submerged by Carboniferous sediments.

Evidence used by Garwood (1913, p. 552) and others to suggest that the Carboniferous floor was almost flat across the Lake District is based on inaccurate correlations of the Lower Carboniferous succession over the region. Recent work has shown that the lowest Courceyan deposits were laid down in the Stainmore - Ravenstonedale basin southeast of the Lake District and successively higher horizons onlap as the succession is traced north. High Arundian and Holkerian deposits form the base of the Carboniferous sequence round much of the Lake District, but this rises by onlap to Asbian in the north (Mitchell, 1978). The position of the rim of Carboniferous rocks at the present day is the result of erosion of the thinner and less resistant shore-line and near-shore deposits from the margins of the Lake District. Lack of clastic sediment derived from the emergent Lake District island in the surrounding Dinantian carbonate sequence suggests that the land surface was thickly covered with vegetation which slowed down the processes of sub-aerial erosion. It is noteworthy that little

clastic sediment is found derived from other Dinantian islands such as Rookhope, central on the Alston Block (Dunham et al. 1965) and Crummackdale - Ribblesdale at the southern margin of the Askrigg Block (Dunham et al. 1953).

The Dinantian island or more probably islands of the Lake District persisted longer than those of the Alston Block and the Askrigg Block because the region was more mountainous with thick uplifted Lower Palaeozoic formations overlying a deeply buried and buoyant major granite batholith. The chronology of erosion and unroofing of the Lake District during the Upper Palaeozoic and the development of Dinantian islands described in this paper is tentatively summarised in figures 1 and 2. Though direct geological evidence of the islands is long lost owing to erosion, their presence is well supported by stratigraphical deductions. Like Galloway to the north and parts of St. George's Land to the south, the Lake District appears to have been an emergent region of high topography during Upper Palaeozoic and early Mesozoic times.

ACKNOWLEDGEMENT

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A SEISMIC REFRACTION SURVEY FOR HEMATITE NEAR BECKERMET, CUMBRIA.

C.D.V. Wilson, Ph.D.

SUMMARY

Geophysical methods of detecting iron ore deposits are reviewed briefly. There follows an account of a seismic refraction survey made in 1947, by a team led by the late Sir Edward Bullard, to locate the ore-bearing faults near Haile. Three seismic lines and an arc spread were shot in the vicinity of Hailemoor Mine. Though unsuccessful, owing to insufficient velocity contrast, the survey shows an unusual application of the seismic method to an economic objective.

1. INTRODUCTION

In 1947 the Beckermet Mining Company and the United Steel Co. approached the late Sir Edward Bullard (then Dr. Bullard) of the Department of Geodesy and Geophysics, Cambridge, with a view to testing some geophysical methods either for locating hematite directly or for finding the faults with which the ore is associated. Geophysics had already 'come of age' in 1947 and most of its strengths and limitations were well-known. Sir Edward (or 'Teddy' as I prefer to remember him) quickly sized up the situation. The following appraisal is made with a little hind-sight, but follows essentially his diagnosis.

There are many case-histories of the successful location by geophysics of iron-ore deposits concealed beneath a thin cover. Most of these have used a magnetic method, both airborne and on the ground (see e.g. Wahl & Lake, 1957, Hansen, 1967 and Parasnis, 1975). This method can only locate magnetite, since hematite is non-magnetic. Some workers have followed up the magnetic survey with a gravity survey, which responds to the much more common hematite; it can be very effective in estimating the total tonnage of iron-ore present, e.g. at Svappavaara, Sweden (Parasnis, 1975).

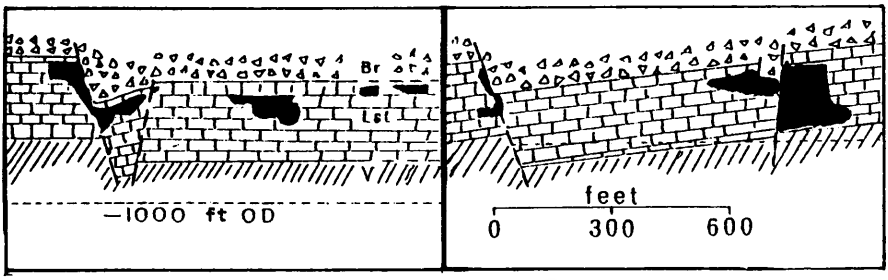


Fig. 1 DIAGRAMMATIC SECTIONS ACROSS BECKERMET MINE (WINSCALES). Redrawn from Mem. Geol. Surv. 8, 1924. Br = Brockram, Lst = Carboniferous Limestone, V = Borrowdale Volcanic Group, Black = Hematite.

However, this approach can only be used on rather compact bodies lying fairly close to the surface.

In the Cumbria orefield the iron-ore deposits are far from compact, but are found in 'flats' and 'veins', often near faults (see Fig. 1) of which there are many. Furthermore, in the Beckermet - Hailemoor area there is a cover of some 250 - 350 m of Brockram and St. Bees Sandstone over the Carboniferous Limestone which hosts the iron ore. The gravity method therefore seemed unpromising, but was nevertheless tested with a short gravity traverse run along a heading in the Winscales Mine. Although a hematite boundary was crossed the results proved negative.

Since there is very little, if any, magnetite in the Cumbrian iron ore, the magnetic method was also ruled out. This left electrical methods as a possibility for direct detection of the hematite, but unfortunately the latter is non-conducting; there is insufficient specularite (which is a conductor) to make this method feasible. Today, a review of possible methods would include Induced Polarisation (I.P.), but at that time this technique had hardly left the laboratory.

Teddy concluded that there was little promise of detecting the hematite directly by geophysical methods, and he decided that the only hope lay in finding some of the faults which largely control the emplacement of hematite. Seeking likely geophysical contrasts, it was clear that the best chance lay in exploiting an expected difference in seismic velocity between the Limestone and the younger rocks above. At that time (1947) there was some doubt about getting satisfactory reflections from the Carboniferous Limestone in England, and in any case Cambridge laboratory had no seismic reflection equipment. So it was decided to try a seismic refraction survey, and the present author was assigned to the project, together with John Gerrard, a fellow research student who led the party in the field.

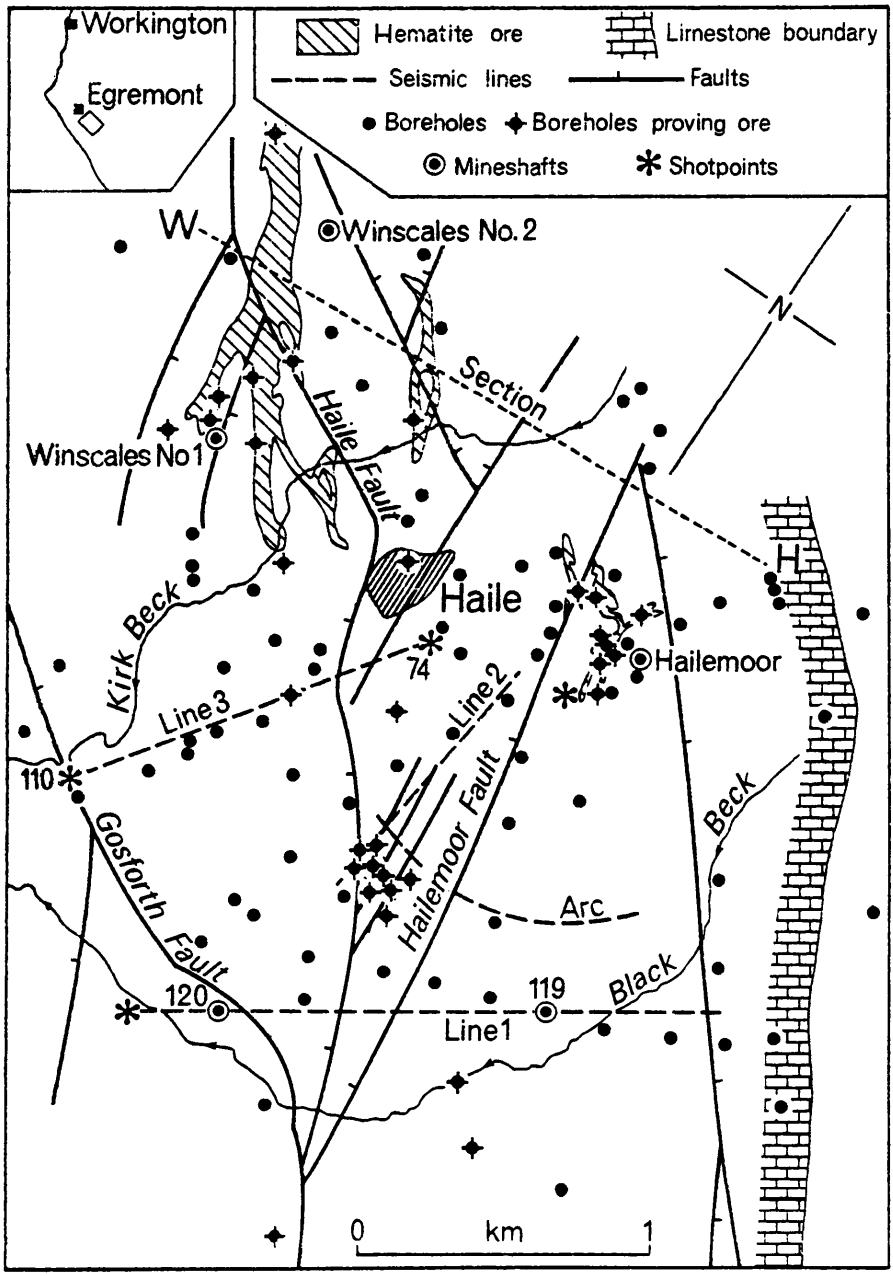


Fig. 2 MAP OF SURVEY AREA.

2. GEOLOGY

Readers will be familiar with the general geology of the area. Fig. 2 shows the mines of that time, the approximate deposits being worked, and the NW - SE system of faults near which the ore is usually, but not always, found. The Limestone thins out to the south, being only 40 m thick at Calder Bridge (1 km SE of Line 1). To the east it is overlapped and cut out by the Brockram (Limestone boundary is shown on the map).

Future prospects therefore lay mostly in a restricted area to the SE of Haile, since any development to the SW (towards Beckermet) would have incurred an overburden of 300 m or more of Permo-Triassic rocks. Section WH (Fig. 4a) is redrawn from the Geological Survey Memoir of Sheet 37 and shows the main faults, including the Haile and Hailemoor Faults, which are thought to converge to the SE meeting the Gosforth Fault near Black Beck. The first seismic line (Line 1) was therefore shot across these faults near Black Beck.

3. SEISMIC LINE 1

Before giving the results from this line, a brief review of the theory is appropriate. The seismic refraction method in its simplest form is shown in Fig. 3a, for a two-layer situation. A

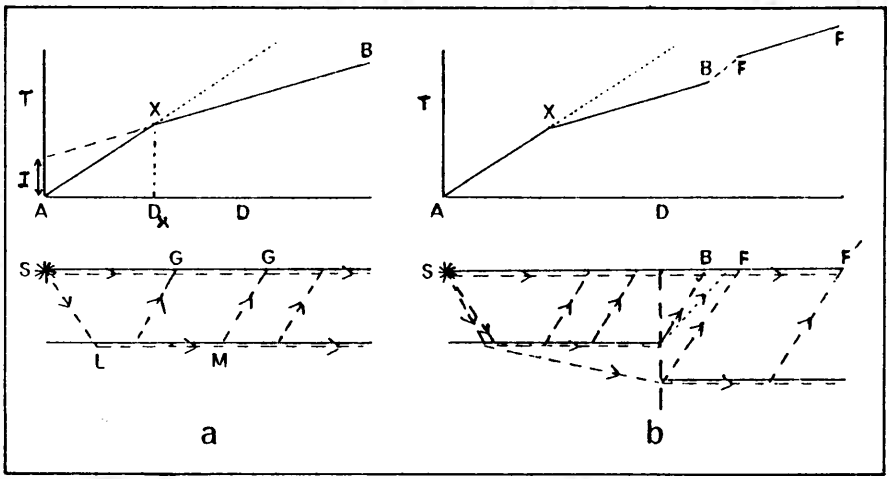


Fig. 3 (a) TIME - DISTANCE GRAPH FOR TWO LAYERS WITH A PLANE INTERFACE, AND A RAY DIAGRAM.

(b) TIME - DISTANCE GRAPH FOR TWO LAYERS WITH A FAULTED INTERFACE, AND A RAY DIAGRAM.

source of energy (explosive or mechanical), usually placed near the ground surface (at S) sets off elastic waves which can be represented as rays. Considering only the P or compression wave, which travels the fastest, there is one ray which travels horizontally along the top layer, giving arrivals at the geophones GG which plot on the time - distance graph as a straight line AX through the origin. If the seismic velocity increases with depth (as it usually the case), there is also a critically refracted ray SLMG which travels down to the interface, along the lower layer and up again to the surface. The arrivals from this path plot on the segment XB. The direct ray is overtaken by the refracted ray at the crossover distance D_X. Beyond D_X the first arrival is always the refracted ray. From the slopes of the segments AX, XB and the intercept I of XB on the time axis, the velocities of the layers and the thickness of the top layer may be computed.

In practice the interface between the layers is usually irregular and this will be indicated by deviations of the refracted arrivals from the straight line XB. The geometry of the non-planar interface may often be worked out; in particular a fault will result in the refracted arrivals lying not on a single segment XB, but on two segments XB, FF^1 (Fig. 3b). If the line is shot the other way FF^1 will be displaced downwards. From the dispositions of the segments the location of the fault, and its throw, may be found.

Clearly the useful information is obtained from the arrivals beyond the crossover distance D_X and the line must be long enough to ensure that D_X is well exceeded; the deeper the interface the further is D_X. In our survey the main refractor was expected to be the Carboniferous Limestone, with a likely velocity of about 5.5 km/s. Assuming that the Brockram and the St. Bees Sandstone formed a single homogeneous layer of velocity 3.5 km/s, with an average thickness at Line 1 of about 250 m, D_X would be about 1 km. This was too far, so it was decided to bring in the refracted wave at a shorter distance by firing shots down a borehole on Line 1, thus eliminating the downward path SL of the refracted ray.

Holes Nos. 119 and 120 (see Fig. 2) were deemed suitable for this purpose, but No. 119 proved to be blocked, so No. 120 was tried. Two shots were fired in that hole, but the wire jammed in the hole and much of it was lost. Also it was doubtful if the explosive used did in fact detonate properly under the water pressure in the hole. In view of these setbacks shot-firing in the hole was abandoned and Line 1 was shot from the ground surface, at a point as far to the SW as possible (Fig. 2). Geophone spacing was 60 m and small shots were also fired to find the thickness of the low-velocity 'weathered layer' all the way along the line. The results were corrected for this surface layer and reduced to a datum of + 100 ft. (30.48 m) O.D.

The resulting time-distance graph is shown in Fig. 4b. The

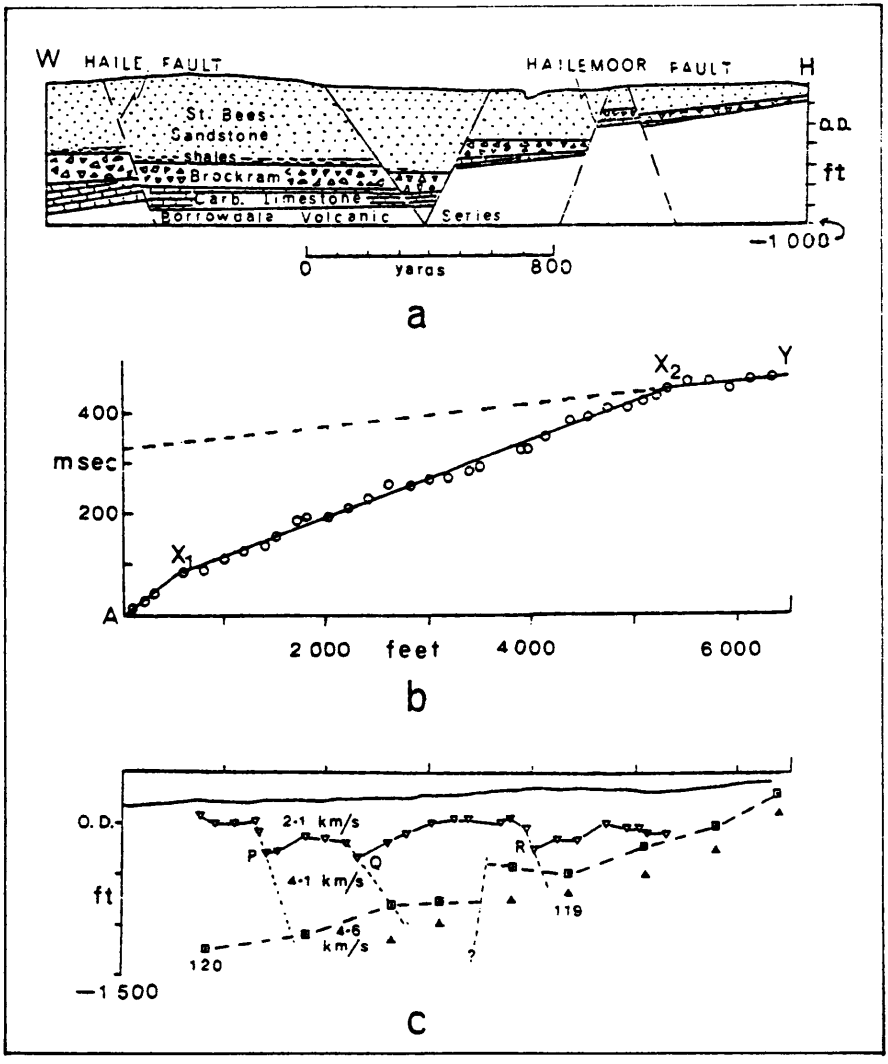


Fig. 4 (a) SECTION WH (Fig. 2) SHOWING THE FORMATIONS AND THE MAIN FAULTS. Redrawn from Mem. Geol. Surv. Sheet 37, 1936.

(b) TIME - DISTANCE GRAPH FOR LINE 1.

(c) SECTION SHOWING RESULTS OF LINE 1, WITH BOREHOLE DATA. Open triangles = interface with St. Bees Sandstone; squares = top of limestone, from boreholes; closed triangles = base of limestone, from boreholes.

arrivals can be fitted to three segments AX_1, X_1X_2 and X_2Y. The first two yielded velocities of 2.07 and 4.1 km/s, while X_2Y was the wave refracted from the Limestone. The line was not reversed, but there was sufficient control from the boreholes near the line to compute the results. Underlying the weathered layer at the shot-point is about 55 m of St. Bees Sandstone, velocity 2.07 km/s, and beneath that are the lower parts of the Sandstone and the Brockram, which are assumed to have the same velocity of 4.1 km/s (Fig. 4c). The interface between these two layers is very irregular and this will be discussed later. The Limestone only makes an appearance at the very end of the line (segment X_2Y); the cause of this is its low velocity, which after correction for dip was found to be only 4.6 km/s.

This result was disappointing; it was clear that Line 1 yielded virtually no information, directly, about the Limestone surface, on account of the unexpectedly small velocity contrast between the bulk of the Permo-Trias (4.1 km/s) and the Limestone (4.6 km/s).

4. SHOOTING FROM THE HAILEMOOR MINE

As shooting from the surface would yield no Limestone arrivals within a useful range, and as borehole shooting had been discarded, it was decided to try shooting from down the Hailemoor Mine, where the wave would be initiated in Limestone or hematite. Line 2 was therefore laid out so as to cross the likely position of the Haile Fault, as well as some other faults. Owing to drilling difficulties the shot point had to be moved to the position shown in Fig. 2. Though it was now offset from Line 2, this could be corrected for. This shot point was at a depth of 240 m.

The results from Line 2, which need not be given here, confirmed, with the borehole control, the velocities found on Line 1. The form of the Limestone/Brockram interface could be computed, but because the velocity contrast was so small the errors were too large and no faults were detected.

One more experiment was made from this shot point. This was 'arc-shooting', at one time much in vogue for locating buried anticlines in oil-prospecting. The geophones were placed about 60 m apart on the arc of a circle as shown in Figs. 2 and 5. Departures from a planar limestone surface would show up as variations, with azimuth, of the arrival times. A fault of N - S or NW - SE trend such as the Hailemoor Fault, should also be revealed as a sharp change with azimuth of the point of refraction at the Limestone/Brockram interface. For each 'spoke' the position of this refraction point was computed and these points were projected onto the ground surface (Fig. 5a). They were also projected onto a vertical plane at right angles to the centre 'spoke', No. 8, i.e. a plane of bearing 80° (Fig. 5b). Neither of these plots show any

sharp break, but merely show a limestone surface rising to the east, as is known from boreholes. The only change, a minor one near the west end (Fig. 5b), is in the wrong sense for the Hailemoor Fault, which throws down to the west. The arrival times also formed a smooth data set.

5. SEISMIC LINE 3

It was noted at Line 1 that the residuals for the main segment X_1X_2 appeared to fluctuate systematically; these were interpreted as due to variations in the thickness of the upper, low-velocity layer of St. Bees Sandstone (Fig. 4c). Searching hopefully for faults, we conjectured that this irregular profile within the sandstone might be due to faulting at places such as P,Q,R where the interface dropped sharply. These 'faults' were tentatively extrapolated down to the Limestone surface, as shown, to see if they matched up with any sharp drops in the Limestone surface as obtained from boreholes. No such correlation was found. The only sharp change seen in the borehole data is at about the centre of the section; this may be the Hailemoor Fault, but it lies between points Q and R.

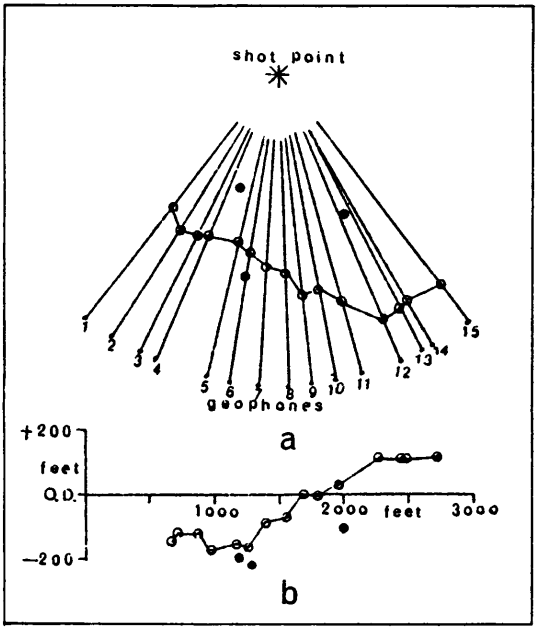


Fig. 5 (a) DIAGRAM SHOWING THE LAYOUT OF THE ARC OF GEOPHONES. Open circles = refraction points projected onto the ground surface; closed circles = nearby boreholes.

(b) REFRACTION POINTS PROJECTED ONTO A VERTICAL PLANE. Closed circles = top of limestone, from boreholes.

Nevertheless, baulked as we were from surveying the Limestone surface directly, this approach to searching for an expression of the (post Triassic) faulting within the much shallower St. Bees Sandstone, seemed the only course to pursue. Line 3 was therefore laid out, from B.H.74 near the village of Haile SW to B.H.110 (Fig. 2). This line

TABLE 1

Formation	Locality	Velocity km/s	Remarks
Bunter (Upper mottled sandstone)	Knutsford No.1 borehole, Cheshire	3.05-4.56 (mean 3.65)	Velocity log in borehole Depth 305 - 472 m
-do-	-do-	4.26-4.87	Silicified zone Depth 472 - 618 m
Carboniferous Limestone	near Kendal, Cumbria	5.25± 0.08	Seismic refraction line (Banks & Gurbuz, 1984)
Carboniferous Limestone	Vale of Clwyd North Wales	5.38±0.11 (Line 1)	Seismic refraction survey (Wilson, 1959)
-do-	-do-	6.1 - 6.3 (Line 3)	Depth 150 - 300 m

crossed the Haile Fault. The line was reversed, and the geophone interval was reduced to 30 m. No sign was found of any faults within the sandstone, so, very reluctantly, the survey was terminated.

6. DISCUSSION

We had thoroughly tested the seismic refraction method, with three lines and an arc spread - and we had failed (a polite comment would be 'a negative experiment'). In retrospect we were perhaps a little optimistic in expecting a large velocity contrast between the Permo-Trias rocks and the Carboniferous Limestone. Forty years on, much more is known about the velocities of these formations. Table 1 shows some velocities found in the North of England and North Wales; it is seen that the difference in velocity between the two formations can be as little as 0.7 km/s, even where the sandstone is not unduly silicified.

However, we had no way of anticipating this. We did shoot two short lines on outcrops of limestone, one at Rowrah (some 10 km to the north), the other at Mousegill (3 km NE of Haile), but the former gave erratic data while at Mousegill the limestone was too karstic to be typical. Out velocity of 4.6 km/s in the main survey, lower than any values for limestone in Table 1, may be partly due to the dissolving of some of the rock by fluids (whether from above or below) and incomplete replacement by hematite.

Shattering from the many faults in the area may also have played its part.

The irregular interface within the St. Bees Sandstone, separating the low- and high-velocity zones, remains a mystery. The upper, low velocity layer (Fig. 4c) varies in thickness from about 50 m to 150 m and this variation is too large to be ascribed to vagaries of weathering. Nor can it be due to sedimentological features such as channels within the Sandstone. The base of the St. Bees Sandstone has a considerable shale fraction which would increase its velocity, but this applies only to the bottom 80 m. The problem remains unsolved.

7. CONCLUSION

I should like to end with a few remarks about the equipment and field-work, and give some personal impressions of the survey.

The equipment was serviceable, but bulky by modern standards. Recording was by an electro-chemical method, current passing from six moving pens to 'Teledeltos' aluminium-backed paper; a potential of 500 volts was needed. To supply this voltage and to ensure a frequency response flat to 100 Hz, bulky storage batteries had to be used. This limited operation to the van, some sites thus being inaccessible. With modern equipment we could have done more, but I do not think the extra work would have altered our main conclusions.

Communication with shot-point was by telephone wire; the chewing of this by cows was an occasional hazard! When we were shooting down the mine, nearly 1000 metres of wire had to be taken from the recording van across country, down the mine-shaft and along the heading, to the shot-point. Charges ranged from a few ounces to 15 lbs. On the surface, holes were drilled by hand-auger,



Fig. 6 JACKIE BURROWS AND BILL COWAN STANDING BY A 'BLOW-OUT'.



Fig. 7 SIR EDWARD BULLARD AND JOHN GERRARD

sometimes down to 12 or 15 ft. Augering 'Pinnell' a kind of gravelly boulder clay was especially laborious and once or twice we could not drill deep enough to avoid a 'blow-out'. Fig. 6 shows one such hole, with the other two members of our team, Jacky Burrows and Bill Cowan.

When shooting down the mine, where charges of 7 lbs were the norm, the procedure was first to drill a 2-inch horizontal hole about 8 ft. long into the rock. Jacky would then fire a 2 oz. charge at the end of this to make a cavity (there is a rich vernacular word for this) large enough to hold the main charge. This would then be fired, after we had retreated some 30 yards round a corner.

Looking back over almost 40 years, I remember gratefully my first geophysical survey, for that is what it was. We had unstinted support from the staff of Hailemoor Mine, Ridley Gunn the manager, Gilbert Wilson the geologist and many others. Jacky Burrows and Bill Cowan were seconded from the mine to help us; we could not have wished for more cheerful and efficient companions.

Dr. Bill Davies, the geologist from United Steel, came to review our work from time to time, offering us sage advice and gave us all the borehole data we needed. Dr. Hesselwood, the company's physicist helped in several ways. But it was Teddy Bullard who set us off and kept us going through the long hot summer of 1947. Equally at home in the field or in the laboratory, he joined in the field work with boundless enthusiasm. Fig. 7 shows him with his sleeves rolled up, and he took his turn in working the auger. He had invented many of the techniques of seismic surveying at Cambridge before the war and he was keen to return to geophysics as soon as hostilities had ended. So he was particularly interested in applying the seismic method to the finding of hematite-bearing faults. The Fates decreed otherwise, but we had a good try.

A final word for John Gerrard. If this article comes to his notice, I hope he approves of it; I'd like to see him again!

8. ACKNOWLEDGEMENTS

I wish to thank the Egremont Mining Company for their agreement and Leconfield Estates for permission to publish borehole data, and British Gas Corporation for supplying sonic velocity data from Cheshire.

The sections in Fig. 1 are re-drawn from Memoir of Geological Survey 8, 1924, by kind permission of the British Geological Survey. My thanks are also due to Mr. Joe Lynch for drafting Fig. 2.

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BRIEF COMMUNICATIONS

WULFENITE FROM RUTHWAITE LODGE, GRISEDALE - A NEW LAKE DISTRICT OCCURRENCE.

B. Young, B.Sc., B.G.S., Newcastle-upon-Tyne.

The rare secondary mineral wulfenite ($PbMoO_4$) has previously been recorded from a handful of localities in the Caldbeck Fells (Goodchild, 1875; Day, 1928; Russell, 1936; Kingsbury and Hartley, 1955; Braithwaite et al., 1963 and Hartley, 1984). Elsewhere in the Lake District the mineral has been reported only from Hartsop Hall Mine, Patterdale (NY 395 119) (Russell, 1944) and Burtness Wood, Buttermere (NY 176 159) (Clark, 1963).

A few specimens of wulfenite have recently been collected from the dumps of a small trial pit on the Ruthwaite Lodge Vein, Grisedale (NY 355 136) south-west of Glenridding, Ullswater. Here the mineral occurs very sparingly as pale brown to brownish-yellow simple, square tabular crystals up to 1 mm across embedded in thin crusts of dull green microcrystalline pyromorphite on galena. Other secondary minerals found on this dump include rosasite (Kingsbury & Hartley, 1957), linarite, malachite and cerussite. Quartz appears to be the main constituent of the vein with small amounts of galena, commonly as deeply weathered cubo-octahedral crystals, together with a little chalcopyrite and traces of tetrahedrite.

Ruthwaite Lodge Vein is one of a small suite of veins which cut the Borrowdale Volcanic Group at the head of Grisedale. All show a broadly similar primary sulphide mineralogy in which galena, sphalerite and chalcopyrite are associated with conspicuous macroscopic and commonly well-crystallized tetrahedrite. Most prominent of these veins is the Eagle Crag Vein, formerly extensively worked at the mine of that name. Secondary minerals are relatively common at Eagle Crag and include hemimorphite, hydrozincite, aurichalcite, linarite and malachite. However, despite a careful search wulfenite and pyromorphite have only been found at Ruthwaite Lodge.

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COMMENTS ON SIR KINGSLEY DUNHAM'S PAPER: AGE AND ORIGIN OF THE CUMBRIAN HEMATITE (CUMBERLAND GEOLOGICAL SOCIETY PROCEEDINGS VOL. 4 pp. 259 - 266) - A.M.EVANS, Ph.D., The University of Leicester.

I would like to comment on Sir Kingsley Dunham's criticism of the palaeomagnetic investigations carried out by Dr. El-Nikhely and myself on material collected from the Beckermet and Florence Mines. Sir Kingsley contends that our "palaeomagnetic results are therefore in direct conflict with most if not all interpretations (my italics) of the geological evidence".."To resolve the problem, the palaeomagnetic result may be queried on the basis of the possibility of longitudinal error, and perhaps more appropriately because the Lake District block may have rotated as a whole since the Florence orebody was formed..."

As readers unfamiliar with palaeomagnetic investigations may feel that this ia valid criticism, I will consider each possibility in turn. The suggestion of longitudinal error can be dismissed immediately. It is impossible using palaeomagnetic methods to determine longitude. Palaeomagnetic workers have never claimed to be able to determine longitude and Dr. El-Nikhely and I did not claim to have determined the longitudes of any of the pole positions that we measured. The suggestion of longitudinal error must be consigned to the container for red-herrings!

Let us now look at the suggestion of rotation as a basis on which to query our palaeomagnetic results. If we plot on a stereographic projection the pole representing the present geographical position of the Lake District, the palaeomagnetic poles for the Upper Triassic and the Tertiary and the virtual pole positions obtained by Evans and El-Nikhely (1982) for the hematite mineralization at the Beckermet and Florence Mines, then we can test the possibility that rotation could resolve the conflict between the palaeomagnetic evidence and most interpretations of the geological evidence. If we assume rotation of the Lake District about a vertical (or even sub-vertical) axis then we find that there is clearly no way in which our data can be brought into coincidence with the Tertiary pole position thus allowing consideration of a Tertiary age for the mineralization favoured by Dunham (1952) and Rose and Dunham (1977). What about an Upper Triassic age? Our data can be rotated to coincide with the Upper Triassic pole or more correctly with a pole position of early Jurassic age; but a rotation of at least twenty degrees would be necessary.

This possible resolution of the conflict must therefore hinge

on the likelihood of a twenty degree rotation of the Lake District. Surely such a pronounced rotation would be obvious from a study of the geology, especially Caledonian tectonic trends, and would be a well known fact of English geology? I would suggest that any one who takes a long careful look at the tectonic map of Great Britain and Northern Ireland will find it impossible to postulate a rotation of this magnitude for the Lower Palaeozoic rocks of the Lake District and in particular for the region of important hematite mineralization.

Can we rely on the palaeomagnetic work being accurate? I would reply that Dr. El-Nikhely and I followed well established and long accepted techniques and our samples were carefully collected from two different mines. Equally important is the fact that our work is in absolute agreement with the totally independent determinations carried out by DuBois (1962), but not discussed by Sir Kingsley.

It seems to me that the palaeomagnetic evidence for a Permian age of some of the hematite mineralization in West Cumbria should be accepted and I am sorry that Sir Kingsley is so reluctant to do so. He also appears to be unwilling to countenance the hypothesis of multiple periods of mineralization. This has now been well substantiated for many regions of the British Isles using various different dating techniques (including palaeomagnetism) and such a hypothesis may well reconcile various interpretations of the geological evidence with geophysical data.

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NOTES ON THE CUMBRIAN HEMATITE - G.A.Schnellmann, Ph.D.

These are notes for a longer paper intended for publication in these Proceedings, but not completed before the death of Dr.Schnellmann in January, 1985.

These deposits are unquestionably metasomatic. The physico-chemical nature of the ore fluids and their provenance is less certain.

Trotter (1945) make a good case supported by chemical authority for a solution of ferric oxide in ferric chloride at a temperature above 300°C. I find it difficult to accept either meteoric water or resurgent connate brine, or the hematite coating of sand grains in the St. Bees Sandstone, credible sources for such a fluid. This may be due to personal lack of imagination but it leads me to a strong endorsement of Sir Kingsley Dunham's appeal for "experimental work on chloride-iron complexing in which virtually no other minerals are leached" (p.264 of C.G.S. Proceedings Vol. 4, part 3). The gangue minerals are quantitatively not important, but their mode of occurrence appears to me to have some significance - euhedral crystals of quartz, fluorite and barytes in vughs associated with hematite in the form of specularite.

As in many problems of ore-genesis, the evidence is ambiguous or even flatly contradictory (vide the direct conflict between the geological and palaeomagnetic evidence as to age (p.263)). When I became a geologist at Florence in 1946 there were two firmly held, but as I subsequently concluded, unfounded or at any rate unsubstantiated, tenets in the mining fraternity: that no ore would be discovered beneath the St. Bees Shale, and that no ore would be found west of the Baybarrow Fault. The first of these was clearly a corollary of the descensionist theory, the second purely arbitrary but also to some extent linked with the descensionist concept. The one thing that linked them was that, at that time, no-one had looked for ore in either situation. There are virtually no geological parallels to these ore-bodies anywhere in the world, as Sir Kingsley notes. Taking the pragmatic view of an exploration geologist I decided that a hydrothermal origin for the ore had at least not been precluded. The long-established structural association with the post-Triassic fault system, the essentially hydrothermal nature of the veins in the Lower Palaeozoic rocks (Young, C.G.S.Proceedings, Vol.4, pp.269-275) and the possible physico-chemical nature of the ore fluid (Trotter, op. cit.) seemed to me to make a case which could not be written

off. Accordingly I planned a drilling programme which was basically a geometric pattern but based on the crestal pitch to the west of the Dent Anticline and on the post-Triassic fault direction. This was in an area where the St.Bees Shale was present and to this extent was no-man's land (vide sup.). In the order of 1 million tons of hematite in the upper limestones had been indicated by this drilling at the time of the suspension of the programme. The details are with the Geological Survey whose officers examined the cores, but are no doubt classified as confidential. The company's records are presumably in the archives of the British Steel Corporation. Unfortunately blast-furnace practice was by then turning to the high-grade ores, 68% Fe or better, being imported from South America and West Africa (subsequently also from Canada and Australia) and it is doubtful if this discovery was 'ore' in the economic sense, but I think the facts should be placed on record for their scientific value.

The following is a summary of the results of work done in the early 1960's. Unfortunately I no longer have access to the maps and bore-hole journals, and so have no details of the precise location of the bores.

The general area is between Egremont and St. Bees, north of the road running from Egremont to Ellergill Bridge, and around Watson Hill Farm. There was a primary rectangular grid of 16 holes at 1,000 feet centres and a secondary grid of holes on the intersections of diagonals where justified. Within a compact area of 2,025 million square feet these drillings gave the following indications, but I deliberately refrain from using the expression 'Indicated Ore Reserves' to which a special meaning is attached in ore-assessments.

Two adjacent holes proved unrecorded thicknesses of hematite in the Permo-Triassic Magnesian Limestone. This is an unusual though not previously unknown phenomenon. Eight holes proved thicknesses of hematite ranging from 4 ft. to 24 ft.6 ins. in the First Limestone, giving a minimum estimate of 1.35 million and a maximum of 2.09 million tons. Three holes proved thicknesses of 4'5" to 12'3" in the Second Limestone over an area of 28,000 square feet (within the 2.025 million mentioned above), say 224,000 tons. There were random intersections (maximum 2'6") in the uppermost 14'6" of the Fourth Limestone and in the Fifth Limestone.

In all, it appears safe to say that $1\frac{3}{4}$ million tons of 'ore' were drill-indicated. The mineralization appeared to be associated with a trough structure between the NNW - trending Byerstead fault, well known in the adjacent coalfield, and a previously unrecorded parallel fault inferred from the drill cores which I provisionally called the Watson Hill Fault.

Mr. D. McGivern, as agent for the Leconfield Estate, has kindly given permission for publication of these details.

EXCURSION NOTES

MINES OF THE NEWLANDS VALLEY

Leader: Mr. D. Wildridge

28th April, 1984.

26 members and friends met on a fine warm Saturday just below Littletown Farm. Mr. Wildridge began by pointing out the distant workings high up on Littledale Crags, Dover Bank and Blea Crags to which time would not allow a visit on this occasion.

The party began by walking south along the east side of the Newlands Valley, stopping first at a small 'scratching' with shale waste containing disseminated chalcopyrite. This was almost due east of the Goldscope Mine. The next stop was at a level under Lowthwaite Crag, just north of Barnet Gill, but found to be similarly rather barren.

The exposure of a relict deciduous scrubby woody material below a coarse water-borne deposit first noted by J.D.Hinde in 1983 was still fresh and clear at NY 232 182.

A stop at a working on the St. Francis Vein, north of Castlenook Mine was more rewarding. Samples of manganese oxide, galena and pyromorphite were found after patient search. At the Castlenook Vein a near vertical 4 - 5 cm galena vein was visible for approximately 1 metre. The road to the main dressing floor was easily recognised, but the tips did not yield any good samples.

We lunched near the 1920's Longwork Cross-cut. The zigzag path rising towards the presumed site of the St. Thomas' Work Mine was noted. The Longwork Cross-cut still has an 'open' adit descending at near 45°. Its tip was much richer in specimens, mainly in heavy and rusty brown pieces which contained much copper pyrites, with some quite well developed cubic crystals. The Longwork copper vein was followed across to the western slopes of the valley. The vein, extensively worked almost everywhere was well below the ground level around and in places deep stopes were water filled. Large masses of smelt waste, suggesting a possible smelter site, were visible.

Next came the really hard work of the day, climbing the steep zigzag track across Near Tongue and Far Tongue Gills up to the dressing floors of the 18th century Dalehead Copper Mine at about 600 m. Small but distinct samples of azurite, malachite, cerussite, chrysocolla and peacock ore were found. The well-preserved solidly built walls of a roofless hut were the main

remains; far more surviving than at mines of similar age in the western fells. More energetic members climbed another 70 m to the old level, now blocked, but with an obvious tip, just below the highest cliff band on Dalehead. This level is close to a waterfall and at or very near the Skiddaw Slate/B.V.G. junction.

The real treat of the return walk was our exploration of the Lower Pan Holes of the Goldscope Mine. The more timid of us only went about 300 m along the adit to the first under-stoped working with the waste resting on two stagings. Several continued through the 20 cm deep water into the Great Chamber with its four sets (or more) of timber staging vanishing into the darkness above. The position of the 18 ft. water wheel used in the 16th century was shown by the two recesses cut in the two opposite walls. This wheel was used to raise ore from an 18 fathom deep shaft. The crawl to the lead vein was indicated but not followed. The Upper Pan Holes did not provide an entrance, but there were plenty of small fragments of copper pyrites on the vein walls. Little remains of the previous extensive buildings at the foot of the mine-tips, but the positions of the dressing floor and store could be worked out.

Before parting members expressed their appreciation of Mr. Wildridge's expertise on the old mines of the area.

MORESBY AND KEEKLE OPENCAST COAL SITE

Leaders: Mr.E.Lawrence and Mr.R.Mungall

12th May, 1984.

A second visit to this site, situated at Scilly Banks on the outskirts of Whitehaven, was arranged to view progress since the Society's previous visit in September, 1981. Details of the site were published in Proceedings Volume 4, part 2.

The National Coal Board Opencast Executive's Area Geologist, Mr. Eric Lawrence, and the Executive's Site Engineer, Mr. Rob Mungall, acted as guides, first giving a short talk at the site office detailing the progress made on the site working area. Plans showed how the coal had been completely won from the two westerly areas of the Moresby section of the site, and that these were now in course of restoration. Excavations were continuing on another part of the Moresby section and also in the south-eastern coal area of the Keekle part of the site and a regular output of good quality bituminous steam-raising coal was being maintained.

The geological structure of the site was complicated by numerous faults, and as the seams contained washouts, and, in

parts, ancient workings, the winning of coal provided an interesting and everchanging geological picture. The old underground workings were not fully documented. Some records, notably those of the old Wreah Pit were quite detailed, and plans of the workings in the Main and Six Quarters seams of this pit which were worked to 1878, were shown to the party.

The Society was fortunate to have the presence of Mr. Bland of Padstow House, Newlands, as a guest of Mr. Edgar Shackleton. Mr. Bland's family have long been associated with mining developments in the Keekle area, and Mr. Bland had brought with him some fine detailed illustrations of the Heslop steam engine formerly used at Wreah Pit.

The Heslop engine had an interesting history. It was invented by Adam Heslop, an inventor and founder of the Lowca Foundry. The engine was patented on 17th July, 1790 to compete with the better known engine of James Watt. Heslop engines enjoyed great favour for many years at various pits in the Cumberland coalfield, but were never greatly known or used elsewhere. It is said that their principles and merits were understood by only a few.

The engine used at Wreah Pit is recorded as probably made around 1795 and was employed at Kells Pit originally; it was then used at Castlerigg Pit until 1837 when it was removed to Wreah Pit. At Wreah it worked continuously until the closure of the pit in 1878. At that time it was one of the last surviving examples of this fine engine and was taken to the South Kensington Science Museum where it is today.

The party was conducted to various working areas of the site, where working methods and examples of well displayed geological features were pointed out and explained. The exposures of old workings from the old Wreah Pit were of particular interest in the light of Mr. Bland's exhibits and connections, to which special mention was made when thanks were expressed to the leaders.

GEOLOGY OF THE POAKA BECK AREA

Leader: Mr.D.Leviston

20th May, 1984.

The party congregated at Holmes Green (222 752) and proceeded to make their way to Have Slack Hill (235 778). At this juncture the leader explained that the basic geological structure of the

area is a north-easterly plunging anticline-syncline complicated by a series of NE-SW, E-W and N-S trending faults. To the south-west the Skiddaw Slates formed the core of the anticline extending down to the intrusive volcanic rocks of the Greenscoe Quarry complex. To either side rocks of Ashgillian age are faulted into juxtaposition with the Skiddaw Slates.

Have Slack Hill is another volcanic intrusion and vesicular andesites were studied in the quarry. Circumnavigating the hill, areas of contact between the intrusion and the country rock were evident by the baking of the Skiddaw Slates to form a whitish rock.

The party then proceeded to Rebecca Quarry (234 779) where NW dipping Ashgillian mudstones were seen. The effects of the nearby Duddon Boundary Fault were demonstrated by a series of small normal faults in the quarry. Above the quarry coarse grits with mudstone bands were studied. It was explained that since these grits are not exposed in the quarry which is immediately along the strike, a fault must separate the two. Similarly, to the NW the immediate country rock is Brathay Flag, thus demonstrating the existence of two NW-SE trending faults. This locality formed a good vantage point to demonstrate the much modified syncline structure which forms the eastern side of the Duddon. The Duddon Boundary Fault was pointed out, which brings into juxtaposition the Skiddaw Slates and the Carboniferous Basement Beds.

After lunch the party proceeded to Poaka Beck House; a short walk along the reservoir revealing an exposure of Ashgillian Grits faulted against Brathay Flags (243 785). This demonstrated part of the evidence for the roughly E-W fault. The extent of the fault was discussed and it was shown that if the fault were mapped as suggested by the local topography it could extent westwards to meet the Duddon Boundary Fault (a different interpretation from the official maps). From here Stewnor Park (239 786) was visited where a small exposure of volcanic rocks was examined. Nearby highly cleaved Ashgillian mudstones were seen and behind a barn highly cleaved Skiddaw Slates were evident.

At a small quarry (242 788) green-grey mudstones developing into the blue-grey laminated mudstones of the Brathay Flags were seen. Do these curve round as shown on the official map or are they cut off by a N-S trending fault? Both interpretations are feasible.

The final locality was a small quarry at the top of the Brathay Flags (237 794). The rocks here dip in a south-westerly direction and are bounded to the south by a NE-SW trending fault. Above the quarry exposures of grits marking the base of the Horace Grits (Lower Coldwell age) were seen, again faulted against the Brathay Flags by a northerly trending fault.

At the close of the excursion the leader was thanked for a varied and interesting day.

THE PLUMBAGO MINES OF SEATHWAITE IN BORROWDALE

Leader: Mr.K.W.Bond

2nd June, 1984.

After weeks of dry weather, the morning of the excursion brought torrential rain, but as the Excursion Secretary had thoughtfully planned the visit to the Seathwaite Plumbago Mines for 2 o'clock in the afternoon, the sun was shining from a cloudless sky when some 24 members and friends met at the head of Borrowdale. The visit to these graphite deposits and abandoned mine workings combined geology with industrial archaeology at a totally unique location.

According to legend, the graphite deposits (known locally as 'wad') were discovered some time prior to 1600 A.D. when an ash tree, uprooted in a storm, exposed a rich deposit of plumbago. This exposure later proved to be the top of a highly inclined 'pipe' of rich ore. Initially, graphite was used for marking sheep, dying cloth, 'blueing' metal and a host of medicinal purposes. Later, of course, it was responsible for the founding of the Keswick Pencil industry which has survived to this day. So, for some 300 years the mines were worked intermittently and the graphite, which is exceptionally pure carbon, fetched a very high price until the mid-1800's when less pure but cheap imported graphite brought down the price and eventually closed the mines.

Geologically as well as historically, the deposits at Seathwaite are unique. Graphite occurs in stringers and nodular masses associated with a diabase intrusion into Borrowdale Volcanics. The old mine plans show eight veins or pipes up to 100 m deep in a small area and no similar deposits have ever been found within the Lake District. While most commercial graphite deposits originated by metamorphism of carbonaceous sediments, this does not seem applicable to Seathwaite, and Strens (1963) has suggested a possible origin from the reaction

$$2\ CO \lesseqgtr CO_2 + C$$

This requires a vast amount of carbon monoxide derived from the iron-rich pyroxenes and carbon dioxide, and the reaction to give the carbon deposit is catalysed by silica and iron compounds. The theory has a number of drawbacks but is acceptable in the absence of a more feasible explanation.

The mode of occurrence and the theories on the origin of the deposits were discussed on the ascent to the most accessible of the nine levels - Gilbert's Level - some 200 m above the valley bottom. The party split into two groups to make forays of some 150 m into

the fell side to where the near-vertical 'Grand Pipe' is encountered. This was the source of most of the graphite and is open all the way to the surface some 100 m above. Specimens of graphite were found in the loose rubble at the end of the level, but little can be seen as vein material. Back in the sunshine a climb was made to the upper opening of the 'Grand Pipe', examining the diabase and volcanic rocks en route. A number of ruins indicate the old mine buildings, particularly the guard houses which protected the very valuable mine product.

After returning to Seathwaite Farm, a visit was made to the Pencil Museum in Keswick by kind courtesy of the Rexel (Cumberland) Pencil Company. Exhibits showed the early manufacturing methods and the present extensive range of pencils and crayons made by the Company.

Mr. Bond received the warm thanks of the party for organising such an interesting day.

GEOLOGY OF KIELDER RESERVOIR

Leader: Mr.E.Skipsey

11th June, 1984.

A group of members and friends were joined by members of the Open University Geological Society at the Kielder Visitors' Centre where a short film was shown illustrating the stages in the construction of the reservoir.

The Kielder is one of the largest man-made lakes in Europe with a surface area larger than Lake Ullswater. The project is primarily a regional water grid scheme for N.E. England. Water released from the reservoir flows down the north Tyne river to a pumping station at Riding Mill, near Hexham, where supplies are abstracted and pumped through a north-south tunnel to delivery points in the valleys of the River Wear and the River Tees. The reservoir can provide a maximum yield of 250 million gallons per day, but its potential is unlikely to be fully utilised because of the reduced water demands from the conurbations of the north east.

The party drove across the dam to the north abutment car park. The dam is an earth embankment of over four million cubic metres

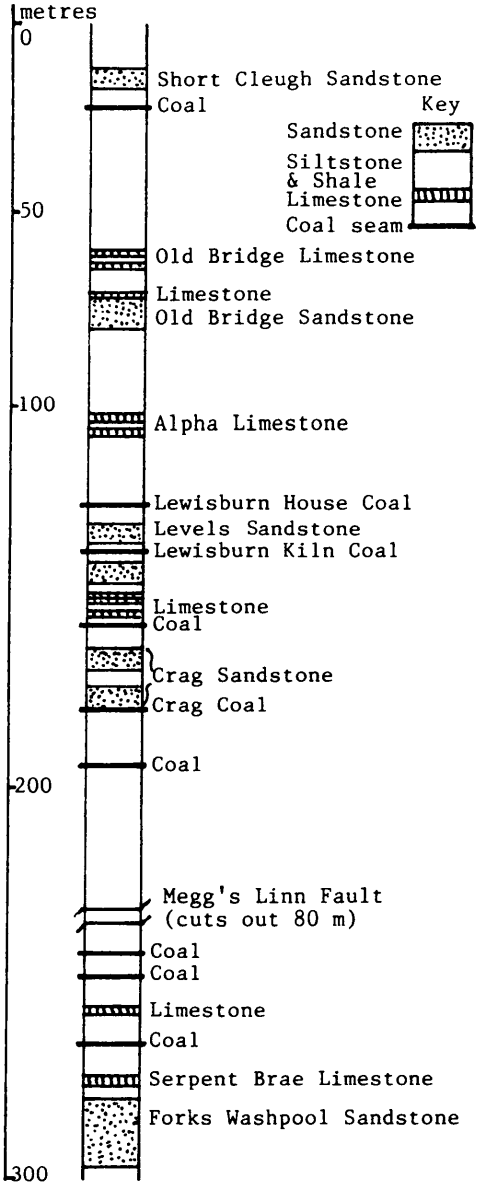


FIG. 1 SECTION AT LEWIS BURN BETWEEN FORKS BRIDGE AND SHORT CLEUGH. Adapted from A. Fowler, Mem. Geol. Survey No. 24.

volume and about 1 km long. Several factors favoured the site of the dam a short distance above the village of Falstone. It occupies one of the narrowest points in the valley while the upstream gradient of the river here is relatively flat, giving an extensive catchment area. Another important factor was the local availability of the vast quantities of raw materials required for its construction. Deposits of local glacial clays provided the material required for the construction of the clay seal in the heart of the dam while sand and gravel deposits were used for the drainage channels and for concrete work. The nearby Lewis Burn Dyke was extensively quarried to provide a hard, durable aggregate.

For many the highlight of the day was a cruise round the reservoir with an interesting commentary by Selby Allan when some of the extensive leisure facilities now provided were seen. The village of Plashetts, now drowned by the reservoir, had developed around a coal mine and a tile works and was served by the North Tyne Railway. Exhaustion of accessible reserves and economic difficulties in the 1930's led to flooding of the mine workings which precipitated the closure of the tile works, and then the railway was abandoned in the 1950's.

Mr. Allan took the boat close to the quarry on the

north bank (669 886) where the outcrop of a large dolerite dyke of Late Carboniferous age was visible. Erosional scars formed by wave action were seen to be developing in several localities along the northern shore.

After lunch at the lakeside the party travelled to the Lewis Burn to the west of the reservoir where some 300 m of Scremerston Coal Group outcrop between the Forks (631 888) and Short Cleugh (630 878) were studied. This sequence, typical of the rocks of the Kielder district, corresponds to part of the Upper Border Series in the Bewcastle district and consists of cycles of sedimentation in ascending order: thin argillaceous limestone - shale - sandstone - seatearth - coal, illustrated in the diagrammatic section.

The thin Serpent Brae Limestone, a typically rust-coloured, sandy limestone, was located about 100 m above the bridge at The Forks. This horizon is a useful marker and lies near the base of the Asbian cycle. A little higher in the succession a series of shales with thin coals were noted in the river bank.

Megg's Linn Fault is an important fracture and can be seen cutting across the burn in a NE direction about 500 m upstream from The Forks bridge. Some 60 m of strata are cut out by a fault and the strata on the down-throw side are vertical, but a short distance upstream they gradually assume a steady south-easterly dip of 30^{o} as far as the old bridge carrying the track over Lewis Burn. This 40 m section consists principally of shales and sandstones. Several coal horizons occur, with the Lewisburn Kiln and the Lewisburn House Coals the principal seams. At one time they were extensively worked with supplies going as far as Roxburghshire by moorland tracks. Traces of the drift mine entrances can still be seen.

A noticeable rusty-weathered limestone about 15 m above the Lewisburn House Coal is known as the Alpha Limestone and contains productids and gastropods. Not far above is a sandstone horizon at least 10 m thick which supports the old bridge and has been quarried for forestry roads. Resting upon the sandstone series are several crinoidal limestones, known as the Old Bridge Limestones, and which are fossiliferous.

The upper part of the sequence consists of shales and thin sandstones, and beyond Short Cleugh stream these beds are repeated on the opposite limb of a tight syncline where steeper dips of 35 - 45^{o} confine the top 80 m of strata to some 200 m of almost continuous exposure.

The excursion ended with the party re-tracing their steps through a very pleasant glen back to the car park.

All present had enjoyed a varied and most rewarding day, and expressed their appreciation to Mr. Skipsey.

CONISTON COPPER MINES

Leader: Mr.E.G.Holland

8th July, 1984.

After meeting at the car park in Coniston village, the party walked up the road beside Church Beck, past Miner's Bridge (pausing to see the adit known as Coniston Waterfall Level), to the Copper Mines Valley, rich in industrial relics, and time was spent examining these and hearing about their history.

After ascending the valley of Red Dell Beck, lunch was taken near a great stone pillar, once the support for the wooden sluice feeding the water wheel which powered the pump of the Old Engine Shaft, and pictured in Fig. 2.

The leader, Eric Holland, is an expert on the mines of this area and has written an excellent booklet 'Coniston Copper Mines', available from local booksellers, which is packed with his own plans and sections and drawings of long-vanished scenes at the mines, coupled with stringent warnings about wandering into adits without experienced leadership and not even with that in many places! He has very kindly given several copies of his drawings to the Society and two are reproduced on the next page.

Under his guidance the party ventured into the adit leading to the Old Engine Shaft which, protected by a chain, yawned frighteningly. Crossing Red Dell Beck and skirting dangerous open stopes, the party climbed the Thriddle Incline (an old wagon-way) past the remains of Bouncy Mine and Thriddle Mine and the 'Glory-Hole' and eventually over the ridge to Levers Water, noting Simon's Nick (where veins have been stoped out to the surface) before going down the valley past the Paddy End workings to rejoin our outward track near the Youth Hostel in Copper Mines Valley.

Eric Holland then took the party (equipped with rubber boots and hard hats) into the Bonser Deep Level which drains most of the mine-water to the open air. After wading through several inches of running water for some 200 m, the party halted before the flooded Bonser East Shaft brimming with water from which projects the iron pipe which formed the rising main of the old pumping system, and which terminates 300 m down in the sump of the Old Engine Shaft.

Skirting this deep shaft the party went up Shaw's 1954 By-pass Level before returning to daylight down the Bonser Deep level.

The Society is deeply grateful to Eric Holland for leading this excursion, for his guidance and expert information and for his permission to reproduce his excellent drawings.

Coniston Copper Mines
E.G.Holland

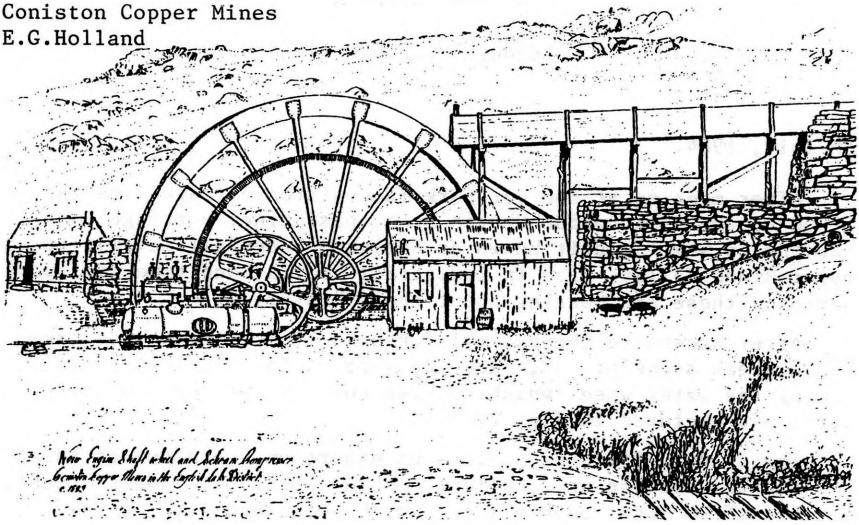


Fig. 1 NEW ENGINE SHAFT WHEEL AND SCHRAM COMPRESSOR, c.1883

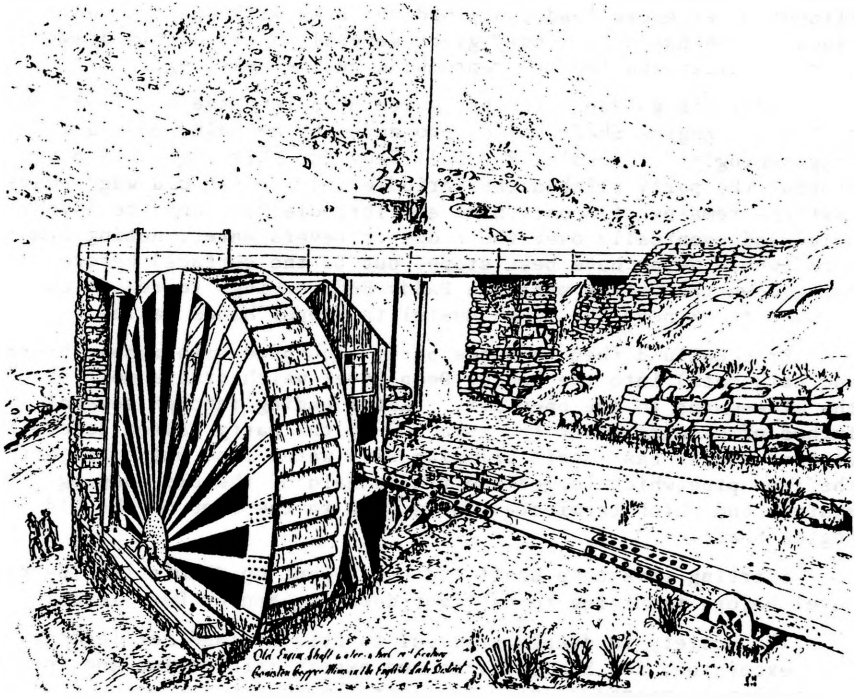


Fig. 2 OLD ENGINE SHAFT WATER WHEEL IN THE 19th CENTURY.

EXCURSION TO THE SKIDDAW GROUP, HOPE BECK

Leader: Dr.A.H.Cooper

29th September, 1984.

This joint meeting with the Northern Group of the Institute of Geologists was attended by 17 members and guests. The party met at the car park near Hope Beck (NY 169 242) and were treated to a fine autumn day for the visit.

The leader outlined the stratigraphy of the Skiddaw Group in this area, following Jackson's (1978) classification, but detailed re-mapping of the district by the officers of the British Goelogical Survey has added to the knowledge of the sequence. The formations exposed along Hope Beck are:

Kirk Stile Formation
Loweswater Formation
Hope Beck Formation

The lowest exposure in Hope Beck (NY 1686 2384) was the first to be visited. Here the party examined the oldest exposure of the Hope Beck Formation recognised by Jackson (op. cit.). This comprises dark grey banded siltstones and mudstones with up to ten percent of thin and medium-bedded, fine to medium-grained quartz-rich greywacke. The presence of appreciable greywacke beds in the Hope Beck Formation had not previously been recognised, but the re-survey by the B.G.S. has found them in most of the Formation in this area. Furthermore, the Formation is appreciably thicker than Jackson found and has yielded a graptolite fauna of low Arenig age. Elsewhere in the Lake District Drs. Rushton and Molyneux of the B.G.S. have recently discovered Tremadoc fossils in beds which underlie the Hope Beck Formation.

The next two exposures visited (NY 1732 2345 and NY 1739 2329) were also in the Hope Beck Formation. The first showed about 12.6 metres of laminated grey and dark grey siltstone with sporadic trace fossils, a subvertical cleavage and a low angle cleavage. The exposure showed another greywacke bed and highly weathered siltstones and mudstones. From this exposure south-eastwards for 800 m along Hope Beck there is no exposure, but the walk allowed ample time to appreciate the glacial morphology of the valley. A small terminal moraine dams the valley below Dodd and a gently sloping fluvio-glacial terrace is impounded behind it; several small alluvial cones spill from small tributary valleys on to this terrace.

The rocks seen at the first three exposures along Hope Beck have an overall gentle dip to the south-east. This dip increases southwards so that where the exposure starts again (NY 1800 2270) the beds are standing near vertical, but still younging to the

south-east. The junction between the Hope Beck Formation and the Loweswater Formation is not visible in Hope Gill. The fourth outcrop visited at the start of the exposure is in the lower part of the Loweswater Formation. Here thin and medium-bedded greywackes are present. These beds display classic Bouma sedimentary sequences (Bouma, 1962) indicative of turbidite deposition and also very useful for the determination of way up and younging directions. At this locality typical B-C Bouma cycle turbidites are present with parallel laminations passing upwards into cross laminations or convolute lamination.

A little further upstream along Hope Beck the greywacke beds of the Loweswater Formation increase in thickness becoming medium- and thick-bedded. At the same time the beds commonly develop massive graded basal units - the Bouma A unit - and complete Bouma A, B and C cycles are present. One thick bed in this sequence (NY 1806 2261) is unusual as it is composed of greywacke which contains up to thirty percent calcite, mainly as cement in the A and B Bouma units. This calcitic material appears to be of early diagenetic origin. A few other beds in the Loweswater Formation are also calcitic.

The party took lunch at this exposure, then proceeded along Hope Beck examining the beds which increase to their maximum thickness at the waterfall (NY 1806 2261). Southwards from here to its faulted junction with the overlying Kirk Stile Formation the bedding thickness gradually decreases to thin and the Bouma cycles simultaneously progress from mainly A,B,C to B,C then C cycles.

After crossing the faulted contact between the Loweswater Formation and the Kirk Stile Formation the party ambled uphill looking for fossils in the screes below Hope Gill Head. The fossils in the mudstones and siltstones of the Kirk Stile Formation, unfortunately, proved a little elusive, but good specimens of Phyllograptus sp., Tetragraptus sp. and Caryocaris sp. were eventually recovered. The slow pace uphill looking for fossils placed the party within easy reach of the ridge between Hope Gill Head and Ladyside Pike. Here (NY 1862 2228) the plunging core of the Hope Gill Head syncline was visited along with the northerly dipping slabs of the peak. The view of the glacially formed Hobcarton Crag was absorbed before most of the party climbed the last 30 m to the top of Hope Gill Head and its panorama. From here the party retraced its steps to the car park where the leader was warmly thanked for guiding the excursion.

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MINERAL DEPOSITS OF THE ALSTON AREA

Leader: Mr.B.Young

12th May, 1985.

A group of about 50 members drawn from both the Cumberland Geological Society and the Russell Society assembled at the site of Nentsberry Haggs Mine, Nenthead. The day's meeting commenced with a brief outline of the geology of the Alston Block and its bearing on the area's numerous mineral deposits. The main types of deposit - fissure veins and metasomatic replacement flats, and the well-developed zonal nature of the orefield, as described by Dunham (1948), were summarised. Theories on the origin of the deposits (e.g. Sawkins, 1966, Solomon, Rafter and Dunham, 1971) were reviewed. It was explained that the sites to be visited during the day were chosen to illustrate the main types of deposit as well as aspects of the differing mineral assemblages characteristic of the main mineral zones.

The party made its way to Blagill Mine (NY 741 473). Several veins were worked here last century, mainly for lead ore, but towards the end of the century some barium carbonate minerals were raised. The main veins strike between E-W and ENE-WSW and, in common with the majority of North Pennine veins, they carried workable ore bodies where they cut competent beds such as limestone or sandstone. At Blagill the main productive horizons were the Great Limestone, the Quarry Hazle and the Four Fathom Limestone. The veins at Blagill lie in the outer, relatively low-temperature, zone of the orefield where the mineral assemblage is dominated by barium minerals. Perhaps the commonest of these is baryte, but the Northern Pennine field is remarkable, and indeed unique in the world, for the abundance of barium carbonate minerals. Of these witherite ($BaCO_3$) is the commonest, but also present are the double carbonates of barium and calcium, barytocalcite and alstonite (Young, 1985). Both have the same composition ($Ba,Ca(CO_3)_2$) and are distinguished as separate species by their crystallography; barytocalcite is monoclinic, alstonite is triclinic (pseudo-orthorhombic). The trigonal trimorph of barium calcium carbonate, paralstonite, has not been found in Britain. Both barytocalcite and alstonite were first described as separate species in this area and in fact Blagill appears to be the original locality for barytocalcite. This mineral is the main gangue in the ENE-WSW vein

known as Fistas Rake where it is accompanied by smaller quantities of witherite and baryte.

In common with many North Pennine veins, Fistas Rake is no longer exposed at the surface and the underground workings are not safely accessible. The mineral assemblage must therefore be studied in the abundant blocks present on the dumps. Excellent examples of all the minerals known to occur in this deposit were obtained by members. Important characteristic features of these were described. In particular the distinctive monoclinic habit of barytocalcite was pointed out as an invaluable and reliable means of distinguishing this mineral from witherite and alstonite. Quantities of baryte forming cavernous masses of sharply terminated crystals were demonstrated as characteristic of baryte which has developed by supergene alteration of primary barium carbonate minerals. Smaller amounts of coarsely crystalline tabular baryte, typical of a primary origin, were also seen. Other minerals found included galena and sphalerite, smithsonite as brown cellular masses (a habit commonly known as dry-bone ore), and pure white or faintly blue coatings of hydrozincite were also noted. Columnar crystalline white calcite in a form suggesting inversion from primary aragonite were also found to be common.

A brief stop was then made at the old opencast workings on the E-W Lough Vein (NY 742 476), a little way to the north of Fistas Rake. Here the vein was worked in the Great Limestone, mainly for iron ore in the form of goethite. This mineral was no doubt derived from the supergene alteration of the primary iron carbonates siderite ($FeCO_3$) or ankerite ($Ca(Fe,Mg,Mn)(CO_3)_2$). Sphalerite also occurs in this vein. Specimens were seen on the dumps showing this mineral extensively altered to smithsonite, in places forming pseudomorphs after sphalerite. Barium minerals appear to be absent from this part of Lough Vein.

En route to the next stop the impressive man-made valley of Dowgang Hush (NY 772 428) was passed alongside the Nenthead to Garrigill road. This old opencast working is on the NE-SW Dowgang Vein, which provides a good example of a typical North Pennine lead vein. At Dowgang the mineralization belongs to the relatively high temperature fluorite zone in the centre of the exposed portion of the orefield. In this zone barium minerals are typically absent, their place being taken by fluorite and quartz, though good specimens are no longer easily obtainable at Dowgang.

Good examples of fluorite zone vein mineralization were seen on the dumps of Tynebottom Mine (NY 738 409) at Garrigill. This mine, which worked last century for lead ore, is perhaps best known for replacement 'flat' deposits. These are common in the North Pennines and have contributed very large tonnages of lead, iron and zinc ores to the area's recorded output. They consist of horizontal belts of limestone adjacent to veins which have been partly or wholly replaced by introduced minerals. In most cases the main

replacement mineral is either ankerite or silica with bands and pockets of galena and sphalerite together with a variety of spar or gangue minerals. Some of the finest crystallized mineral specimens from the area were obtained from cavities in 'flat' deposits. At Tynebottom the Tynebottom Limestone has been replaced for several metres alongside the Browngill and Windshaw Bridge Veins mainly by fine-grained silica. Galena occurs in bands with smaller, uneconomic amounts of sphalerite together with calcite, marcasite, pyrite and some fluorite. Good exposures of the deposit are still accessible here underground by way of the water level which opens on the banks of the Tyne. The party was not equipped for such a visit and the essential features of the deposit were demonstrated in the abundant dump material. Tynebottom Mine is noteworthy for the variety of colourful supergene minerals. Perhaps the best known of these is erythrite ($Co_3(AsO_4)_2.8H_2O$) formed by oxidation of traces of glaucodot ((Co,Fe)AsS) (Ixer & Stanley, 1979) which occurs in microscopic inclusions in other sulphides. Brochantite ($Cu_4(SO_4)(OH)_6$) as deep green crystals, linarite ($(Pb,Cu)(SO_4)(OH)_2$) as deep blue crystals and hydrozincite ($Zn_5(CO_3)_2(OH)_6$) as pure white massive crusts are also present. Good examples of all of these minerals were collected. After leaving Tynebottom Mine the party moved to Tynehead. An exposure of Windy Brow Vein (NY 761 381) in the shale above the Tynebottom Limestone was briefly examined adjacent to the footpath to Sir John's Mine. Windy Brow Vein here carries much calcite and quartz, the latter commonly in large well-developed pyramidal crystals. A level driven along the vein from the bank of the river to intersect Sir John's Vein was pointed out.

The relatively modest surface remains of Sir John's Mine were visited. This mine worked lead ore from Sir John's Vein last century though output appears to have been small. The mine is of more interest as it cuts the Great Sulphur Vein. This vein is unlike any other in the orefield at present levels of exposure. It comprises a north-facing faulted monocline associated with a considerable belt of shearing. Mineralization consists mainly of quartz and iron sulphides. Galena and sphalerite are rare or absent in most localities. A vertical zoning of the constituent minerals is clearly developed in this vein: quartz occurs at high levels with iron sulphides becoming abundant at depth. The sulphide zone was cut in Sir John's Mine. Good examples of sulphide-bearing veinstone were demonstrated on the dumps. The sulphides here comprise pyrite, marcasite, pyrrhotite and a little chalcopyrite. There is today evidence to suggest that at least some of the fluorite-bearing veins of the orefield pass at depth into zones dominated by quartz and iron sulphides very similar to the Great Sulphur Vein (Dunham, K.C. in Sawkins, Dunham & Hirst, 1964). It is thus likely that the Great Sulphur Vein may be the root zone of one such vein or vein system, the upper part of which has been removed by erosion.

All attempts to mine iron sulphides from the Great Sulphur Vein have proved fruitless even under wartime conditions: Sir John's Mine was explored as a possible source of iron sulphide during World War II. A vain attempt to extract gold from the sulphide ore was once made here, and for many years the remains of a crusher and gold pan could be seen near the mine entrance.

The field meeting was concluded with a brief visit to the outcrop of the Great Sulphur Vein in the bed of the River Tyne (NY 760 375) about 300 metres upstream from Sir John's Mine. The vein here consists of a shatter belt about 100 metres wide in the Whin Sill and underlying Tynebottom Limestone. Mineralization at this point consists mainly of quartz with only minor amounts of iron sulphides.

Mr. Young was congratulated on providing yet another comprehensive survey of a mineralized area.

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THE LOWER CARBONIFEROUS OF THE ORTON SCAR AREA

Leaders: Mr.A.S.Day and Mr.J.C.Wilson

19th May, 1985.

Above the Asbian rocks of Orton Scar, known as the Potts Beck and Knipe Scar Limestones, lie a series of repeated cycles of limestones, shales, sandstones and in some cases thin coals. Like the lower rocks these have a general north-westerly dip so that the sequence youngs northwards when followed down into the Eden valley. The series continues until the Great Strickland Limestone is reached at the base of the Namurian near Kings Meaburn (620 212). There are nine of these major sequences (cyclothems) in the area. The cyclothems vary in thickness as do the individual beds within the cyclothems.

The cyclothems are interpreted as deltaic sediments laid down at a time of fluctuating sea levels. However, the limestones are too laterally continuous to sustain this idea satisfactorily and it is now thought that the sandstones, although transported originally by large deltaic rivers, are essentially terriginous sediments which have been re-worked and deposited in shallow coastal bays. The debate continues and theories may have to be modified again in the light of further research.

The limestones are typically dark and bituminous in contrast to the lighter-coloured purer limestones of the Knipe Scar Beds. The terriginous deposits are a sequence predominantly coarsening upwards and within it are beds, fining upwards, which have been interpreted as deposits of a fluviatile regime.

The party met at the top of Orton Scar and after a few words of introduction proceeded to the head of Scale Beck (646 126). Here the stream had cut through the Askham Limestone and exposed an inlier of the thin cyclothem underneath with the basal Gaythorne Limestone in the stream bed. The stream was actively depositing tufa of which large blocks were scattered about. The cyclothem was nicely exposed in the low cliff and waterfall; a bed of iron nodules was conspicuous below the sandstone. Above the sandstone, a thin seat earth was overlain by a very thin coal which completed the cyclothem. The Askham Limestone, above, was relatively thick and moderately fossiliferous, containing corals S. panciradiale, Syringopora sp. and Diphyphylloid sp., some Gigantoproductids and a few pink weathered algal nodules (Girvanella?). The limestones had the characteristic dark colour caused by the presence of impurities.

Following this visit the cars were parked at the roadside near

the entrance to Crabstack Farm (634 195). The leader explained that by following the stream southwards a complete section of the Grayber Limestone cyclothem would be seen in descending sequence. The first exposure in the bank of the stream by the farm lane belonged to the upper leaf of the Newby Mill Limestone, part of the cyclothem overlying the Glayber cyclothem. This was a very muddy limestone with a red-brown colour probably caused by solutions percolating down from a one-time cover of red Permian rocks long since removed by erosion. The limestone was very fossiliferous and yielded fine examples of bivalves, spirifid brachiopods, plant remains, fragments of fossil wood and the ubiquitous trace fossil Zoophycus.

Moving upstream and down the sequence, the shale below this limestone was exposed and below that, the lower leaf of the Newby Mill Limestone at 634 192. Its character is different from that of the upper leaf, being lighter in colour with a purple tint, of greater thickness and harder. The shale band between the leaves wedged out westwards so that eventually they merged into one continuous bed, the shale representing an incursion of mud which temporarily interrupted limestone deposition.

This part of the day turned into a pleasant ramble through unfrequented pastures in contrast to the morning's exposed localities swept by cold winds. The sheltered valley along which the stream meandered had the typically flat bottom and steep sides of a glacial meltwater overflow channel. Several large erratics were scattered along the valley floor, mainly Borrowdale Volcanics and Shap Granite. At 635 186 the bed of the stream was slabs of coarse-grained sandstone, often containing ill-defined carbonaceous matter. Further up the stream and lower down the sequence, the sandstone was finer with cross-bedding, sometimes of the planar type. The lower part of the sandstone was coarse-grained with a sharp base which could be seen cutting into underlying shales in the river bank. The Little Beck Sandstone has been interpreted as a channel deposit with an erosive base and a fining-upwards sequence. The upper coarse sandstone was probably a series of infilling flood deposits which included plant material and wisps of coal at the top as relics of final quieter swamp conditions.

The underlying shales were unfossiliferous until the exposure of the junction with the basal Grayber Limestone at 636 182 just above water level. There, the bottom 10 cm of the shale contained small impressions indicating that some marine life survived the influx of mud; but not for long, for the rest of the shale was barren.

The bottom limestone of the Grayber cyclothem was pale to medium gray with crinoid fragments and plant impressions and distinctive green glauconite grains. Easily seen under a hand lens, when examined by microscope the glauconite appeared to encrust foraminifera. It is thought to have originated soon after

deposition. From this point the party returned to the cars, where thanks were expressed to the leaders for explaining this area so well.

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THE 'SUBMERGED FOREST' NEAR ALLONBY

Leader: Dr.F.J.Cockersole

5th June, 1985.

This Wednesday evening excursion broke new ground. The existence of traces of a buried forest-soil horizon at various localities off the Cumberland coast was first recorded in 1877. Similar exposures have been described generally around the northern parts of the Irish Sea, for example off the Lancashire coast and off the Isle of Man. Similar evidence of post-Glacial sea-level changes is found in many places round northern Britain including the coasts of Northumberland and Durham. Because of tidal scour and long-shore drift in the area between Maryport and Silloth the exposures of the forest beds vary from time to time both in position and extent. Two localities were visited:-

(a) About half a mile north of Allonby (at approximately 078 442) where buried soil horizons and partly consolidated ancient beach deposits are to be seen.

(b) South of Mawbray (at approximately 083 483), where definite stumps, fallen branches and tree trunks were currently exposed. (This locality or one very near it is described in the 1926 Carlisle Geological Survey Memoir).

The submerged forest consists of a horizon of peaty soil, quite thin but containing recognisable organic material - twigs and rootlets as well as in places obvious larger portions of tree material. Below the soil is a poorly developed but typical seat earth which in turn rests on Boulder Clay. This forest layer has been dated elsewhere by ^{14}C methods to the early part of the post-Glacial or Flandrian period, i.e. about 9,000 - 8,000 years B.P. In other localities bones and antlers of deer have been found and

possibiy Mesolithic flint artefacts. There is little information readily available about the type of vegetation, but most of the tree stumps exposed are said to be oaks. The forest layer constitutes one of the Recent or Holocene (i.e. the 10,500 years of post-Glacial time) deposits in the area and it is overlain by raised-beach gravels and warps, marine and fluviatile alluvium and peat and blown sand.

The existence of the forest layer provides important evidence of sea-level changes in post-Glacial times. Sea-level changes can be eustatic or global in effect due, for example, to the formation or melting of ice-caps, or they can be epeirogenic, i.e. related to localised tectonic changes resulting in elevation or depression of the land surface. Towards the end of the last (Devensian) glaciation the sea-level was very much lower than at present because of the water locked up in the ice-cover. The climate then showed a marked amelioration allowing the formation of forest vegetation. A post-Glacial eustatic rise in sea-level (the Flandrian transgression), related to the melting of the ice, brought the sea-level up to several metres above the present level. This rise culminated at about 7,000 - 6,000 B.P. forming the raised beach features along parts of the Cumberland coast. The forest beds were inundated and submerged to a depth of about 18 m below the present High Water Mark. River alluvium and flood terraces along the valleys of the Derwent and Ellen can be related to this rise in sea-level. There has been a subsequent rise in land levels of between 3 and 5 metres due to isostatic uplift following the release of the ice load. The consequent sea-level fall is therefore epeirogenic in nature. This process may still be continuing, and has resulted in the exposure and erosion of the forest horizon which has been elevated into the intertidal zone.

At the end of the evening's exploration Dr. Cockersole was warmly thanked for bringing to the attention of the Society this interesting exposure.

Short visits were also made to the Ellen Valley (Netherton), the Embleton Diorite, Ramsgill (Dent) and the Greta Gorge. Repeat visits (see previous reports in the Proceedings) were made to St. Bees Head/Barrowmouth, and Hassnesshow (Buttermere). The Kirkby Thore Gypsum Mine visit was cancelled. Very wet weather led to the abandoning of two short evening excursions, but information was given under shelter!

Shortage of space in this issue of the Proceedings prevents the reporting of excursions held after 5th June, 1985. It is hoped that these will find a place in the next issue of Proceedings.

LECTURE REPORTS

GEOLOGICAL ASPECTS OF

RADIOACTIVE WASTE DISPOSAL

Dr. T. McEwen

This lecture-meeting was held on 7th March, 1984, at West Cumbria College, Workington, and was attended by 21 members and guests. The speaker, from the British Geological Survey, Nottingham, was welcomed by the President, Dr.F.J.Cockersole.

Dr. McEwen first outlined the classification of wastes as being of low, intermediate or high activity: there are international definitions and widespread controls.

Very low-level (not more than a luminous clock face) wastes arise from hospitals and laboratories, and are simply disposed of in landfill sites. Slightly higher-activity waste is disposed of in trenches in glacial deposits at Drigg. A rather higher activity waste used to be sunk in drums in the Atlantic off Portugal, but this policy is currently discontinued, and a ship specially built to drop drums from the hull has not yet been used. All this, and some gaseous waste, is within the low-level category.

Intermediate-level waste is all stored at Sellafield: it is mostly cladding from fuel rods and cannot be reprocessed to recover the cladding material.

High-level waste is stored in liquid form at Sellafield: development work has been going on to convert it into glass blocks, but it is not being disposed of at present. It has less bulk than the low and intermediate level wastes.

Control over disposal is exercised by NIREX (Nuclear Industry Radioactive Waste Executive). For low-level and short-lived intermediate-level wastes a site at Elstow Bridge Depot near Bedford, owned by the Central Electricity Generating Board, might be suitable. There is an 18m bed of Oxford Clay which could be trenched and the waste encased in concrete. The wastes need a minimum of 300 years storage. Longer-lived intermediate-level

waste could possibly be stored in part of the disused Billingham mines: there, one important factor to be considered is that parts of the local Permo-Trias sequence are used as aquifers. Reports are being written on these two locations.

Options which have been suggested for disposal of high or intermediate-level wastes were outlined. Shooting it into space would be very costly and potentially dangerous in the event of any malfunction. Storage on the surface presents the prospect of its having to remain for more than a quarter of a million years. For ocean disposal international agreement seems unlikely, though it would be quite feasible to embed it deeply in the ocean floors. Emplacing it, from the land surface, into suitable rock formations seems to have the highest probability: a specially designed 'mine' layout was illustrated, with access shaft and disposal holes which might extend down 200 to 2000 metres.

Dr. McEwen had been engaged in a major study of Strath Halladale (near the north eastern tip of Scotland), an area of granite and Moine Schists, but covered in peat - leading to some operational difficulties, as could be appreciated from the slides shown. Three 300m deep holes were drilled. The cores, and river bank exposures, showed extensive fractures in the rock and these affect its hydraulic conductivity. A very full study of water movement through the rock is of prime importance since that movement is most likely to determine how long it would take for leached components from the waste to reach the biosphere.

Infra-red aerial photographs were taken of the river: these showed changes in colour at various points along the river (as readily seen from the slide shown), indicating changes in water temperature. This indicated that in places there were additions of water of different temperature from springs.

Variations in the extent of rock fractures with depth were assessed by lowering down the boreholes a sonic probe. This has at one end a transmitter producing compression waves, and at the other a receiver recording both these and the transverse-waves produced at the borehole wall. Results indicate both the number per unit length (or Rock Quality Designation) and orientation of fractures at particular depths. The R.Q.D. can be related to the bulk modulus of the core sample from the particular depth.

Water flow properties were investigated down the boreholes by a pair of expanding packers from between which water could be withdrawn. It was found that there was a 10^6x difference in water flow between different parts of each borehole.

The general movement of water is, of course, from topographic highs (acting as headers) towards topographic lows (river-sites). Faults, or regions of highly developed slaty cleavage can act as drains, and full information of structural aspects is essential.

The embedding in rock of high-level waste from reprocessing could not be done immediately. The heat output from a canister of waste of the planned size would be sufficient to melt rock and vapourise groundwater. It is considered that probably the best procedure would be to reprocess fuel rods early and store the waste on the surface for 70 to 100 years after which time heat emission would be reduced by a factor of 100. At that stage it seems feasible that the canisters could be put in rock at regularly spaced intervals such as a cubic array. The actual spacing would be calculated for the particular waste and rock type.

One projected mine-type waste repository would take metal canisters spaced out in tunnels which would be gradually back-filled with bentonite and crushed rock. Eventually the canisters would corrode and radioactive compounds start leaching: the rate of migration must be sufficiently slow for the activity to have died away to safe amounts before reaching the biosphere. A great problem would be the circulating water system resulting from the large heat emission.

The repository is assumed to hold the reprocessed high-level waste from 5000 GW thermal years of PWR power generation. This corresponds to 55,300 tonnes of fuel, reprocessed after 4½ years and stored for 100 years before disposal, at which time it would be releasing 8.1 MW of heat.

One encouraging discovery is that the radioactive glass (into which waste can be converted) reacts with granite forming new minerals which are geochemically stable, therefore effecting a slowing-down of the migration of radioactive compounds. Not yet known, but under investigation, are the effects of bacteria. Also being studied are the extremely slow flows of water through clays, a subject largely ignored for other purposes: the work includes pressing out the pore-water for analysis.

In concluding, our speaker remarked that to report on a particular site needed study of an area of perhaps 1000 km^2 and a prediction of its geology for the next quarter of a million years. It is necessary to estimate both the shortest (the worst situation) and the longest (the best situation) possible migration times. Of least importance is the time when leaching starts, i.e. the quality of the canister.

In replying to a number of questions Dr. McEwen suggested that finding a solution to the problem would be more likely with a work-programme which was continuous, not sporadic as in recent years. It is not entirely certain which rock would be best, but in his opinion the emplacing of waste in granite below a thick sediments cover might be the safest method, but would be difficult to model. Sea disposal looks unlikely at the moment. Although offers of foreign disposal sites, e.g. the Quatar Depression, or part of the Gobi Desert, had been made, Britain considers that it should not

dispose of its waste in some other country. A query on the possibility of tracing the migration of individual element ions drew the comment that this would be very complicated since they are changing as they go. The answer to a time-scale question was that it would take several thousand years for high-level waste to decrease in activity to that of intermediate-level waste.

In thanking the speaker, the President remarked that this lecture had certainly left the audience more educated and better able to understand the situation.

A MINI-LECTURE EVENING

On the 4th April, 1984, members and friends, 31 in all, met at the Derwent Centre, Cockermouth. Not only the scheduled lecturer but many of his colleagues had been stricken by 'flu, and alternative arrangements had been made by Mr. Dodd on the previous evening.

Mr.J.D.J.Wildridge, using a succession of slides, took the opportunity of briefing the audience on some aspects of his forthcoming excursion on 28th April.

Barrow Mine (sometimes referred to as Uzzicar Mine) has a number of bell pits round it. Some spoil has been removed recently exposing mineral specimens. The old smithy is to be seen in the background.

The Goldscope area (Scope End, Littledale, with Doverbank at its head, and Robinson) was depicted. A site shown by the O.S. as a quarry was the place from which they re-entered the mine after the Great Crush of 1854, when the vein collapsed and the miners refused to enter the stope from the adit. At the head of Littledale is a small reservoir, the water of which was leated to a water wheel inside the mine. A plan and section of the mine were shown. Before its closure it had been proposed to install a second water wheel to enable them to work even deeper, but as the cost was to be about £3,000, an enormous sum in those days, the mine was abandoned.

Some pyromorphite is to be found on top of Blea Crags on High Snab Bank. The road to Castlenook Mine shows tips and dressing floors.

Across the top of Newlands Valley is the open cut of the German Long Work of about 1664, and the site of the buildings of Dale Head Copper Mine (1702) was pointed out.

At Stoneycroft is an example of stope-and-feather working and higher up the beck the site of a smelt mill.

Mr.S.H.Gate contributed a travelogue of Malta, explaining that it was not geological, the visit having arisen from a wish to see again the magnificent harbour of Valletta. However, having viewed some of the harbour details and buildings (many with British connotations), the audience saw slides of some of the aeromotors on the higher parts of the island which are used to pump water from the Greensand aquifer, with its base of impervious clay. A limestone scarp and a quarry were shown. One local craft is cutting and polishing 'Malta Stone' (calcite dripstone). Though fossil sea-urchins were obvious on one shore-line, lack of hammer and chisel prevented their extraction.

On Malta frequent use was made of the excellent buses, all starting from the Valletta terminus, each bus having a religious ikon and text beside the driver. Beautiful churches abound, that of Mosta having had its dome (the fourth largest unsupported dome in the world) pierced by a German bomb which failed to explode.

Crops included lemons, ripe in March. Some shoats, a cross between sheep and goats were seen. Further slides showed the nearby island of Gozo with a neolithic temple estimated to date from 2800 B.C., and a charming rocky fishing village.

Dr.F.J.Cockersole gave a talk on Sumatra. Prior to departure he had obtained a geological map of the island. It had hand-coloured divisions, but lacked a colour-key!

Sumatra has a subduction zone off its west coast, and volcanoes extruding andesite occur on the south coast. On the north coast are Tertiary sediments. The island has been undergoing a clockwise rotation.

A photograph of a rocky stream course, just clear of the dense forest was shown, looking, as Dr. Cockersole remarked, like a Lake District stream since the rock-type was the same. Some soil-profiles, however, were of different appearance, showing iron pan and tropical lateritisation.

A visit was made to a quiescent volcano, its jagged crater-wall remains clearly indicating an enormous explosion in the past. Fumeroles were numerous. The crater floor was of layered volcanic

mud showing surface desiccation contraction patterns, and in places peculiar structures due perhaps to disturbance by steam jets. There were many encrustations. One local man arrives daily to ladle out liquid sulphur amid choking fumes, casting it in hollow bamboo stems to form cylindrical pieces some three inches in diameter which he carries all the way back for sale.

A large coastal petrochemical installation was visited where natural gas is purified, liquefied and exported to Japan. The gas wells are 40 km inland and are 6000 m deep so that the gas is under high pressure. The last slide showed the result of a blow-out, with horizontal flames thundering out. It was three months before this was controlled - by Red Adair, at vast expense.

In conclusion, Mr.M.B.Dodd thanked the three members who had stepped in at short notice.

ASPECTS OF METALLIFEROUS MINERALISATION IN THE LAKE DISTRICT.

Mr. B. Young

The first lecture meeting of the 1984-5 winter session was held at the Derwent Centre, Cockermouth on 5th September, 1984, when 36 members and guests attended. The Society recently benefited from the speaker's other roles as author and excursion leader: in introducing him the President gratefully acknowledged the continuing firm support by B.G.S. staff. Members were reminded that details of the Russell Society (a body devoted to mineralogy) could be obtained from Mr. Young.

Our speaker stated that the B.G.S. is only at the start of a comprehensive study of the areas's mineralisation. Whilst there are published details of separate ore-bodies, no one has yet put together the whole Lake District story. The main ores are those of lead, copper, zinc, tungsten and iron; there are lesser

quantities of cobalt, nickel, arsenic and barium minerals. Though now pretty well dead as a mining area, in the 16th and 17th centuries, when Britain was the world's largest copper and lead producer, the Lake District provided a good deal of them.

A series of slides reminded the audience of a number of old mines - Roughtengill, Hartsop Hall, Paddy End, Simon's Nick near Levers Water, Coniston, and Sandbeds (Caldbeck). At Hagget Gill, Ullswater, the B.G.S. are investigating an antimony occurrence. Force Crag may have a working future, and Carrock Mine will probably work again when the price of tungsten rises. Iron mining in the fells, as at Nab Gill, is unlikely to be revived.

The geological map shows there are in the area many outcrops of granites: these in some way control the mineral deposits. The whole area is underlain by a batholith, which is probably a composite of different granites. Almost all of the minerals are vein deposits with the metal ore in a 'gangue' of other minerals, mainly quartz. Most veins occupy faults. Examples shown of old vein workings were from Eagle Crag, Grisedale (the actual vein being only 0.4 m wide), the old stope at Sandbeds Mine (now collapsed), and Drygill Vein, from which good campylite specimens used to be obtained.

The proved extent of the batholith was illustrated: the B.G.S. has now established the detailed contouring on the top of the batholith by means of detailed gravity surveys. It falls away steeply to the south ('S. wall'), probably steeply to the north ('N. wall'), but less steeply to the east.

Various studies of the main mineralisation have been made by, for example, Postlethwaite, Eastwood, Kendall and Kingsbury. More recent studies by C.Stanley have concentrated on the metal sulphides which he suggested were emplaced during the episodes of mineralisation between the Devonian and Jurassic in veins which vary in metal content, e.g. dominant copper or dominant lead. He also stated that the directions of veins did not allow reliable correlation, and that the wall rock minerals' age often differs from that of the ore mineral.

There is no obvious regional zonation to the deposits, unlike the North Pennines. There can be, however, a zonation within individual deposits, e.g. Force Crag has barytes and manganese oxides in the top of the mine, a barren middle part, and in the bottom much zinc, lead, a little chalcopyrite and a much smaller amount of barytes than in the higher levels. The temperature of deposition was greater for the bottom deposits than for the top ones.

How did the veins get there? The older idea, of more than 30 years ago, was that granite gave off mineral-bearing liquids: today this is largely discounted. Minute cavities in quartz crystals associated with ore veins contain fluid found to be salty

water. This suggests that ground-water, or water trapped in sediments dissolves mineral substances dispersed in sediments, so concentrating them. These fluids may have been circulated by convection processes driven by a heat source such as a granite which may retain a high heat flow long after its emplacement (the Cornish tin mines are very hot 700 m down). Drop in temperature of a solution ascending a fracture would result in deposition. It is now considered possible that mineralisation may result from the interaction of meteoric water descending, connate water percolating sideways and hot hypersaline brines ascending. Some minerals formerly regarded as secondary, e.g. pyromorphite, were probably directly deposited as a result of such interactions.

Mr. Young then gave a commentary, illustrated with slides, on three mining areas.

Working of the copper deposits at Coniston ceased when much magnetite was encountered. In those days (though not now) separation was difficult. It is sad to reflect that much of the discarded waste contains two or three times more copper than deposits currently being worked abroad - most British deposits are high-grade but small. It was noted that the vein-width was usually less in the tuffs where faults tend to close back after fracture, whereas rhyolite stands open after fracture, allowing easier percolation of fluids, and hence, usually, better veins.

The Coniston workings were very large, but only a small part remains accessible to present-day geologists. Records indicate vertical zonation. In the Bonsor Vein chalcopyrite was accompanied downwards by arsenopyrite and magnetite. Depositional temperatures are considered to have been around 200°C at the highest part of the veins, and around 350°C at the greatest depth reached.

Carrock Mine is the only British site outside Cornwall where tungsten has been mined. The Harding and Emmerson Vein outcrops are of sharp 'text-book' aspect and were formed in the Devonian. Besides wolfram there are scheelite, arsenopyrite, molybdenite, bismuthite and also some complex lead-antimony sulpho-salts. The latter were formerly supposed to be distinctly later than the tungsten ores, but both have recently been found in the present mine in close association. It is probable there was a phase of antimony mineralisation in the Devonian. Similar complex antimony minerals have been located in a vein in West Swine Gill, south of Carrock. In upper Brandy Gill the tungsten veins are crossed by lead veins producing a set of rare lead-tungsten minerals including the first stolzite found in Britain.

On the flanks of Helvellyn, Greenside Mine was the most productive Lake District lead mine, extending through a large vertical interval. The productive part of the mine was in Borrowdale Volcanic Group wall rocks. Skiddaw Group rocks were

reached in the deepest levels but proved to be unproductive. The suite of minerals changed downwards from barytes at the top, followed by increased metal sulphides, then more sphalerite and chalcopyrite, indicating increased temperature with depth.

A few kilometres south of Greenside, Eagle Crag Mine shows a long straight fault-fissure vein containing galena, quartz, barytes and tetrahedrite.

As to the future, it is unlikely there will again be mining on the scale of the past, though, as mentioned earlier, Carrock and Force Crag Mines may well re-open since small-scale workings can pay.

Further information was included in answer to a number of questions. The cobalt on Causey Pike, though in minute amount, is considered to have resulted from Devonian mineralisation. Most of the copper may have been produced by leaching from the Borrowdale Volcanic Group. No significance could at present be attached to the scarcity of fluorides in the Lake District.

The President expressed the Society's thanks for a fascinating lecture which most fortunately followed a summer in which a number of mineral sites had been visited by the Society.

THE GEOLOGY OF EAST LOTHIAN

Dr. A. D. McAdam

At the start of the meeting of 3rd October, 1984, at West Cumbria College, Workington, the 23 members and guests present observed a short silence after the President had announced with regret the death of Mr.G.S.Gowing, and referred to his valuable services to the Society.

The speaker, from the B.G.S., Edinburgh, where he kindly led a Society excursion three years ago, was warmly welcomed. Dr. McAdam's generous screen illustrations included early to recent maps, depictions of the surface at relevant geological periods, diagrams and scenes both volcanic and intrusive, rock textures, features and sequences, and beautiful coastal and inland scenery

often with North Berwick Law or the Lammermuir Hills as background. East Lothian, as our speaker remarked, can be regarded as a geological jewel, and shows the Midland Valley features in miniature.

Hutton, Necker, McCulloch and Hay Cunninghame were among the early geologists who increased our knowledge and produced successively more complex geological maps. East Lothian was the first target in Scotland for the Geological Survey, editions of Sheet 33 being published in 1860, 1910 and most recently drift and solid maps in 1978-82.

Relationships between Lower and Upper Palaeozoic rocks are well exposed along the coast. Hutton's classic unconformity at Siccar Point shows how Old Red Sandstone sandstones and conglomerates truncate upturned Silurian greywackes. Inland, Old Red Sandstone strata are exposed in Fairy Glen, Oldhamstocks Burn, where modern processes produce small delta fans in an arid climate with high relief, mimicking the Old Red Sandstone environment. Calciferous Sandstone Measures strata are dominated by the Garleton Hills Volcanic Rocks. A thin basaltic extrusive sequence can be studied along the shore at North Berwick. Inland the sequence thickens and also includes trachytic rocks in the Garleton Hills and as proved in the I.G.S. Spilmersford borehole. Intrusive igneous rocks form many of the district's topographical features, e.g. the volcanic plugs of North Berwick Law and Bass Rock, sills such as Fidra and laccoliths like Traprain Law with its magma flow structures.

Marine limestones are geologically and economically the most important beds in the Lower Limestone Group. At Oxwell Mains the south quarry is almost exhausted after 20 years of limestone extraction and is now restored, necessitating development of the new north quarry. The cyclic nature of these sediments can be studied in fine sections at Dunbar and Aberlady. The many thick coal seams in the Limestone Coal Group, once of great economic importance, are no longer mined underground. Large opencast coal excavations at Blindwells, Tranent, are uncovering examples of the earlier mining.

The Upper Limestone Group and Passage Group are poorly represented in East Lothian, and an unconformity may cut out strata across their boundary. New evidence of the Coal Measures sequence was obtained from offshore drilling in Musselburgh Bay, enabling production of detailed geological maps of the offshore coal basin.

During subsequent eras East Lothian was mainly land subject to erosion. In the Quaternary a thick ice-cap covered the district eroding and moulding the countryside as seen in the crag-and-tail of North Berwick Law and in the spectacular glacial rucking of coal-bearing strata uncovered at Blindwells. During

deglaciation meltwater carved out deep and shallow glacial channels all over East Lothian, producing extensive sand and gravel deposits.

Even within the last century erosion, transport and deposition at Tyne Mouth has altered the landscape.

In answering a large number of questions, Dr. McAdam provided further information. There are no pillow lavas in East Lothian: plant fragments and fish scales occur in some ashes, indicating very low land and shallow sea. It is doubtful whether the Dunbar harbour columnar features are basaltic, they may well be intrusive; the rocks are very altered involving segregation of iron from the centres to the sides of the blocks. There are no mines now in East Lothian. There are some coals in the Lower Limestones, as well as in the Coal Group and Coal Measures. There are glacial channels and sand and gravel deposits, but the till is devoid of features. The ice originated from the Highlands and the Southern Uplands. The rucking of strata at Blindwells cannot be explained other than by ice, and an eroded channel is visible where ice could have got in and pushed: the folds extend downwards only 13 m. The rift valley concept now disfavoured, Carboniferous volcanics may have resulted from the Southern Upland Fault. There is evidence of basic/acid lava gradation with time, and of magmatic differentiation at depth.

The President expressed thanks to our speaker for a fascinating lecture in which there had been something of special interest to everyone.

THE GEOLOGY OF COUNTIES MAYO AND GALWAY

Dr. A. E. Currall

On 7th November, 1984, 20 members and friends met at West Cumbria College, Whitehaven. Our President took particular pleasure in welcoming as speaker the Yorkshire Geological Society President, Dr. Currall, met by many members on excursions and at dinners, and a good friend of the Cumberland Society.

Dr. Currall proposed a sub-title of 'Travels with a Donkey'

which reflected the widespread use of the donkey for transport purposes in the rural areas of Counties Mayo and Galway when he started working in the West of Ireland some 35 years previously. The talk was amply illustrated throughout by a fine collection of colour slides.

Since the main geological formations of the two counties are Dalradian and Moinian, which have been correlated with the Scottish Highlands, it was useful that the lecture should start with a look at the geology of County Donegal to the north east which provides a link. There is evidence that the Great Glen Fault system of Scotland may continue through Donegal, although the lateral displacement is by no means as great. The magnificent topographical feature of the Barnesmore Gap is probably part of this system. Although glaciation is responsible for this very fine U-shaped valley there is evidence of a wide shatter belt along its length which may be seen in the stream sections in the Gap.

Research workers, mainly from Imperial College and the University of Liverpool over the period 1950-65 established correlations between the Dalradian of the classic Argyllshire sequences and those found in Donegal and on into Mayo and Galway. Especially important in this respect is the Boulder Bed of the Upper Dalradian and its associated stratigraphy which extends to the south west along the south side of Clew Bay (Mayo) and also into the Dalradian of Connemara. Along the south side of Clew Bay we find similar sequences and structures to those of the Scottish Highland Boundary Fault zone. Most workers would accept that these fault structures which are also picked up further west on Clare Island represent an extension of the Highland Boundary Fault. Thus we may accept that the Highland Boundary Fault zone extends right across the British Isles from Stonehaven to Clare Island.

Between the crystalline rocks of Counties Donegal and Mayo lie the Lower Carboniferous Limestones of County Sligo which in general show a softer gentler landscape characterised by drumlins from which rise the cliff sided flat topped and horizontally bedded hills such as Ben Bulban beloved of photographers. This is in marked contrast with the desolate scenery of the large area of the Donegal Granite and some smaller intrusions such as Ardara which show a well marked metamorphic aureole in which large crystals of chiastolite, garnet and kyanite may be found. Some fine views were shown of the Poison Glen and of the high cliffs of the Slieve League peninsula falling nearly 2000' to the sea. In contrast there are the beautifully sandy shores or strands derived from the weathering of these crystalline rocks.

The geological map of the British Isles shows that by a rough extrapolation of the Great Glen Fault and of the Highland Boundary Fault they appear to meet near to the Mayo coast in Clew

Bay. There is no doubt that the structural geology of this area of Mayo is complex. Running 40 miles N.E. to S.W. from Sligo to Castlebar lies the narrow belt of the Ox Mountains, some four to five miles wide, composed of a migmatite core flanked by psammitic and pelitic rocks of varying degrees of metamorphism and deformation. They present a striking contrast to the typically Dalradian sequences elsewhere in Mayo and further south in Connemara and are probably Moinian in character.

The lecturer paused at this point to show a few slides illustrating more recent events, such as the drowned drumlins which form the several hundred islands of Clew Bay seen spectacularly from the summit of Ireland's Holy Mountain - Croag Patrick, and the vast North Mayo Bog covering some 500 square kilometres and many metres deep and the peat-fired power station in its midst at Bellacorrick. It was also interesting to see Kildownet Castle on the eastern shore of Achill Island, home of the legendary Grace O'Malley who fell out with Queen Elizabeth I, who refused to accept her as an equal.

The wildness of the countryside was emphasised by the general absence of trees except in sheltered spots, although the fuschia thrives as a hedging shrub because despite the wet climate and severe gales it is mild with infrequent frost and snow. In particular this was characteristic of Achill Island where the landscape is virtually tree-free and the large numbers of whitewashed crofts present a scene more reminiscent of Iceland or the Falkland Islands.

The effects of faulting on the predominantly quartzite rocks was shown in the fine cliff sections of the western facing cliffs from Achill Head southwards.

South of the assumed extension of the Highland Boundary Fault zone of the south side of Clew Bay lies the Lower Paleozoic syncline within which the sequence ranges from the Arenig downwards with the Upper Silurian lying unconformably on the Arenig. Fine views of the classic fjord of Killary Harbour were shown.

Immediately to the west of Galway City lie the main outcrops of the Galway Granite and its associated smaller intrusions which range towards the basic. In particular reference was made to the banded basic and ultrabasic igneous rocks of the Roundstone area, upon which Professor L.R.Wagu was working prior to his expedition to Greenland in the early 1930's where his discoveries of similar phenomena on a far larger scale led to his classic investigation of layered rocks.

Northwards we were shown the spectacular skyline of the Twelve Pins of Connemara, and the Connemara Marble quarries of Streamstown using the traditional Italian mode of cutting by endless wire, sand and water.

The lecture concluded with some shots of Galway City, the restored remnants of the fishing community's housing at the Claddagh and some of the mediaeval buildings of the city which show the influence of Spain. Dr. Currall emphasised right through his lecture the relationship between geology, scenery and local history, lacing his talk with accounts of the origin of such terms as lynching and boycotting, both of which owe their origins to events in Galway and Mayo.

At question time further points of interest were gathered. The only coal in South Ireland is the anthracite of Tipperary. The granite of North Galway Bay could not be considered the cause of the marble, which has no granite near, and which probably arose from regional metamorphism. Though banded basics intruded into Lower Palaeozoics is a situation reminiscent of the Lake District, unlike the latter there is no associated mineralisation.

Raised beaches or submerged forests are absent: only the Clew Bay drumlins show evidence of submergence, most of the coast is cliffs. There is not yet evidence, due to very limited exposures, of any shift of the normal Highland Boundary Fault by the Great Glen Wrench Fault: there is in fact a thrust element as well. Research on these points by Irish geologists is going on at present. Although the Tertiary Volcanics are prominent in West Scotland and Northern ireland, none are seen here.

In conclusion the President, Dr.F.J.Cockersole, gave the sincere thanks of the audience to Dr. Currall for his talk and the excellent photographs which would encourage anyone to visit the area. Appreciation of the historical and picturesque, as well as the geology, was to be commended in any tour!

ORDOVICIAN STRATOVOLCANOES IN THE DUDDON VALLEY

Dr. D. Millward

This lecture-meeting was held in the British Legion Club, Workington, on 5th December, 1984, when 28 members and friends attended. The President expressed pleasure in introducing the speaker, met previously in the field, formerly a research student at Birmingham University, now with the British Geological Survey,

Newcastle. His present work, Dr. Millward stated, is related to the production of new geological maps of the Borrowdale Volcanic Group as part of the B.G.S. Lake District Regional Geological Survey.

To understand better the Borrowdale Volcanic Group stratigraphy attention was drawn to a schematic cross-section of a typical strato (i.e. composite) volcano. The central zone, 0.5 - 2 km radius, consists of dykes, sills, abundant coarse-stratified, poorly sorted pyroclastic ejecta and thick siliceous lavas. Next is the proximal zone, between 5 and 15 km from the central vent constructed of abundant broad, thick lavas, lahars, well-sorted lapilli tuffs and coarse ash (locally re-worked) and ignimbrites. The outermost, or distal, zone comprises thin-layered coarse to fine-grained tephra, commonly extensively re-worked, lahars and ignimbrites.

The area of the B.V.G. under consideration in the talk is overlooked or bounded by Sca Fell, Eskdale, Crinkle Crags, Hard Knott and Harter Fell. The geological map indicates the rocks here to belong broadly to the lower half of the B.V.G. sequence. The major structure in the area is the WSW - ENE trending Wrynose Anticline, with a gently dipping northern limb and a steep (up to 80^{o}) southern one. Locally, as on Hard Knott, dips vary considerably, partly as a result of a plunging anticline in the Lingcove area to the north, and partly to rapidly changing palaeo-slopes.

There are three lithological divisions: (i) the Moasdale (east of Hard Knott) Andesite Formation, occupying the central part of the Wrynose Anticline; (ii) the Birker Fell Formation in the north; (iii) the Dunnerdale Formation of Cold Pike, Red How and north east of Greyfriar.

The Moasdale Andesites are typically andesite to dacite block lava flows with thin intercalations of volcanoclastic rocks, mud-flows and ignimbrites. The lavas separated by pyroclastic layers give rise to trap topography. The structures within the andesite block flows show some variation in vertical sequence. Commonly there is a thin basal 'traction'-breccia succeeded by a massive central zone showing pronounced flow-joints parallel to the base. Higher, flow-banding may be present sometimes becoming contorted into flow-folds. The top is extensively brecciated (the flow-breccia first recognised by Green), and the open-network cavities of the upper part of the breccia are filled with thin-laminated volcanoclastic sandstone. Additionally, breccia pipes and dykes occur within the central parts of some flows that may have resulted from steam pressure built up below a lava which flowed over a stream. Examples of this structure occur to the south of Hard Knott Pass at Harter Fell.

The lavas of the Moasdale Andesite Formation are generally

laterally impersistent and the only reliable stratigraphic markers are ignimbrites. Some are traceable over several kilometres and one, illustrated by a slide, of garnetiferous eutaxitic (fiamme) texture, is interbedded with probable base-surge deposits.

The Birker Fell Formation crops out in Upper Eskdale and consists of basalt, andesite and dacite lavas, thin intercalations of volcanoclastic sandstone and ignimbrite. The basalts, some containing phenocrystic pseudomorphs after olivine and/or clino-pyroxene, are commonly highly amygdoloidal with many laterally impersistent massive channels within a clinkery (aa?) breccia. These flows are possibly compound lava fields.

Primary pyroclastic fall deposits have low-preservation potential on the sides of an active volcano. Loose ejecta tend to slide down the volcano side, become sorted by rivers and often give a heteroclithic end-product. Thus most of the fragmental rocks previously referred by many authors to 'tuff' or 'bedded-tuff' within the B.V.G. are volcanoclastic in origin. Within the Eskdale-Duddon area these deposits comprise part of the Dunnerdale Formation; the Grey Friar, Red How and Cold Pike successions were illustrated. On Cold Pike is a greater proportion of ignimbrites than to the south of the Duddon, otherwise commonest are parallel and thinly-bedded volcanoclastic sandstones. In them are seen examples of slumping and minor faulting, perhaps due to earth-quakes, or of soft sediment deformation (soft sediment folds). Scoured channels occur, some showing lines of rip-up clasts, others showing cross-bedded stream infill. Coarser deposits are structureless: in places there are boulder-flows with little matrix, presumably water or mud-transported. On Red How, and Harter Fell also, is a nodular ignimbrite useful as a marker that extends south west to Devoke water.

The strata at the top of Hard Knott appear to represent the infilling of a canyon. Welded ignimbrites 130 m thick are succeeded by boulder beds or breccias (one 4 m block was illus-trated) which grade to lapilli tuffs; the sequence is capped by a rhyolite lava flow.

Finally a return to the sketch illustrating the volcanic zones of strato-volcanoes was made with the conclusion that the rocks described in the lecture correspond to the proximal and possibly distal zones.

In answering a number of questions, Dr. Millward stated that no main vents had yet been located, though some vertical pipes mentioned by Oliver in the Sca Fell region, for example, could be minor vents. It is useful to bear in mind that a central zone would usually have been destroyed explosively or by erosion. However, rhyolites do not flow far. Directions of flow of ancient rivers (flowing down-slope) might assist in finding the approximate position of a main vent. Submarine intercalations have not been

found in the area described, but are present in Holehouse Gill (near Ulpha). However, water-lain sediments are abundant within the B.V.G., lacustrine deposits occurring, for example, at Honister and Chapel Stile. At the onset of volcanism (probably before the close of the Arenig) the palaeogeography of the B.V.G. can be interpreted as being generally fairly planar between the composite volcanoes. Rivers and temporary lakes (possibly including crater-lakes) were common. Extensive dissection by rivers and catastrophic eruptions may later have produced a very irregular topography.

The President thanked the speaker, stating that there could hardly have been a more interesting lecture for a geological audience, which could now set out to apply new interpretations of rock textures and relations.

HEMATITE MINING IN CUMBRIA

Mr. D. McGivern

On the 9th January, 1985, over 40 members and guests met at West Cumbria College, Whitehaven. The speaker, a director of the Egremont Mining Co., was introduced by the President as a person known by many members, and probably unique in having had a large experience of hematite mining in all three major ore-fields - West Cumbria, Furness and Hodbarrow.

Traces of ancient hearths suggested, said Mr. McGivern, that the Romans probably took some surface hematite (though more commonly they smelted copper or lead). Actual mining started in the 12th century, such as at Bigrigg by the monks of Holm Cultram to supply small charcoal furnaces. Gillfoot (Egremont) and Crowgarth (Cleator Moor) were also ancient workings. Large-scale iron-works date from 1709 in the Midlands when Abraham Darby started using coke; these, however, only produced cast-iron. Wrought iron and steel were made by small-scale charcoal processes. A large demand for hematite, as distinct from other iron-ores, dates from 1856 when Bessemer's 'acid' steel-making process needed it.

In the mid-19th century Workington's harbour facilities had become better than Whitehaven's, and in 1872 Workington had blast furnaces, foundries, Bessemer Converters, and rolling mills. By the end of the 19th century there were 54 furnaces between Maryport and Millom, and a total of 234 ore-shafts and 24 adits. A total of 6500 men were employed in mining.

Almost all of the West Cumberland hematite is found in the Lower Carboniferous Limestones. Of these, the most important for hematite are the 1st (e.g. Bigrigg, Crowgarth and part of Frizington), and 4th (e.g. Bigrigg, Montreal, Lamplugh, and part of Frizington) and the 7th (all the Egremont and Beckermet mines).

In the Lamplugh area there were 8 mines, the most important being Coronation, Murton and Whinnah, all in the 4th Limestone. Around Frizington were the Agnes, Margaret, Eskett, Postlethwaite, Frizington Parks and Parkside Mines. Cleator Moor had the Montreal, Jacktrees, Crowgarth and Crossfield Mines, with a total of 17 shafts. Montreal Mine, being on a suitable fault, produced both hematite and coal. Though there are still remnants of mines around Cleator, there is little information on them. There were 4 mines in Moor Row: Stirling, Dalzell, Moor Row and Postlethwaite's Moor Row. Bigrigg had the Sir John Walsh, Parkhouse and Langhorn Mines. There were 7 shafts near Pallaflat. Several mines north of Egremont, including Longlands, lay on the Skiddaw Group/Limestones boundary fault. Egremont itself had workings under the streets, the deepest mine being Oregill (1287 feet), while just south east were the Ullcoats and Florence Mines. The Beckermet Mines had several shafts in the Haile area, No.1 Beckermet being 1578 feet deep.

Barrow developed from a hamlet as the Furness hematite, owned by the Dukes of Buccleuch and Devonshire, was exploited. Industrialisation was overseen by an expert organiser, James Ramsden. The Furness Railway was built in 1843 to Askam and Kirkby, and extended in 1848 to Millom, and in 1858 to Whitehaven. Ulverston prospered when its canal was built in 1830. The Furness Mines were north and north-west of Dalton (then capital of Furness), at Lindal, and in the Stainton area. There were 16 furnaces between Millom and Carnforth.

The Yarlside Mine, though the last to close (1947) in Furness, latterly produced only sand. The renowned big sops, each pear-shaped with a sand core, and mostly less than 650 feet deep, were The Park (worked by Barrow Hematite), yielding a less good ore, Burlington, Nigel No.1 and No.2 (run by Kennedy Bros. of Ulverston), amd the California No.1. All of these were right on the Greenhow Anticline. There were mines also at Woodhead and around Askam (hence the Askam furnaces).

The stratal sequence from the surface downwards in both the Furness and Hodbarrow areas is 'Pinnel' i.e. sand (a mining

hazard), Gleaston Beds (Yoredale type), Urswick Limestone, Park Limestone, Dalton Limestone, Red Hill Oolite, Martin Limestone. The only reliable marker is the Woodbine Shale in the Urswick Limestone, otherwise these limestones are not easy to distinguish. Only one mine found ore in the Urswick Limestone; mostly ore was from the four limestones below it.

At Millom, Hodbarrow produced overall over 25 million tons, beginning with a 17th century opencast. In 1840 veins were exploited which eventually led into a huge deposit. There was continuous trouble from moving sand, and later from the sea. The first sea-wall built soon collapsed, then a second more substantial one was built. The Moorbank deposit was discovered in 1920 but, due to running sand, the shaft was successfully sunk only in 1931. The method used for working, i.e. upwards from the base of these sops, may have been the best for minimising the loose sand difficulties. Mines were also once worked at Whicham and Waterblean, the latter in Coniston Limestone.

Mr. McGivern discussed the present situation. He ascribed the closing of Beckermet Mine four years ago to the cost of electrically-powered lifting and pumping, which reached a quarter of a million pounds a year. There were plenty of reserves left, though some could not be removed, e.g. the half million tons under Cleator Moor Square, or the quarter million tons left as pillars to support the street at Wyndham, Egremont. However, there are no streets above the quarter million tons left in Florence No.2 or the 1 million tons in Ullcoats. Beckermet reserves are over 100,000 tons. Unexploited yet are an estimated 2 million tons below St.Bees Moor (west of Egremont and south of Oregill).

There are enormous reserves of water in the old iron mines. At Florence (presently operated on a small scale) two and a half to three and a quarter million gallons per day run in; the water is pure and of exactly correct fluoride content. It is pumped into the River Ehen (where it becomes polluted) from which B.N.F.L. are allowed to extract water. The Lamplugh mines hold 12 million gallons, Salter 53 million, Frizington 174 million gallons. Inflow in the Cleator Moor and Egremont areas is in each case 2000 gallons per minute.

Theories on the origin of iron ore were briefly referred to, the latest being Sir Kingsley Dunham's.* Great significance was attached by Mr. McGivern to the association of ore deposits with an anticline in all three areas - the Dent Fell Anticline, the Greenhaume Anticline and the Black Combe Anticline; moreover there was no ore beyond two miles from an anticline. Opinion was

* A paper on the subject by Sir Kingsley Dunham is published in the previous 'Proceedings' (Vol. IV part 3).

divided as to whether there was hematite under the Duddon Estuary and the question has never been resolved: there is limestone and there is hematite on both sides of it.

At question time there was some discussion on mining methods. Various observations made included the following: The Eskdale hematite, in granite, differed in origin from deposits in limestone, the latter being replacements. At the old Margaret shaft there was heard recently a sound as of water being pumped: no reason was known, but peculiar underground movements do take place. In Sir Kingsley Dunham's view there was no iron ore under the Duddon Estuary; English China Clays had once drilled, but their results were not known. Pack-horses had been the only means of bringing ore from Ore Gap (Angle Tarn-Bowfell area), and there was thought to be a lot left. Mr. McGivern however, considered this to be doubtful.

In conclusion, the President remarked that the audience, including a number with direct mining connections, had obviously been greatly interested, and the Society was very grateful and indebted to Mr. McGivern.

DIAGENESIS OF LIMESTONES WITH SPECIAL REFERENCE TO THE CARBONIFEROUS LIMESTONES OF SOUTH CUMBRIA.

Dr. A. E. Adams

The President introduced the speaker, from Manchester University, to 35 members and guests at the Derwent Centre, Cockermouth, on 6th March, 1985.

Dr. Adams commenced by saying that the conclusions presented are part of a study of Carboniferous environments in South Cumbria and North Lancashire being undertaken at Manchester by himself and his research students. Some of the ideas presented form part of the thesis work of Richard Vaughan.

A definition of diagenesis (not the first Welshman!) might be given as 'all processes affecting sediments after deposition prior to metamorphism'. Since this leaves an area of uncertainty between diagenesis and metamorphism, it is better to state that diagenesis is restricted to conditions at less than 100°C and less than 2 km depth, and is part of sedimentology. Unlike many depositional processes, it cannot actually be observed as it happens.

The raw materials of limestones accumulate today in shallow marine sites such as the Bahamas. These sediments are largely a mix of mud, shells and grains of aragonite and magnesian calcite (up to 15% $MgCO_3$), with only minor amounts of calcite and dolomite. By contrast the Carboniferous Limestones of Hodbarrow, Millom, for example, are mostly calcite and dolomite. Both minerals may display some iron substitution, i.e. are ferroan minerals. This change in mineral composition is an example of diagenesis. Another is the reduction in porosity from perhaps 50% in the unindurated sediment to perhaps only 1% in limestone such as the British Carboniferous Limestone.

Although many carbonate sediments are deposited in shallow marine waters, these diagenetic changes occur more readily in waters of meteoric origin. Thus sea-level changes (caused by tectonics or glaciations) which alternately drown and expose shallow platforms may be an important controlling factor in diagenesis.

Six techniques for studying carbonates were outlined:

(1) Of prime importance, Dr. Adams stressed, is sound fieldwork.

(2) Micropetrography usually involves chemically staining the thin section. Calcite, for example, is stained pink whilst dolomite is unstained by Alazarin Red; or the presence of iron in the section is seen by the blue stain developed by hexacyano-ferrate (II) reagent. An alternative to a thin section (though more limited) is an acetate peel of a flat, polished, etched and stained surface. This shows some of the structure and often the staining, and can be given useful magnification by a 35mm projector.

(3) The Scanning Electron Microscope is useful for viewing small crystals at high magnifications.

(4) Cathode Luminescence describes the effect of X-rays on carbonate minerals producing a red/yellow luminescence. The causes are not fully known, but it is thought that the presence of manganese causes, and of iron quenches, the luminescence. Photo-micrographs show sharply contrasting layers parallel to crystal edges, i.e. the way crystals grow.

(5) The Electron Microprobe is used for chemical analysis including the detection of very small quantities of elements on a small area (about 50 microns across).

(6) More expensive is the investigation of C^{13}, C^{12} and O^{18}, O^{16} isotopes by Mass Spectrometer.

Diagenetic processes leading to porosity reduction were illustrated. An example of a recent carbonate sediment from the Caribbean was shown where the limestone grains had become coated

with aragonite. A Derbyshire limestone section showed blocky crystals in original pore-spaces: these apparently grew inwards from the edges of the pore-spaces; they often contain iron. Most limestones become cemented, not in the marine environment, but later, by circulating ground-water. On burial a mechanical compaction is common: this is demonstrated in sections where the outermost of the growth-layers of ooliths have fractures as the ooliths were pushed together. Pressure-solution compaction is deduced from the presence of stylolites, as in a limestone shown from Urswick, which was of pseudo-breccia type.

Other processes increase porosity. Fabric-selective solution describes the situation where the more readily soluble aragonite crystals are dissolved, leaving the calcite. One Pleistocene limestone section showed only moulds of fossil shells remaining. Another example showed calcite replicas of shells, implying that the original aragonite had dissolved, then later the mould spaces had been infilled with calcite cement. A Jurassic limestone photomicrograph showed very many spaces, probably originally ooliths. Though very porous, the very low permeability of this type of rock has led oilmen to call it 'heartbreak rock'. (A non-fabric-selective solution would produce vugs or caves).

Processes which have either no or variable influence on porosity are (a) dolomitisation, (b) silification, (c) recrystallisation.

Production of dolomite implies a sufficient concentration of magnesium in a body of water. This may have resulted from evaporation of sea-water, perhaps left trapped on a coastal flat after a storm. Deposition of calcium carbonate followed by calcium sulphate would leave, after at least four-fifths of the volume evaporated, a solution sufficiently rich in magnesium and low in calcium to allow dolomite crystallisation (hypersaline dolomite). A dolomitising solution may be produced in a mixing zone of saline (below a sea) and meteoric water. Some dolomite also results from hydrothermal action. One example of a dolomitised limestone thin section showed dolomite rhombohedra superimposed on the still visible original structure: another showed complete replacement by dolomite with no original structure visible. Silification results, structurally, in either chert nodules or euhedral prism quartz crystals. Recrystallisation implies that some original $CaCO_3$ dissolves and later crystallises as calcite.

The South Cumbria limestones are regarded as those in the Kendal, Grange, Furness and Millom areas. These were deposited on a shallow platform with a basin to the south and, possibly, at least early in the Carboniferous, a ridge of land to the north. This ridge probably became quickly submerged so that the shallow platform became isolated from any uplands which might have provided detrital input.

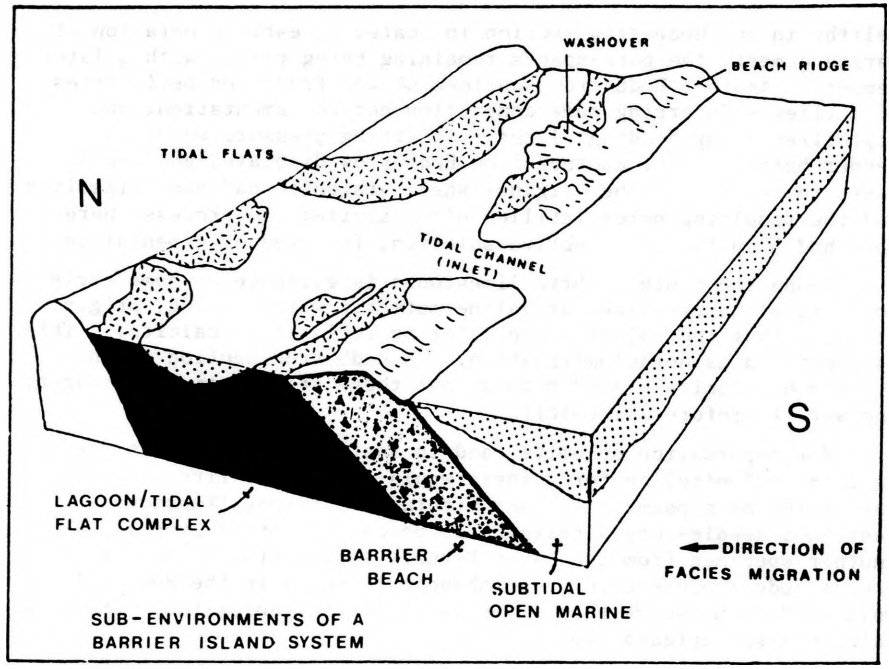


Fig. 1 TRANSGRESSIVE BARRIER ISLAND - LAGOON MODEL

It is chiefly the Millom and Duddon outcrops of the Red Hill Oolite and the Martin Limestone* which are to be considered here. A depositional model has been deduced as, N - S, tidal flats/ lagoon/barrier/open sea; the equivalent deposits being, N - S, fine grained/coarser/open marine. A section of a fine lagoon-facies Hodbarrow limestone showed fenestrae (sporite specks) indicating tidal flats subject to desiccation, and the filling of spaces with cement was shown by a peel. A barrier island facies from Hodbarrow was distinguished by cross-bedding and wave-ripples, whilst a sub-tidal marine type showed shell fragments (a bioclastic rock). It was emphasised that since the water was very shallow any change in sea level would produce a very large difference in environment. See figure 1 above.

The diagenesis of the Red Hill Oolite and the Martin Limestone during the Lower Carboniferous has been unravelled, and some of the evidence was shown. Crusts of radial calcite crystals around

* A South Cumbria limestones succession table is shown in the Society's Proceedings Volume 4 part 3, page 304.

ooliths in one Hodbarrow section indicated an early generation of marine cement, the pore-spaces remaining being filled with a later cement. Another Hodbarrow specimen showed fractured peripheries of oolites - inferring some compaction before cementation, and stylolites along bedding planes - inferring pressure solution on deeper burial. Yet another from Hodbarrow displayed gastropod casts in calcite. The original shell aragonite had been dissolved and the resulting pores infilled with calcite: the process therefore had been fabric-selective solution, followed by cementation.

Among the South Cumbria limestones is evidence of some early dolomite of hypersaline, or saline/meteoric water mixing, origin. It seems that the dolomite can later be replaced by calcite. This is described as de-dolomitisation. A Hodbarrow section shown contained dolomite-shaped rhombs, but these stained pink by reagent and were therefore all calcite.

For hypersaline dolomite (and in South Cumbria this is the earliest dolomite) to form, there would need to be first a separation of gypsum. A clast within a Hodbarrow limestone contained needle-shapes believed to be calcite after gypsum. Another specimen from the Leven Estuary showed similar needles. The cathode luminescence of rhombohedral specks in the Red Hill Oolite, Millom, shows them to be calcite after dolomite. The same calcite also replaced gypsum.

A situation considered likely to be due to 'mixing' formation of dolomite (regarded as a second dolomite phase in South Cumbria) was illustrated. From around the edge of a pore-space, crystals had grown inwards. Cathode luminescence showed successive red/

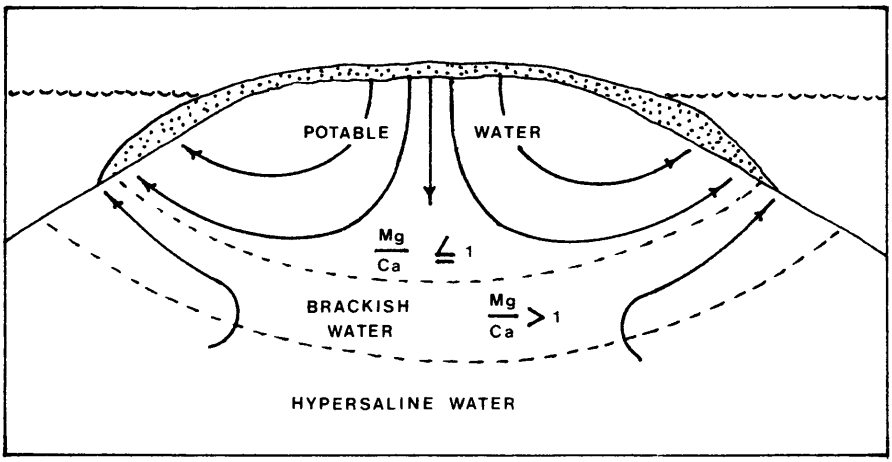


Fig. 2 MIXING ZONE DIAGRAM

yellow/brown layers of them. Yellow represents calcite, the others are dolomite, the latter confirmed by the crystal shapes under the scanning electron microscope, after etching out the calcite. A hypothetical diagram of a mixing zone (figure 2, previous page) was also shown where, below the barrier bar, a lens of fresh water would lie above sea-water.

It is considered that the diagenesis of the Red Hill Oolite and the Martin Limestone were completed in the Lower Carboniferous. Little then happened until the Permo-Trias when there was some uplift, and some limestone fragments went into the Brockram: there was also some late solution. At the end of the Cretaceous came the third dolomitisation phase, the hydrothermal dolomite, most commonly seen in the field, associated with hematite mineralisation, and in thin section contrasting sharply with neighbouring calcite. Other sections showed dolomite cemented by calcite crystals in pores, or bent crystal faces of rhombohedra, which is typical of hydrothermal dolomite. The examples were from Hodbarrow and Dunnerholme.

Microprobe analyses were able to indicate some differences in the composition of dolomites of differing origins:

	$CaCO_3$%	$MgCO_3$%	$FeCO_3$%	$MnCO_3$%
Early mixing zone dolomite	52-55	44-48	~ 0.05	up to 2
Late hydrothermal dolomite	50.5-50.8	47.5-48.2	~ 0.05	0.5

The small iron content separates as goethite on dedolomitisation: a rosette of that mineral from Hodbarrow was shown in a scanning electron microscope photograph.

The porosity of the South Cumbria limestone has varied. On deposition porosity of 50% changed by compaction and cementation to almost nil; Permo-Trias uplift increased it; Jurassic-Cretaceous burial decreased it, Tertiary uplift increased it, and in the Quaternary there has been an increase on weathering.

A number of questions were answered at the end. Wavy bedding planes in the limestone are considered to be due to pressure-solution. The gypsum-forming environment would probably be the inter-tidal zone. For chert, the source of silica was very local, mobilised from sponge spicules or radiolaria in, or near, the limestone. The pseudo-breccia in the Urswick Limestone probably originated from burrowing and early cementation: it is concretionary, but follows burrowing.

All the evidence was shown to the audience by means of a comprehensive series of photomicrographs, projected diagrams and tables. In expressing the Society's gratitude, the President remarked that it was with regret that the meeting had to close. It had been a masterly lecture from which much could be learned about presentation as well as geology!

OSTRACODS AND THEIR GEOLOGICAL USES

Professor J.W.Neale

The last of the 1984-5 indoor meetings was held on 3rd April, 1985 (during the Easter vacation), at West Cumbria College, Workington, when 12 members were present. The Vice-President said it was his pleasure and privilege to introduce Professor Neale, of Hull University, who has made a study of this fauna, both living and as fossils throughout the whole rock sequence.

Professor Neale remarked that, to the majority of geologists, ostracods were not particularly well-known. They are described better by the German term 'mussel-crabs' than by our common term 'water fleas'. Their average length is about 1 mm, and two could be placed side by side on a pinhead, although one exceptional living form reaches a length of 2.5 cms. The ostracod shell is a right and left valve and is like a mussel with a shrimp inside, as was illustrated by diagram and photomicrographs of dissected specimens. There are seven pairs of legs (fig. 1): the first propel the organism downwards, a situation which is rectified by the second pair which beat downwards to provide compensating 'lift'. The antennal gland and spinning bristle (which forms a 'safety-rope' in some forms) is associated with this second appendage. This is followed by the mandible with its in-out movement across the length of the animal and the maxilla with its vibratory plate for the production of a current and gas exchange. Behind this are the walking limbs 5, 6 and 7. In males a large proportion of the posterior is occupied by a copulatory organ as a result of which the males tend to have longer shells in proportion to their height than the females. All the forms described so far are marine and these tend to have robust and often highly ornamented shells.

Fresh-water forms show some differences. They tend to have smooth shells and are often highly coloured, some having three brilliant violet spots on each valve, e.g. Strandesia sexpunctata which lives in Indonesia. The colour could be defensive, giving the impression of something bigger if the spots are seen as 'eyes'. The habitat of that genus varies from rice-fields and ponds to the mud of churned-up paddy fields. Other typical modifications were illustrated by Ilyocypris. Here the fifth legs are short (i.e. not for walking), the seventh legs are flexible and modified to form cleaning limbs and there is an extra fork-like furca at the end of the body. In the latter genus, and in Stenocypris and Indiacypris, are relatively enormous copulatory pumps of muscular

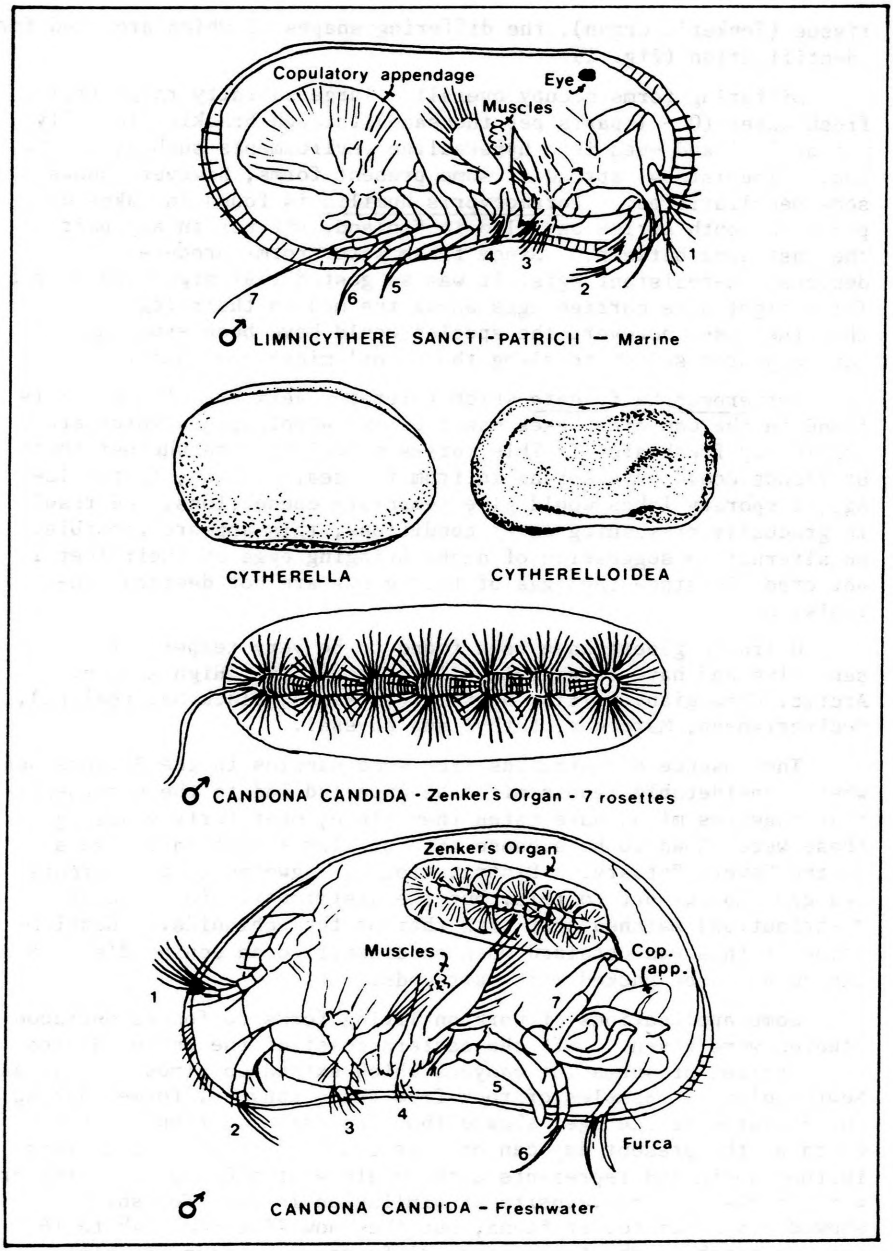


Fig. 1 OSTRACODS

tissue (Zenker's Organ), the differing shapes of which are used for identification (fig. 1).

Differing forms occupy overall a large salinity range from fresh water (0 - 1 parts per thousand) through brackish to fully marine (34) and even into hypersaline environments such as the Dead Sea. The lateral spread of some present forms, however, shows some peculiarities. Potamocypris humilis is found in lakes or ponds in South Africa and also in Finland, but not in any part of the vast area between. Since fresh water forms produce desiccation-resistant eggs, it was suggested that migrating Arctic Terns might have carried eggs among the mud on their legs. Were that the case, however, the species would have been expected to have appeared somewhere along the terns' migratory route.

Cytheromorpha fuscata which tolerates very brackish water is found in the Canadian Lakes Manitoba and Winnipegosis which are completely freshwater. This raises speculation on whether these ostracods could have spread in from the sea. Since, in the Ice Age, temporary lakes would give temporary connections, and result in gradually freshening water conditions, this appears feasible. An alternative suggestion of ducks bringing eggs on their feet is not credible since the eggs of this genus are not desiccation-resistant.

Ostracod genera have been found to be very temperature sensitive and have been divided into Provinces - High Arctic, Arctic, Norwegian, Celtic, Baltic (brackish), Black Sea (saline), Mediterranean, Maroccan, bathyl and abyssal.

The absence of ostracods from some samples in the Barents Sea where considerable faunas might be expected led to the hypothesis that ragworms might have eaten them since, over forty years ago, these were shown to be a cause of a similar reduction in fauna in the Severn Estuary. Distribution of ragworms in the Barents Sea gave no support to this, but the distribution (or lack of distribution) matched best with that of the echinoids. Confirmation of this was obtained when on dissection an echinoid's stomach was found to be packed with ostracods.

Some applications of work on living forms to fossil ostracod studies were given. Off the eastern coast of the United States are a series of submarine canyons which extend up almost as far as Newfoundland. Samples of rock from these canyons, formed during the Pleistocene ice age, showed that the ostracod fauna is one which at the present day can only be found at least five degrees further north and represents a temperature of $5^{o}C$ lower. Similar work on Pleistocene deposits at Dimlington in East Yorkshire showed a similar colder fauna, but they now live some 14^{o} to 16^{o} further north. The temperature difference, however, is similar, the increased latitudinal spread being accounted for by the Gulf Stream. Similar work has been done in the United States to show

variations in temperature during the course of the Tertiary.

Roundstonia, characterised by knobs on its shell, exists in cold, probably brackish shallow water in the Britain-Norway Province. Its distribution in the Pleistocene suggests a Wicklow-Lleyn land bridge which prevented the migration north of the diverse faunas of the southern Irish Sea until about 8,500 years B.P.

In the Eocene of the Isle of Wight a whole range of different faunas controlled by salinity was worked out. Two fresh water faunas were recognised, one occupying deeper water with less plant life on the bottom than the other and the same differences have been traced in these rocks in France. The various faunas enabled a picture to be built up of the palaeogeography of the time with its shallow seas, lagoons and freshwater lakes and the various changes with time (salinity profiles) to be worked out.

Whilst useful as environmental indicators the smooth shelled freshwater forms are not much used stratigraphically. Nevertheless, Candona (fig. 1), a smooth, thin-shelled genus which has the peculiarity of being bisexual in temperate latitudes but producing only females and reproducing parthogenically (virgin birth) in the Arctic, has been utilised by the Yugoslavs who use the various species to zone the fresh water deposits of the Tertiary in the Pannonian Basin.

Work in the eastern United States resulted in the recognition of various ranges of sea-bottom temperatures from late Miocene up until recent times. Further back in time there are fewer forms like living ones. However, in a group of ostracods not mentioned so far, the Platycopina, which differ in only having six pairs of legs and not seven, there are two genera which have changed little over at least 130 My. These are the smooth shelled Cytherella and the ribbed Cytherelloidea (fig. 1). Cytherella has a worldwide distribution but in the Cretaceous (as at present) the ribbed Cytherelloidea only occupied the warmer waters where, on present day evidence, the temperature never drops below 11°C throughout the year.

Tracing the northwards migration of this genus in Europe during the early Cretaceous suggests a gradual warming up of the seas as Cretaceous time progressed. Cytherelloidea first appeared in southern France and then successively in the Paris Basin, North Germany and Britain. Some other genera show the same type of migration. Unfortunately, these are extinct so it is not possible to ascertain their temperature requirements but it is very tempting to consider them as being in the same category as Cytherelloidea in this respect. The rib pattern in Cytherelloidea also shows a number of evolutionary sequences with time and so can be used to some extent for zonal purposes in the marine Cretaceous in a similar way to the use made of trilobites in the Lower Palaeozoic.

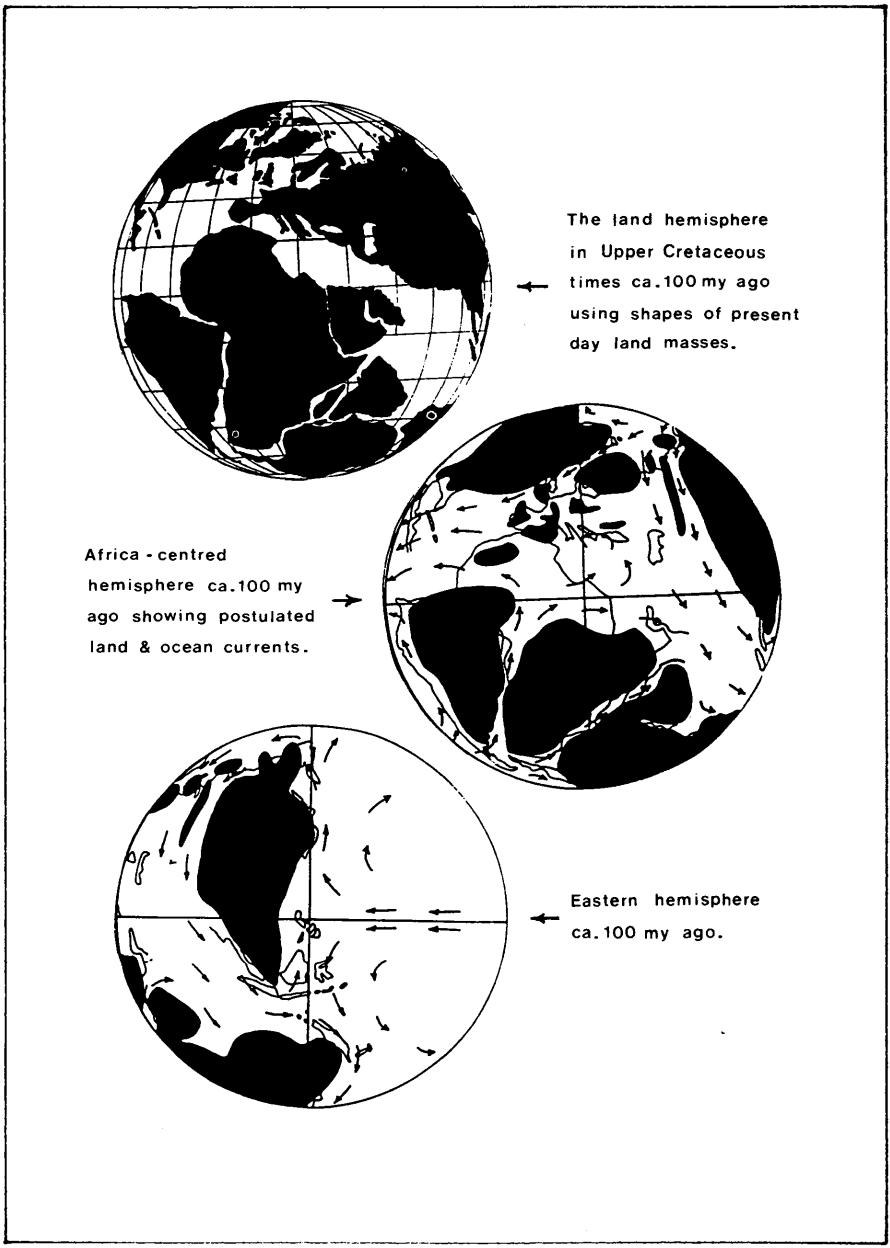


Fig. 2 CRETACEOUS LAND MASSES AND OCEAN CURRENTS

The Australian Cretaceous rocks at Gingin, some 130 km north of Perth, yielded some interesting ostracod faunas. These rocks, whose lithology is like the English Chalk, yielded several groups of ostracod genera. Some were universal (being also found in Europe), others were Austral (found in Australia and Africa) and yet others were Endemic (Australia only). Since they were not strong swimmers, and the group to which they belong do not produce desiccation resistant eggs at the present day, their distribution must be explained by sea-currents. Palaeomagnetic evidence on the distribution of land in the Cretaceous indicates that there was a complete N - S sea hemisphere (the only time that this is known to have happened) which was unbroken by land 'hot spots'. Consequently it is possible to postulate a circulatory system and the form the currents would take in the seaways between the known land areas of that time. In this way it is possible to put forward some explanation for the distribution of these genera as we currently know them (fig. 2).

On the other hand the Cretaceous non-marine ostracods show distinct distributions in the northern and southern hemispheres with no species in common between the two. It is possible to correlate accurately between Brazil and Gabon, West Africa, using them, and between Britain, Spain and Germany, but not between the southern areas and the northern. Presumably this is due to the direction in which the winds carried the resistant eggs. Attention was then drawn to some most remarkably preserved freshwater ostracods from the Lower Cretaceous of Brazil about 110 million years old. The ostracods, which all belonged to one species, were apparently feeding on a dead fish whose decay caused it to release phosphatic salts which caused apatite to replace the calcium carbonate of the ostracod and preserved the appendages perfectly. It was thus possible to study them in much the same way as a modern dissection and to assign them to their correct freshwater family.

Various other studies were outlined. An ostracod zonal scheme exists for the British Cretaceous and the ostracods have been used to establish the presence of saline and freshwater phases in the Upper Jurassic/Lower Cretaceous (Purbeck/Wealden) rocks.

Whilst the further back one goes in time the less the faunas have in common with the present day it is still possible to recognise the different environments and an example was shown from the Westphalian (Upper Carboniferous) of Spain where faunas were shown to be divisible into associations linked with the freshwater Carbonita facies, the brackish Geisina facies, the brackish/marine Lingula facies and the successive marine environments characterised as Lamellibranch facies, Biostraome facies and Productoid-Lamellibranch facies. An earlier example from the Middle Devonian of Germany showed that the faunas varied through Lagoon/Back Reef/Reef Core/Fore Reef/Solitary Coral Zone to Brachiopod Zone with the most robust and highly ornamented forms (over 70%) occurring in the

high energy Reef Core and Fore Reef areas.

This correlation between shell form and environment has been noted in many areas and different ages. Generally shallow water forms are robust and highly ornamented, deep water forms often thin shelled and smooth or with the ornamentation forming a strong but light girder system, interstitial forms are smooth and elongate, planktonic forms are lightly calcified and so on. An example of this was seen in the Devonian of the Voronezh region of Russia. Here the calcareous clays had a variety of highly ornamented forms with spines and frills which would prevent them sinking into the mud, the purer limestones had smooth, unornamented streamlined shells suggesting that they were reasonable swimmers and the domanik facies of bituminous limestones (suggesting de-oxygenated bottom waters and a generally inimical habitat) were characterised by planktonic forms.

Finally the question of whether the ostracods existed in the Cambrian was solved by the finds of beautifully preserved phosphatised material in Sweden. Here the preservation was so perfect that it was possible to see all the delicate bristles on the seven pairs of appendages and to reconstruct the anatomy. It was thus possible to recognise the two early genera Vestrogothia and Hesslandona.

In only a short time remaining for questions, it was stated that algae and other minute plant materials, rather than animal organisms, are now regarded as the chief contributors of oil-forming hydrocarbon material. Ostracod shells are all calcium carbonate based; freshwater ones are fragile, marine robust and abyssal variable in strength. A rather unlikely fact was that the soft parts did not explode when brought up from water depths of 5 km.

In thanking Professor Neale, the Vice-President stated that he had introduced us to another dimension in geology, and far from palaeontology being a little exclusive, it produced accurate zoning, indications of salinity, reconstruction of environment and evidence of continental drift. It had been a major factor in making geology an interdisciplinary science.

THE GEOLOGICAL EVOLUTION

OF THE EARTH-LIKE PLANETS.

Dr. L. Wilson

On the 4th September, 1985, the President welcomed 15 members and guests to the inaugural lecture of the season and introduced the speaker, Dr.Wilson, of the University of Lancaster's Department of Environmental Science, who explained that his Department could be described essentially as Earth Sciences, but with very diverse interests. Better understanding of the evolution of the Earth results from studying the evolution of planets.

Ample slide illustration was based on spacecraft and astronomical telescope observations. The first of these, integral views of the nearer planets, compared their appearances with that of the Earth. Venus is slightly smaller than Earth, and dense cloud obscures surface detail. Mars, of approximately half Earth size, has a thin atmosphere, whereas the Moon has not enough gravity to hold any atmosphere. Mercury, of approximately Moon size, has only been photographed on one side. Views were also showed of Jupiter, and Saturn with its satellites.

Planet sizes having been measured from images and masses having been calculated from spacecraft trajectories, their mean densities have been found. Most other attributes are merely consequential assumptions, such as that Mars and the Moon are mostly silicate rock, and that Mercury has an unduly large core, thus accounting for their smaller or greater mean densities.

On Earth the lithosphere is active due to heat transfer from its energy-charged interior, and the presence of an atmosphere and hydrosphere has resulted in great changes to the surface.

The earliest rock known on the Moon is dated at 4.35×10^9 y since solidification; the average Moon-crust's age is 4.6×10^9 y since the Moon's accumulation. Its surface shows numerous round craters, their shape inferring impact rather than volcanic activity. These features are considered to result from a 500 million years bombardment by asteroids - and this same bombardment period applies to other planets. There has, however, been volcanic activity which flooded the 'mare basins', and the far side of the Moon is probably heavily intruded by dykes and sills. The surface area/mass ratio is greater than that of the Earth; hence the Moon has faster cooling, and its centre is calculated to

be just not molten - which inference was confirmed seimologically by the Apollo missions. Vulcanism ended approximately 3 x 10^9 y ago.

Impact craters of all sizes have three scientific uses: they excavate, and thus provide samples of, subsurface material from depths up to half the crater diameter; their ejecta blankets provide time horizons which may be traced for half the lunar circumference in the case of 100 km diameter craters; and the numbers of craters of a given size within a given area can be used as a means of assigning relative ages to geological units. Apollo samples have been used to turn a large part of this relative scale into absolute ages.

Photographs illustrated details of some Moon features: glass beads which had resulted from fire-fountaining, and surface rock fragments which had been ejected from nearby impact craters. Channels formed when basalt eruptions (over perhaps 6 to 12 months periods) melted the surface, leaving channels 200 - 300 metres deep. Through all the Phanerozoic no individual eruptions on Earth seem to have been as great, but some Archaean lava-flows were probably as rapid: there is some evidence of similar channels. These Moon lavas are rich in iron and titanium. Some appear to run up a ridge: the latter must, of course, have been raised later. Apollo's radar indicated layers in the Moon's lava sheets, and even some faults.

Mercury resembles the Moon in having no atmosphere, but there is less contrast between highlands and plains, and debris clusters and secondary craters lie nearer to impact craters due to the greater gravity.

The numbers and areal distribution of large craters and basins suggest that Mercury had a similar early history of crust formation and subsequent impact bombardment to that of the Moon. Crater counting has established relative age scale for features, but there is no way yet of assigning absolute ages.

Some prominent scarps probably result from thrust-faults, the total area decrease they imply is compatible with the shrinkage to be expected on the cooling of an iron core. Some hills may be extrusions: the plains are perhaps formed from impact debris in some places and lava flows in others.

Mars is subject to very high winds, has surface temperatures about - 30^{o}C, and clouds of crystalline carbon dioxide and water ice. It shows the oldest cratered terrain of all planets: there are several very large impact craters, but no sign of Earth-type plate tectonics. Mars is now perhaps just past the end of all crustal activity, since in places there are relatively recent lavas, there are channels and hills, and there are craters deformed by crustal fault movements.

Some Mars features are not sharp, having undergone erosion. Mars once had a higher atmospheric pressure, and drainage patterns on some older surfaces perhaps imply there was once water - some of this possibly from ice melted by volcanic intrusion (ice is trapped in surface layers). Near the polar caps is some polygonal ground, but of strangely large scale. Large canyons might have resulted from collapse after frost subliming. However, neither of these features has really been explained in any detail.

Volcanic hot-spots on Mars probably dating back 4000 my gave rise to features such as a 100 km diameter caldera: elsewhere large smooth-floored areas are probably lava-flows, their extend depending mainly on effusion-rates; other smooth areas are probably ash surfaces.

The number of craters per unit area has been plotted for all the planets and, with the other information, points to a similar history for the old highlands of the Moon, Mercury and Mars.

Satellites of Jupiter have usually surfaces of mixed ice and rock, e.g. Ganymede, of highly grooved appearance (compression or torsion?). Europa, however, has a cover wholly of ice which is all fractured due to stress; but there are no impact craters, hence this is concluded to be a very young surface 10 to 100 my old. The surface of Io is covered with a layer of sulphur, inferring an enormous heat flow from the interior due mainly to tidal stresses from Jupiter: there must be silicate rock below.

The time remaining for questions was restricted. The 'pimple' in the centre of an impact crater marks the highest temperature zone (from kinetic energy transfer) producing some melting: energy calculations on this are very complex. The practical value of planetary exploration has included better prediction of how far lava will flow, advances in physical chemical petrology arising from improvements in the technique of analysing very small samples, and the implications that the Archaean nickel sulphide deposits on Earth are probably in melted-out lava channels. There is now improved communication of data from Russian space projects. On whether uniformitarianism can be applied generally, it was stressed that in most Earth history there were no vast catastrophic events, though some large cratering events must have occurred. Some features, like the surface of Europa, cannot be explained in familiar Earth terms.

The meeting closed with thanks to Dr. Wilson by the President who remarked that this had been a fascinating evening with a high information flux. Perhaps further aspects could be presented on some future occasion.

APPENDIX

The subject of Venus had to be omitted due to lack of time on the lecture evening, bur Dr. Wilson has kindly supplied the

following information:

The massive heat-trapping, largely carbon dioxide atmosphere of Venus, laden with cloud droplets of concentrated sulphuric acid, is opaque to visible light and most of the infra-red, so that information about the surface is obtained mainly from radar echoes, using both Earth-based systems and orbiting satellites. Topography is determined from the delay time of echoes, roughness is found from the blurring of echoes, and electrical properties - and hence a rough idea of composition - are found from signal strength.

The global range of topographical heights is similar to that of the Earth, with regional uplands similar to terrestrial continents. However, there are no clear signs of the ridges or trenches that might imply Earth-style plate tectonic activity. Instead, some regions seem to be dominated by large shield volcanoes and long lava flows while others show complex patterns of crustal compression and faulting. Impact crater counts imply an average age for the visible surface of the order of 1000 million years.

Four Soviet probes with cameras have soft-landed on the surface and shown views of layered rocks suffering small amounts of erosion, possibly due to chemical weathering under the 90-bar pressure and 750 K temperature of the atmosphere. In situ analyses at two sites found basaltic rocks - one alkali basalt and one tholeiite. We are not yet sure how to relate the lander information to the global pattern of constructive and destructive processes.

GLACIATION WITH SPECIAL REFERENCE TO THE LAKE DISTRICT

Dr. F. J. Cockersole

This meeting was held on the 2nd October, 1985, at West Cumbria College, Workington, when 20 members and their guests attended.

Due to British Geological Survey Staff, including Dr. Allan, who was to have lectured, having to attend a meeting in Wales at short notice, the President had kindly agreed to act as substitute speaker.

By way of introduction a resumé of the stratigraphical development of the Lake District's eroded dome was given, perhaps suggesting the question of why, after so long, were there ice ages only in the Quaternary? Although world-wide there had been other glaciations in the Pre-Cambrian, Ordovician and Permo-Trias, our particular continental plate had, apparently, been in warmer climates during these episodes.

Slides, both scenic and diagrammatic (some by courtesy of Mr.Tom Shipp) were used as illustrations. One of these, summarising the chronology of the Lake District glaciation, showed how temperature had varied over the last 2 million years. Not much difference in temperature is needed to produce continuous glaciation once the climate has produced long icy winters. There have been more than 4, probably 7, major cold epochs which divide the Quaternary into Stages. Within the Stages are Stadials and Interstadials which represent minor climate variations. The last glaciation, i.e. advance and retreat, was the Devensian, after which came a Post-Glacial period of 10,000 years. Smaller climate changes during that time have been deduced from pollen analysis.

Onset of glaciation is determined, of course, by temperature, depending on altitude and latitude. On Scottish mountains are tiny pockets where ice persists all year. Unless thawed in summer, further annual increments of snow will build up, compress, and become ice. As the climate deteriorates, the ice extends to lower ground. Diagrams in the literature show the southern limit of Britain's ice-cover at various times in the Quaternary, reaching at its greatest extent the Severn - Thames line; south of that were tundra conditions throughout. These lines are difficult to draw since later ice rides over and obliterates evidence of earlier advances: however, glacial drifts usually contain typical erratics which facilitate recognition of glacial stages. The Older Drift (over 235,000 years old) is more eroded and dissected than the Newer Drift. Interglacials and Interstadials are marked biologically, by peat, for example.

Chiselling out by glaciation was a major factor in the development of the scenic delights of Lakeland, such as Wasdale. Radial drainage was established on the Lake District dome in the Tertiary, therefore, in the Quaternary, valley glaciers followed approximately the same radial pattern. The effects of ice on valleys such as straightening, deepening, and steepening of sides can be judged by viewing present day glaciated valleys in Switzerland, where above the ice contrasting sharp angular rock exposures can be seen. Ice movement in the Alps is about 1 metre per day, though this varies between glaciers depending on the accumulation rate and the steepness of the valley. Another view of the head of a Norwegian glacier showed ice sagging over a rock lip from the ice-field above. Movement is by regelation at the sole, many cracks are produced and shuddering is evident. Bare rock at the

sides has been scraped by more extensive ice at an earlier stage and a detritus cone was evident in the ice/rock angle at the side.

At present glaciers are in retreat and examples abound of valleys with glaciers only in their upper reaches: lower down, vegetation soon begins to establish on the moraine left. In places bench-marks have been made to indicate the year, say 1880, and the position of the glacier snout at that time. Various illustrations were given of lateral moraines, U-shaped valleys and misfit streams. One of the best examples of a back-wall (or trough-end) is Warnscale Bottom. Whereas rocky areas recently heavily glaciated (demonstrated by aerial photographs of the Himalayas) show jagged skylines, the outline of Grasmoor is slightly rounded after 10,000 years of post-glacial erosion, the arêtes having been blunted.

Initiation conditions for a corrie site, including vagaries of wind gusting, were outlined. Corrie development by freeze-thaw action leaves, after glaciation, the site for a tarn. A crescentic moraine often increases the volume of water retained. Such tarns include Small Water and Blea Water on High Street, Low Water on Coniston Old Man (its blue appearance pronounced by one observer to be due to copper!), and Red Tarn on Striding Edge.

Various glacial features were indicated on a view of Glenridding, Ullswater. Good examples of truncated spurs are seen on the side of Saddleback (Blencathra) looking from St.John's in the Vale (and implying 300 - 500 metres of ice at the height of the glaciation), or the side of Yewbarrow Fell, Wastwater. The numerous waterfalls in the Lake District usually result from hanging valleys; Easedale, Grasmere, is an excellent example.

Being more recently produced, more perfect roches moutonnées are found in Skye and Norway; one near Grasmere is probably the best local example. These, and the common striations, show the direction of ice movement. Over longer distances ice travel is indicated by erratics of, for example, Criffel or Shap Granite, or Carrock Gabbro.

Retreat of ice is marked by deposition of debris. The hummocky moraines near Easedale Tarn represent the very last stage of ice-retreat (about 15,000 years ago) as the climate warmed in the Windermere Interstadial. There did follow a further cooling, the Loch Lomond Stadial, before the British glaciation ended, which in places resulted in some ice accumulation, but extending little beyond the corries. This would explain the fresh look of some corries, and the hummocky moraine often seen on high ground only, such as Dunmail Raise (where the moraine's age is probably 9,000 to 10,000 years). The material of moraines, where erosion has dissected them, is usually seen to contain a completely heterogeneous mix of rocks and pebbles. However, on the slopes of Skiddaw facing Keswick is a stratified scree deposit. This is

thought to be due to thinly laminated Skiddaw Slates fragments having been suspended in and deposited from torrential meltwater.

Lowland features including kames and eskers are well displayed in the Mockerkin Tarn area, and similarly near Brampton.

At the present we are probably in a climatic amelioration stage, but oscillations have to be considered quite probable. A slide of Deep Gill showed some residual snow in June, inviting conjecture on the situation should the climate become cooler.

In conclusion, a general view of Langdale provided a review of nearly all the glacial features mentioned.

Some further aspects were discussed at question-time. Any 'greenhouse effect' countering further cooling was probably insignificant compared to nature's previous additions of CO_2 to the atmosphere. The discovery of Roman mine workings under Alpine glaciers showed that some of the latter have advanced in recent times more than was once thought. There is evidence that deep ocean temperatures have decreased. Rock-type has little influence on where corries form, their initiation depending largely on the vagaries of wind-swirls. Absence of glaciation in some extremely cold regions due to lack of water vapour, and protection by thick ice-cover in other regions were also briefly mentioned.

The Senior Vice-President, Mr.M.B.Dodd, thanked the speaker who, he said, had not merely stepped into the breach, but had given a particularly well-presented dissertation and reminded the Society of the importance of interpreting local features.

MINERAL IDENTIFICATION AND THE IMPORTANCE OF COLLECTING

Mr. B. Young

On the 13th November, 1985, 26 members and guests were present at the Royal British Legion Club, Workington. The Senior Vice-President welcomed the speaker as one already well-known to the Society from previous lectures and field meetings. Mr. Young is now working on a revision of part of the Cumbrian coalfield.

Introducing his topic Mr. Young touched briefly on the precise nature of minerals, pointing to a well established definition of a

mineral as being 'a substance of fixed chemical composition and physical structure formed by the inorganic processes of nature'. A few apparent exceptions to this rule were noted e.g. secretion of calcite and aragonite by various organisms - notably corals and molluscs and of phosphates in kidney and gall stones! Synthetic minerals were mentioned - some substances previously known only as man-made have subsequently been found in nature as minerals.

As with any study of natural objects, a form of classification of minerals is an essential starting point to their study. It was important to understand how to identify individual minerals or groups of minerals. In this context it was worth observing that many amateurs are significantly better at hand specimen mineral identification than very many professionals. In learning to identify minerals the most valuable tool is experience. There is a true adage that 'the best mineralogist is the one who has seen the most minerals'. Much can obviously be learnt from text books and theory but there is no substitute for actually handling minerals and developing a feel for them. A mineralogist friend of the speaker has observed that a mineralogist passes through several stages in his apprenticeship: stage 1 where he thinks he knows nothing, stage 2 where he feels he knows everything, followed by stage 3 where he feels he knows very little. Stage 3 is the one to aim for as it stems from a healthy scepticism and uncertainty, coupled with a wish to investigate fully. Sadly a number of apprentices rest at stage 2!

Methods of investigation of value to the interested amateur were briefly reviewed. In particular outlines of crystallography, colour, hardness etc. were discussed and simple chemical and physical tests were described. With care and experience a very surprising range of minerals can be identified with fair precision. Many, however, can never be identified beyond a group or family name. For instance, it is impossible in hand specimens to distinguish between the various members of the pyromorphite - mimetite - vanadinite series. For these, sophisticated analytical techniques such as X-ray diffraction are needed. Today very many highly complex determinative tests are at the routine disposal of most professional mineralogists, though it is worth stressing that much good work can still be done by the interested amateur. An important lesson for an amateur to learn is to realise when more advanced help is needed and if possible to seek it.

Mention today of collecting can often draw adverse comments from several quarters especially those promoting conservation. However, the speaker expressed his view that on balance he favoured responsible mineral collecting. Comparisons of mineral collecting with, e.g., butterfly or wild flower collecting were in his opinion somewhat unfair. There was a risk of overcollecting of some material in some places, though experience showed that many new and important discoveries came to light only through the activities of

collectors. Stress must however be laid on responsible collecting. There are undoubtedly far too many collectors around who happily attack sites with an overimpressive armoury of tools and even in certain cases explosives! A small but over-effective group of commercial collectors have done much damage. This mass destruction cannot be justified, especially when the material being sought is not used for any useful scientific purpose. There is little point in anyone assembling a huge range of interesting species from an area if no use is made of it nor the most valuable results published. The impulse to collect minerals merely to assemble a vast 'stamp collection' cannot really be justified; the profit motive in seeking to obtain as many saleable specimens as possible from a site is especially deplorable.

Much is heard today in various collecting circles about 'micro-mounting'. This unnecessary term was introduced to this country from the USA several years ago to describe the practice of collecting tiny examples of minerals to be viewed and enjoyed under a binocular microscope. Its claims to respectability stem from the belief that as only small specimens are retained, the hobby is helping to conserve fast-dwindling supplies of rare minerals. The speaker's experience of the micro-mounting world is very different. The main object of most, though by no means all, micro-mounters is to acquire specimens for their aesthetic appeal. In order to do this, considerable and commonly vast amounts of mineralogical material are broken up in the search for a few treasured 'micros'. In the process much valuable material which has little 'micro-mount' appeal (generally because it is not crystallized, or otherwise does not look attractive) is destroyed. The speaker would be more convinced by the micro-mounters' conservation argument if the micro-mounter used a micro-hammer! In his experience the 'micro-man' is the chap with the biggest hammer who uses it with the most devastating efficiency!

The responsible collector is one who does not overcollect. He (or she) looks at material carefully and intelligently, having taken the trouble to learn as much as possible about the area of interest. Any specimens to be retained in his collection will be labelled as accurately as possible with their locality. If a collection is to have any value at all the specimens must be accompanied by full location details. The identification of the mineral or minerals present is, surprisingly, less important. Perhaps this is not so surprising when it is realised that this factor can be checked by anyone at any time after its collection - once the locality details are lost they can never be recovered. A good collector will wish to use the information and knowledge he acquires as well as the specimens he collects. If he collects something he does not understand he will seek help from an expert. If he obtains something new, e.g. a mineral not previously known from the locality or area, he will, if possible, see to it that the find is recorded - either by writing a note himself for publication

in a suitable journal or by giving the information to someone who will do this. The value of local journals such as this Society's own Proceedings cannot be overestimated in this respect. Any good spare specimens should be given to a museum - preferably a national museum. In this way knowledge of new occurences gained by collecting reaches the attention of the geological and mineralogical world at large. Field mineralogy is one of the few sciences in which there is still a place, and a valuable one, for the non-professional.

In conclusion several separate examples known to the speaker of interesting and important discoveries being made as a result of collecting in the last few years were outlined. These included a description of the aluminium sulphate minerals in the Tertiary sediments overlying the Chalk at Newhaven, Sussex, the discovery of nickel minerals with much associated magnetite in the Harwood Valley, Teesdale, and the newly located antimony-bearing vein at Wet Swine Gill in the Caldbeck Fells. All have been discovered as a result of intelligent collecting and when investigated all had yielded information of value beyond the confines of the individual occurrences.

Mr. Shipp expressed the thanks of the Society to Mr. Young.

Mr.E.H.Shackleton had kindly brought for inspection a few specimens from his superb mineral collection.

REPORT ON RECENT INVESTIGATIONS

IN THE LAKE DISTRICT BY THE BRITISH GEOLOGICAL SURVEY

Dr. P. M. Allen

At West Cumbria College, Whitehaven on the 4th December, 1985, 30 members and guests heard the President announce the sad death of Harry Kellet, before going on to welcome Dr. Allen of the British Geological Survey who has been engaged in a reinterpretation of Lake District geology since 1981. He had in a previous lecture (see Proceedings Volume IV part 3) outlined the investigations as proposed and had more recently led two excursions.

Achievements, Dr. Allen remarked, had not matched intentions. There had been staff shortages and budget cuts. However, 400 km^2

had been mapped, most of the specialists had been retained and about 20 publications were out or in preparation. The talk, he added, had been put together from data in these papers and was a report of the work of the whole team, not his alone.

Research had been carried out on the Skiddaw Group, the Borrowdale Volcanic Group, the Windermere Group and the Eskdale Granite.

The Skiddaw Group is structurally complex and consists almost entirely of muddy siltstone and greywacke. It is difficult to map and requires a knowledge of lithologies, palaeontology and structure to interpret its stratigraphy. Previous workers divided it into as many as ten formations. Jackson (1978) reduced these to Hope Beck, Loweswater Flags, Kirk Stile, Tarn Moor Mudstone and Latterbarrow Formations. It is now considered that the Latterbarrow Formation, which Wadge (1978) removed to the Eycott Group should remain in the Skiddaw Group.

In the area of the western outcrop the three main formations in the group are Hope Beck, Loweswater and Kirk Stile. Careful mapping of the greywacke turbidites, in particular by recording the different bedding characteristics of the turbidites, has led to further subdivision.

Most advances have been made in the biostratigraphy. Jackson used graptolites to erect a biostratigraphy in which the Arenig was divided into four zones: Didymograptus deflexus, Didymograptus nitidus, Isograptus gibberulus and Didymograptus hirundo. Work on the lower part of the succession has extended the age range into the Upper Tremadoc. New zones recognised with macrofossils are Tetragraptus phyllograptoides (lowest Arenig), Dictyonema murrayi and Angelina sedgwickii (Upper Tremadoc), the last named being based on a mainly trilobite fauna. Work on the acritarchs (microflora or early protozoa) has given eleven assemblages diagnostic of age. These include a Lower Tremadoc assemblage. Thus, the Skiddaw Group contains rocks ranging in age from Lower Tremadoc to Upper Llanvirn.

The structural succession in the Skiddaw Group shows four events: first folds are recumbent and show no cleavage; second folds are open, with cleavage, and represent the main Caledonian deformation; third folds are sideways closing, open and with cleavage; fourth folds are associated with minor kink bands. Most work by the B.G.S. has been concentrated on a reinterpretation of the first fold phase. A major anticline has been mapped west of the Vale of Lorton. It is several km long, lobate, overturned to the east and believed to be a major slump fold. Many so called second folds are also now believed to be initiated at this first deformation but have been tightened during the second phase and have a cleavage imprinted on them. The major first slump fold around Buttermere and on Robinson is overturned in the opposite

direction, to the north west, and palaeontology shows that in this area there must be some considerable thrusting. It is, therefore, possible that the greywackes on Robinson belong to a different formation from the greywackes around Loweswater, on the other slump fold.

The depositional environment postulated for the Skiddaw Group is probably shelf edge.

The Latterbarrow Sandstone is exposed for 3 - 4 km^2 around the lower River Calder. Another similar sandstone occurs near Redmain, north east of Cockermouth. The Latterbarrow Sandstone consists of about 400 m of unfossiliferous coarse quartzose sandstone. It overlies the Skiddaw Group with a marked unconformity. The overlying rocks of the Borrowdale Volcanic Group are mostly mudflow deposits. They overlie the sandstone apparently unconformably locally, e.g. in the Calder below Gill Force, but regionally the relationship is one of conformity. It is interpreted that the sandstone was deposited in an estuary, uplifted, rapidly eroded and dissected by gullies. Mudflows were then deposited on this uneven surface producing local, small unconformities. There is evidence of contemporaneous volcanism throughout the Latterbarrow Sandstone, which must, therefore, be regarded as the basal formation of the Borrowdale Volcanic Group.

The sandstone of Redmain is compositionally different from the one at Latterbarrow. It does not contain any evidence of contemporaneous volcanism. Nothing can be said of its age except that it probably post-dates the Skiddaw Group and is overlain by the Carboniferous.

The Borrowdale Volcanic Group has long been known to post-date the Llanvirn and be older that the Longvillian Stage of the Caradoc. Acritarchs found in the upper part of the group now put it firmly in the Caradoc.

Two stages of evolution of a volcano are represented in the group: the constructive stage and the destructive stage. The constructive stage is represented by the thick pile of lava flows in the lower part of the group. Among the lavas are clinkery basalt flows, andesite block flows and composite andesite lavas. The last are widespread in the Lake District, but generally rare. They usually consist of a lower component of andesite, an upper blocky basaltic andesite component and, between them, a zone of interlayering. The flows are the result of simultaneous eruption through the same vent of two different liquids and are important in the study of mixed magmas.

The destructive phase began with the formation of a caldera at which time much of the cone was either blasted away or collapsed. There is a marked unconformity representing this initial explosive event. The rocks above it are mostly ash flows and volcanic sediments, some of which were laid in a lake, but with

subsidiary rhyolite domes, minor andesite piles, avalanche deposits and airfall tuffs. Important in this interpretation has been the recognition during mapping of widespread marker horizons represented by airfall deposits, a rhyolite flow and a distinctive nodular ashflow tuff.

Subsidence during the destructive phase led to the local deposition of marine mudstones within the succession, but this was followed by uplift and erosion before the Windermere Group was unconformably deposited on the volcanic rocks.

This last episode of uplift possibly coincided with the first phase of intrusion of the Lake District granite batholith. Geophysical modelling shows that the Eskdale Granite is part of a large body of buried granite in the western Lake District, separate from the Shap and Skiddaw Granites. The identification of several cleavage zones crossing the Eskdale Granite confirms the early ages given to it on isotopic age determinations. Mapping also shows that the Eskdale Granodiorite truncates the Ulpha Syncline, confirming that there was a period of major open folding before the Ashgill. The Eskdale Granite itself is a complex of coarse and fine-grained granites representing multiple intrusion.

The Lake District batholith is probably responsible for the metamorphism seen in the Borrowdale Volcanic Group. It is also the cause of the Crummock Water hydrothermal alteration zone. This is 25 km x 3 km and extends from Outerside to Egremont. Within it the Skiddaw Group has been bleached and baked to hard, splintery rock. During the alteration there was some veining and replacement by tourmaline, and a massive removal of many elements. Enough Zinc was removed to stock the North Pennine Orefield and it is believed that the processes observed in this alteration zone are important in studies of metallogenesis.

As a result of their studies, the B.G.S. are just beginning to get a new picture of this western part of the Lake District: they have probably reached an approximate half-way stage of the task.

Answers to questions supplied further information. There is not a lot of calcium in the Latterbarrow Sandstone: the top 30 m is arkose. Finding graptolites can present difficulties to the field geologist as well as to C.G.S. members! It is most likely that just one volcano produced the Borrowdale Volcanics. Short-term volcanism is compatible with a subduction zone involving continuing volcanism. Though deposits in one area arose from one volcano over a relatively short time, other volcanoes along the same plate margin would be active slightly earlier or later. The Lake District volcanism was part of an island arc with the Welsh volcanoes in the back-arc. Reports of the B.G.S. studies will be appearing in papers in the Journal of Geology, and the Yorkshire Geological Society and the Geological Society (London) journals. There is no evidence of any deposition on the central Lake District

dome structure after the Silurian. Clear details of rock structures were shown on excellent slides. In thanking Dr. Allen, the Senior Vice-President described the lecture as a remarkable 'tour de force' delivered with clarity and precision.

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GEOLOGICAL FIELD WORK IN ARCTIC NORWAY

Mr. T. Shipp

At a meeting of 27 members and guests at West Cumbria College, Workington, on 8th January, 1986, the President remarked that the speaker hardly needed any introduction since he had probably done more for the Society than almost anyone else as Editor, Secretary, excursion leader and lecturer.

Mr. Shipp explained that he had visited the Lyngen Peninsula in Northern Norway in the summer of 1984 as mountaineering expert among 23 leaders accompanying nearly 100 young people aged between 17 and 19. This British Schools Exploring Society expedition lived for six weeks under canvas, studying geomorphology and botany and learning mountain safety. The expedition flew by special charter from Gatwick to Tromso on 22nd July, 1984, and was transferred by buses to the small village of Furuflaten on the edge of Storfjord on the east side of the Lyngen Peninsula. Several days were spent transporting tons of equipment and food by rucsac and backpack 8 km up the valley of Lyngsdalen, a rise of 220 m in altitude, along narrow paths and at one point crossing a glacial torrent by an aluminium bridge, custom made in England for the expedition. The camp site was in a tundra area of birch scrub with bilberries. Near the base camp the valley was floored by outwash boulders and gravel, intersected by rapidly shifting braided streams of melt-

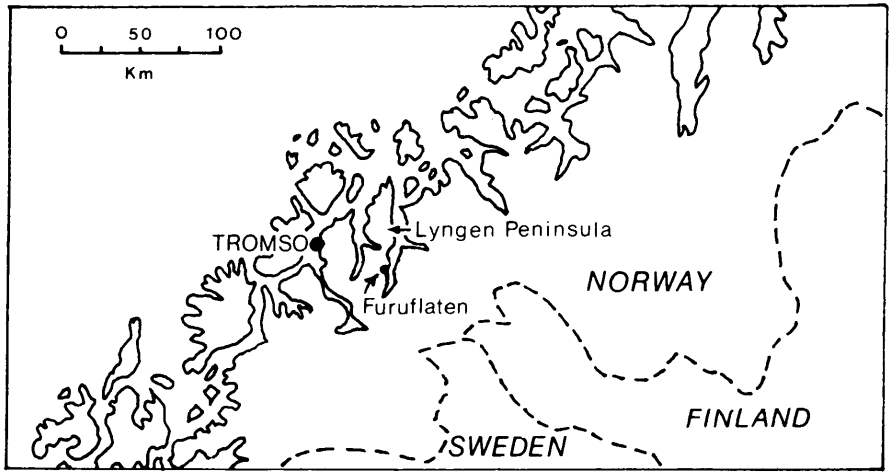


Fig. 1 SKETCH MAP OF TROMSO AREA, NORTHERN NORWAY.

water from glaciers 2 km further up the valley. The streams were cold (near zero C), swift (ropes were used for stream crossings) and very turbid. Looking down from a local summit the discharging silt could be seen as a plume in the fjord below.

Before going on any summit, however, all members went through a training programme including basic cooking, first aid, radio procedure, and movement over rough ground, snow and ice. A lateral moraine provided a convenient gravel path to a training area where use of crampons, ropes and ice-axes was practised even to the extent of 'rescues' from crevasses - a danger when there is fresh snow.

The Lyngen Peninsula lies 35 km east of Tromso at latitude 69 - 70° N, within the Arctic Circle. Its most obvious feature on a geological map is the N - S trending spine of gabbro over the whole 85 km length of the Peninsula, whose general appearance is reminiscent of the Cuillins. The gabbro appears 'bedded'; in fact some of the layering and the lenticular structures seen on some weathered surfaces were produced by complex thrusting and folding. In the process the rock has been extensively metamorphosed. Thin sections of some samples show two alterations, Saussuritisation and Uralitisation. The first describes alteration of plagioclase feldspar into albite and epidote, with occasional zoisite, prehnite and grossularite. Uralitisation describes alteration of augite crystals into a mass of spiky hornblende crystals and biotite. Where hornblende was dominant the gabbro could be regarded as hornblendite. In some places the gabbro appears banded where feldspars and pyroxenes seem imperfectly mixed.

Gravity surveys suggest that the Lyngen Gabbro forms a westerly dipping wedge probably thrust 100 km eastwards from its source area in the lower crustal layer of Western Norway during the Caledonian Orogeny. It is bounded by thrust faults dipping west. The gabbro lies in contact with, and in places seems to be concordant with metamorphosed sedimentary and igneous rocks of Cambrian to Silurian ages. These have been very severely deformed and chemically altered (though sometimes leaving relict structures) and consist of: (1) Amphibolites, some of which appear to have originated from basalts. These amphibolites, and indeed the gabbro itself, frequently show development of the fibrous amphibole asbestos, and some striking specimens were found. (2) Phyllites, often showing characteristic 'wavy' foliation and sheen. Since these originated as incompetent, easily-deformed argillaceous rocks, some tortuous fold structures were encountered. (3) Schists, with layers of sparkling mica crystals, and very occasionally showing well-developed dodecahedral garnet porphyroblasts. (4) Quartzites, metamorphosed arenaceous rocks, usually very hard, often finely banded. (5) Impure marbles, originating as dolomitic limestones.

The total thickness of the Cambro - Silurian sediments is estimated to be in excess of 7000 m. Within the gabbro, large masses of ultrabasic dunite occur, composed mainly of the mineral olivine, perhaps originating from upper mantle peridotite, and weathering to a pale orange-brown colour (hydrated iron oxides).

Summits in this area are all approximately the same height, suggesting it is a glacially dissected plateau at 1500 - 1600 m above sea-level. The greatest erosion resulted in the fjords which are aligned N - S along the strike of the metasediments. The central gabbro spine is breached half way up the peninsula. U-shaped valleys, scoured rocks and moraines abound. Raised beaches and old cliff-lines provide evidence of recent isostatic recovery after recession of the ice-cap.

Near base camp, melt water streams' daily variation in level and flow were measured, the former by simple scale, the latter by adding a known volume of standard salt solution upstream and measuring electrical conductance changes. Velocity profiles were taken using a set of miniature propellers. Changes in shape of stream beds were plotted by surveying. Suspended sediment studies needed 'fishing nets' of standard apertures. Study of traction movement was by painting and numbering hundreds of small boulders and following their progress downstream. Collation of results was aided by the camp's generator-powered computer in the laboratory tent.

An arctic climate produces a proliferation of frost-shattered boulders, dunite being particularly affected. Steeper slopes showed boulder movement as 'ploughing blocks'. Stone stripes and solifluction lobes were evident: trenches were dug through them to

record stratification and depth of permafrost. In the uplands frost heave had developed stone polygons.

One important task was to observe what changes had occurred since a previous expedition in 1979. The snouts of the Sydbreen and some other glaciers were surveyed and mapped: there has been a general shrinkage back since the previous survey. On the high summit ice-cap of Balgesvarre, however, surveys gave inconclusive evidence of change. Red dye and wire netting had been left by the 1979 expedition and pits were dug down through the snow to try and locate them and so gain evidence of speed and direction of ice movement. They were not found, but the diggings showed the annual snow layers, and density measurements were made. In these upland areas colossal avalanches (sounding like express trains) were frequent, forming debris cones. These areas were avoided!

For this part of the work high camps were set up which involved taking heavy loads up a steep ice slope and loose scree using fixed ropes. The fine gravel centres of the stone polygons made good tent sites! At this altitude winter arrived in mid-August producing blizzards over several days with temperatures down to - 10°C: radio batteries had to be kept warm in sleeping bags. 'Arctic Conquest' tents withstood blizzards; another brand did not! Since no more field work could be done the party climbed down to base camp where shrub leaves were yellow in the brief autumn.

Relative ages of moraines can be assessed from the extent of weathering. By measuring diameters of lichen patches, it was hoped that actual ages could be estimated. On lower ground, turf hummocks' distribution was surveyed and, by digging through, internal structure was examined.

There is a little sheep rearing in the area, some birch-wood management, and the Lapps keep small herds of reindeer: a Lapp hut provided shelter in bad weather away from camp. Doubt being felt as to the edibility of Boletus fungi they were left well alone, but sliced puffballs fried in margarine were enjoyed as were crowberries, cloudberries, cranberries and bilberries. Recovery of vegetation in arctic conditions must be slow, as the effects of the 1979 base camp could still be seen. Records were made of numbers of people, weights and loads carried on the camp footpaths during this 1984 expedition, with some observations of the effects on the paths, as a basis for future studies on regeneration.

During the lecture all aspects of the visit were illustrated by a series of excellent slides, concluding with spectacular sunset, moonrise and dawn shots.

In thanking Mr. Shipp the President said it was obvious the audience had enjoyed the talk which had included something for mountaineers and botanists as well as geologists. Before leaving, the audience were able to examine a set of specimens of rock brought back from the expedition.

Geoffrey Senior Gowing, M.A., F.G.S.

It was with long experience of other geological societies that Geoffrey Gowing joined the C.G.S. in 1962, and for almost 20 years thereafter was a great source of strength to the Society.

Wise counsel and a constant sense of correct procedure were hall-marks of this quiet, courteous man. He was Vice-President of our Society from 1963 to 1965 and served on the Council from 1967 to 1971 and from 1973 to 1974. During the earlier part of that service he produced a draft of Society Rules which once approved by the Society had then to be followed to the letter. The C.G.S. grew in stature in those 20 years; Geoffrey was one of those who made a major contribution. His incisive intellect enlivened many a meeting and his sharp eye contributed often towards a fuller knowledge of field-work. A ready wit frequently sparkled. Whilst on one field excursion when others were undecided about carrying packed lunches or leaving them in the car, he announced that he made it an invariable rule never to be separated from his sandwiches.

He was a splendid organiser and his membership of many societies resulted in his having numerous useful contacts with authoritative geologists.

We came to know Geoffrey Gowing when, on retirement, he came to live in Keswick. Geology had been his chief leisure interest together with rambling, climbing and pot-holing. By profession he had been an inorganic chemist who graduated from Oxford (in the days of the celebrated Professors Hinchelwood and Sedgwick) and worked for I.C.I. on the industrial synthetic production of ammonia and the production of petrol from coal, becoming a works manager. During part of that time he was twice seconded as a consultant, once to the Transvaal and once to advise the Indian Government.

His wife, Kathleen, a charming lady well known to the C.G.S., died soon after their retirement: that blow he bore with fortitude. His son, Richard, was also an active C.G.S. member before moving to Cheshire.

Geoffrey Gowing died in October, 1984, aged 82, after a remarkably full life in which he inspired and helped all with whom he became acquainted.

S.H.G.

Gustav Anthony Schnellmann, Ph.D., A.R.S.M., F.I.M.M.

Dr. Schnellmann first became acquainted with the local hematite deposits over 50 years ago during some vacation work - whilst a student at the Royal School of Mines - at Florence Mine. By coincidence, as he put it, after demobilisation in 1946 he became employed as a geologist, at Florence and Ullcoats Mines, by the Millom Hematite Ore and Iron Co., later becoming general manager. In 1951 he left to set up a consulting practice in London and was retained as a consultant to the mines until British Steel took them over.

His company, Messrs. Mackay and Schnellmann, based in High Holborn, London, became an institutional member of the C.G.S. in 1969; in 1982 when he semi-retired he became an ordinary member. Clearly from his letters to officers of the Society he held it in high esteem. In autumn, 1984, he was engaged in writing an article on the hematite reserves and their possible origin; the notes published in this edition of the Proceedings he had intended to supplement and enlarge upon.

He died in January, 1985, aged 72 and we lost a talented 'geologist with first-hand personal knowledge of the underground detail of these remarkable deposits'.

S.H.G.

Harry Kellet

It was with great sadness that the Society learned of the death of Harry Kellet. Whilst Harry was not a member of the C.G.S., he was always ready to lead an excursion. His unique style provided many memorable excursions in the Duddon and Furness areas. Harry's interests were not restricted to geology: he was respected by many experts in the fields of botany, industrial archaeology and vernacular architecture. Those who had the privilege of knowing Harry will realise that in his passing they have lost not only a good friend, but an infinite source of local knowledge.

D.L.

F. Denys Beddard, C.B.

Having been previously a member of Westmorland Geological Society, of which he became Chairman, Denys Beddard joined our Society about three years ago. He had held a Ministry of Health administrative post, from which he retired to live at Staveley, quietly pursuing his gardening interests and helping people and organisations with whom he came in contact. C.G.S. members will miss his friendship and pleasant company at our meetings.

S.H.G.

ANNUAL DINNER, 1984

The Annual Dinner of the Society was held on Saturday 12th May at Mockerkin Hall, when 36 members and their guests enjoyed a very pleasant meal. The guests of honour were Mr. and Mrs. Wyndham Evans. After dinner Wyndham Evans gave an entertaining talk on the history and work of the British Geological Survey, of which he is now Director of the Northern Region, based at Newcastle.

24th ANNUAL GENERAL MEETING, 1985

The twenty-fourth Annual General Meeting of the Society was held at the Royal British Legion Club, Workington, on the 6th February, 1985, with the Vice-President, Mr.T.Shipp, in the Chair.

The accounts for the year ended 31st December, 1984, (reproduced opposite) were presented and approved and the following Officers and Council elected for the ensuing year:

President	F.J.Cockersole, M.B.,Ch.B.,F.R.C.O.G.
Vice-President	M.B.Dodd, M.A.
Vice-President	T.Shipp, B.Sc.,M.I.Geol.,F.G.S.
General Secretary	D.Leviston, B.A.,M.Sc.,C.Eng.,M.I.Mech.E.
Treasurer	F.T.B.Lawton
Membership Secretary	B.D.Allen
Excursion Secretary	M.B.Dodd, M.A.
Publications Secretary	E.Lawrence, B.Sc.,M.I.Geol.,F.G.S.
Editor	S.H.Gate, M.Sc.
Librarian	M.F.Burton
Members of Council	I.Gray, B.Sc.
	J.D.Hinde
	T.P.Loftus
	E.Skipsey, M.Sc.,M.I.M.M.,M.I.Geol.,F.G.S.

The Membership Secretary reported membership figures for February, 1985, as being: Ordinary Members 177, Associate Members 23, Joint Members 37, Institutional Members 17, a total of 254.

INCOME AND EXPENDITURE ACCOUNT

INCOME:	£	1983 £	EXPENDITURE:	£	1983 £
Subscriptions			Cost of Publications	758.25	9
Arrears for 1983	28.80	6	Lectures & Excursions		
1984	495.25	479	Lecturers' expenses	65.36	67
Advances for 1985	5.00	10	Hire of films	-	-
Sale of publications	198.97	199	Hire of Rooms	16.63	16
Royalties 'Lake District'	159.42	174	Subs. to other Societies	7.50	15
Inland Revenue refund	87.18	91	Library books	7.45	-
Other income			Annual dinner expenses	243.90	255
Donations	6.08	15	Administration		
Bank interest	140.83	130	Printing	131.27	-
Annual dinner	238.00	239	Stationery & Materials	70.44	123
Sale of duplicator	5.00	-	Telephone	20.70	14
			Postages	215.59	83
Total income for 1984	1364.53	1343	Travel (petrol)	63.44	-
Surplus(deficit) for yr.	(236.00)	761	Total expenditure 1984	1600.53	582
Bal. forward from 1983	2577.42	1816			
Bal. forward as revenue	2341.42	2577			

CHARLES EDMONDS MEMORIAL FUND

INCOME:	£	1983 £	EXPENDITURE:	£	1983 £
Interest 3½% War Stock	5.10	5	none	-	-
Bank interest-	2.84	3			
Increase in fund 1984	7.94	8			
Bal. forward from 1983	41.67	34			
Balance forward to 1985	49.61	42			

BALANCE SHEET: 31st December, 1984

CAPITAL EMPLOYED:	£	1983 £		£	1983 £
Assets					
Equipment (nom.value)	-	8	Surplus (deficit) year 1984	(236.00)	761
Stock of publications	1290.00	2259	Accumulated funds	3881.01	4081
Deposit a/c at bank	1646.83	2087			
Annual dinner a/c	513.14	249			
Current a/c at bank	77.93	298			
Cash in hand	00.55	1			
Publ.Sec. cash in hand	18.59	8			
Cheques in hand	102.97	-			
	3650.01	4910			
LESS liabilities					
Creditors (uncl.cheque)	-	58			
Subs. in advance	5.00	10			
TOTAL NET ASSETS	3645.01	4842		3645.01	4842

ANNUAL DINNER, 1985

The 1985 Annual Dinner was held on the 23rd March, once again at Mockerkin Hall Hotel. It was a most enjoyable occasion, with good food and company. The guests of honour were Mr. and Mrs. Murray Mitchell. Murray Mitchell is on the staff of the British Geological Survey at Leeds, is a long standing member of the Society and, after the meal, entertained the company with an account of his family's connections with geology and, in particular, their close association with the geology of the Lake District.

25th ANNUAL GENERAL MEETING, 1986

The twenty-fifth Annual General Meeting of the Society was held at the Royal British Legion Club, Workington, on the 5th February, 1986, with the Vice-President, Mr.M.B.Dodd in the Chair.

The accounts for the year ended 31st December, 1985, were presented and accepted (see opposite) and the following Officers and Council elected for the ensuing year:

President	F.J.Cockersole, M.B.,Ch.B.,F.R.C.O.G.
Vice-President	M.B.Dodd, M.A.
Vice-President	T.Shipp, B.Sc.,M.I.Geol.,F.G.S.
General Secretary	D.Leviston, B.A.,M.Sc.,C.Eng.,M.I.Mech.E.
Treasurer	F.T.B.Lawton
Membership Secretary	B.D.Allen
Excursion Secretary	M.B.Dodd, M.A.
Publications Secretary	E.Lawrence, B.Sc.,M.I.Geol.,F.G.S.
Editor	S.H.Gate, M.Sc.
Librarian	M.F.Burton
Members Council	I.Gray, B.Sc.
	T.P.Loftus
	M.Sanderson
	E.Skipsey, M.Sc.,M.I.M.M.,M.I.Geol.,F.G.S.

The Membership Secretary reported membership figures for February, 1986, as being: Ordinary Members 168, Associate Members 24, Joint Members 31, Institutional Members 16, a total of 239.

INCOME AND EXPENDITURE ACCOUNT

INCOME:	£	1984 £	EXPENDITURE:	£	1984 £
Subscriptions			Cost of Publications	-	758
Arrears for 1984	8.50	29	Lectures & Excursions		
1985	472.00	495	Lecturers' expenses	117.54	65
Advance for 1986	86.50	5	Hire of films	-	-
Sale of publications	141.36	199	Hire of rooms	28.95	17
Royalties 'Lake District'	158.15	159	Subs. to other Societies	17.50	8
Inland Revenue refund	83.52	87	Library books	4.75	7
Other income			Annual dinner expenses	286.00	244
Donations	4.49	6	Administration		
Bank interest	224.78	141	Printing	106.65	131
Annual dinner	301.00	238	Stationery & materials	12.51	70
Sale of duplicator	-	5	Telephone	6.13	21
	1480.30	1364	Postages	112.99	216
			Travel (petrol)	27.80	63
			Miscellaneous	10.36	-
Surplus(deficit) for yr.	749.12	(236)			
Bal. forward from 1984	2341.42	2577	Total expenditure 1985	731.18	1600
Bal. forward as revenue	3090.54	2341			

CHARLES EDMONDS MEMORIAL FUND

INCOME:	£	1984 £	EXPENDITURE:	£	1984 £
Interest 3½% War Stock	5.10	5	none	-	-
Bank interest	4.71	3			
Increase in fund 1985	9.81	8			
Bal. forward from 1984	49.62	42			
Balance forward to 1986	59.42	50			

BALANCE SHEET: 31st December, 1985

CAPITAL EMPLOYED:	£	1984 £		£	1984 £
Assets					
Equipment (nom. value)	-	-	Surplus (deficit) year 1985	749.12	(236)
Stock of publications	1266.27	1290	Accumulated funds	3531.53	3881
Deposit a/c at bank	2442.63	1647			
Annual dinner a/c	490.85	513			
Current a/c at bank	154.48	78			
Cash in hand	2.58	1			
Publ. Sec.cash in hand	10.34	18			
Cheques in hand	-	103			
	4367.15	3650			
LESS liabilities					
Creditors (uncl.cheque)	-	-			
Subs. in advance	86.50	5			
	4280.65	3645		4280.65	3645

SHETLAND ISLES - Geological Impressions. F. Jones

Situated approximately half way between Scotland and Norway, the Shetland Isles exhibit geological affinities with both countries.

Unst, the most northerly of the group, is divided from north to south by thrust movements to give schists and gneisses to the west and serpentine to the east. Chromite ore was formerly mined at Baltasound and good specimens were obtained, whilst excellent specimens of green antigorite serpentine were found in a quarry opposite the ferry to Yell at Belmont. Close examination of the chromite ore revealed the presence of kammererite (magnesium, iron, aluminium silicate); pink crystals within the matrix.

Yell, the middle island, is composed mainly of schist with occasional outcrops of limestone, but it is deficient in minerals and not so interesting from a geological point of view. The main product obtained from the serpentine is talc which is quarried in the form of steatite.

Mainland, the largest of the Shetland Islands group, has a central axis from north to south composed of schist and gneiss (the Kames) but this is divided by a number of long fertile valleys which outline the Dalradian Limestone. The Limestone, following the north to south trend has been eroded away at each end by the sea, to leave the Voes (fjords). One such Voe, Sullom Voe, is the centre for the oil pipelines. The north-west corner of the island consists of a red perthitic granite which was well exposed at Busta Voe and Ellwick during road-works.

Old Red Sandstone predominates to the west and in the southern area at Sumburgh Head, also at Lerwick and Bressay Island. There is a good display of local geological matter in the new museum at Lerwick; also at a 'jewellery' craftsman's shop at Whiteness Voe where local green garnets were seen.

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