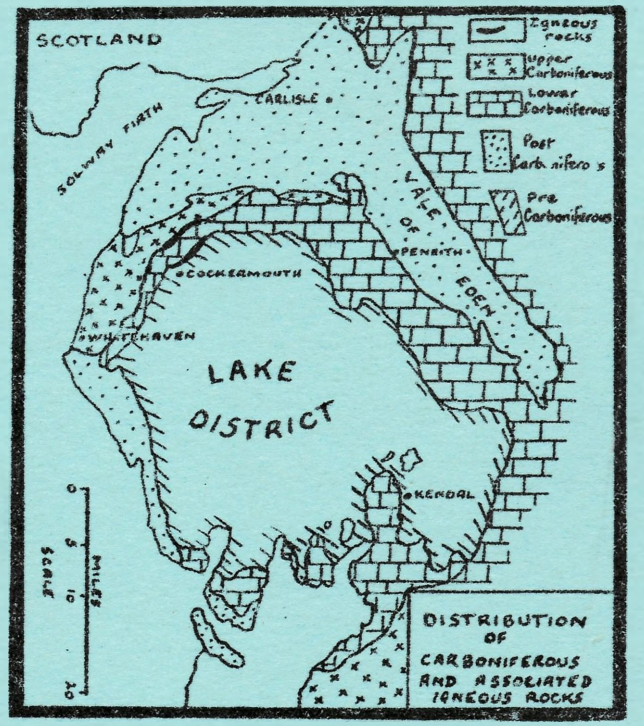
# CUMBERLAND GEOLOGICAL SOCIETY




# PROCEEDINGS

VOLUME 2. PART 2.

— 1967 —

**********

FIVE SHILLINGS

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THE CUMBERLAND GEOLOGICAL SOCIETY

President:

E. H. SHACKLETON, F.G.S.

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# PROCEEDINGS
# VOLUME 2: PART 2.

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Published by the Cumberland Geological Society, December, 1967.



GENERAL SECRETARY: R.E.O. Pearson, [redacted]

PUBLICATIONS SECRETARY: K.R. Baker, [redacted]

EDITOR: T. Shipp, B.Sc., [redacted]

THE SIXTH ANNUAL GENERAL MEETING OF THE CUMBERLAND GEOLOGICAL SOCIETY

Held on February 14th.1967 at Whitehaven College of Further Education

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The Chair was taken by the President, Mr. E.H. Shackleton, F.G.S., who called upon the General Secretary to read the minutes of the previous Annual General Meeting. These were adopted. Reports were submitted by the General Secretary and the Treasurer, and the President expressed appreciation of the work done by all the elected Officers in promoting the Society's interests.

The following Officers and Members of Council were elected:

| | |
|---|---|
| President | E.H. Shackleton, F.G.S. |
| Vice-President | H. Bland. |
| General Secretary | R.E.O. Pearson. |
| Treasurer | H.A. White, B.A. |
| Excursion Secretary | R.H. Hewitt. |
| Publications Secretary | K.R. Baker. |
| Editor | T. Shipp, B.Sc. |
| Librarian | M.F. Burton. |
| Members of Council | Miss E. Pimblett, B.A.; H.H. Walmsley; H.C. Stone, B.Sc.; G.S. Gowing, M.A.,F.G.S. |

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The A.G.M. was preceded by an Extra-ordinary Meeting at which a number of changes of rules were made, as follows:

Rule 33a to be renumbered Rule 34 Librarian.

Rule 35 to be inserted, as follows:
"Publication Secretary. The Publication Secretary shall be responsible for the printing and distribution of all Society publications, with the prior approval of the Council, and under the guidance of the Editor."

Rule 36 to read as follows:
"The Charles Edmonds Memorial Fund.
(a) The fund, raised by public subscription and vested in three Trustees who shall be appointed by the Council of the Cumberland Geological Society.
(b) The fund shall be suitably invested by the Trustees and the interest used to provide a prize to be awarded every three years, or more frequently if the Trustees so decide.
(c) The prize shall consist of a book, or books, suitably inscribed, and shall be presented to the successful candidate at the Annual Dinner of the Society.
(d) The prize shall be awarded by a panel consisting of the President, Vice-President and General Secretary of the Cumberland Geological Society, together with one other person who shall be appointed by the Council of the Society.
(e) Candidates for the prize shall be limited to:
(i) Students who shall be natives of, or residents in Cumberland, at school, university, training college, or other institution of full-time education, who show especial interest in Geology and its allied disciplines.
(ii) Amateurs, being members of the Cumberland Geological Society, who

have, by their activities inside or outside the Society, helped to further the sread of knowledge of Geology.
(iii) Any geologist, amateur or professional, who has by his researches made contributions to knowledge of the geology of the six northern counties of Cumberland, Northumberland, Westmorland, Durham, Yorkshire and Lancashire, or who, being a native of Cumberland, has made contributions to Geology in general.

Rules 34 - 42 to be renumbered 37 - 45.

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## THE GENERAL SECRETARY'S REPORT

Membership of the Society now stands at

149 Ordinary Members (an increase of 33).
81 Associate Members (an increase of 21).
1 Honorary Member.
9 Institutional Members (an increase of 3).

Although in name we are a County Geological Society, it may be of interest to record that 45 of our Members live outside Cumberland.

The activities of the Society in 1966 have followed the pattern set in previous years. There have been some first class lectures and excursions which have been very well attended. The Council have given a good deal of thought to the teaching side of Geology, and to that end a sub-committee of the Council was set up under the Chairmanship of Mr. H.H. Walmsley to investigate means by which the Society could assist individual teachers by providing information and specimens of geological material.* Mr. Walmsley was also instrumental in bringing to the notice of the Society an excellent geological collection housed at Cleator.

The Society is, I feel, consolidating its position in the Geological field. We do, however, need more Members taking an active part in the running of the Society. In putting this my usual plea, I would reiterate that any society is only as good as its individual members make it. In this respect I would welcome a change of General Secretary, as I intimated this time last year.

We have an exchange agreement with the Liverpool and Manchester Geological Society, Leeds Geological Association, the N.E. Lancashire Branch of the Geologists' Association, and the Geologists' Association. Copies of Proceedings of all these bodies may be had on loan from the Librarian.

R.E.O. Pearson.

* Report by Mr. Walmsley on page 103.

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## THE HONORARY TREASURER'S REPORT

The financial affairs of the Society continue to be in a healthy state. From the Income and Expenditure Account it will be seen that we began the year with a balance at the bank of £99 - 1 - 8, but of this £69 - 17 - 2 was the sum of contributions to the Charles Edmonds Memorial Fund, so that £29 - 4 - 6 was actually standing to the Society's credit.

Our subscription income for 1966 totalled £77 compared with £52 for 1965 and £45 for 1964, indicative of the steady rise in membership. A

## INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDING 2nd. JANUARY, 1967

| 1965 | EXPENDITURE | | | | 1965 | INCOME | | | |
|---|---|---|---|---|---|---|---|---|---|
| £ | | | | | £ | | | | |
| (79) | Paper, stencils, etc. | 48 | 16 | 1 | (38) | Balance at Bank 1/1/66 | | | |
| (25) | Postages | 27 | 11 | 7 | | after making provision | | | |
| (11) | Subs. to other societies: | | | | | for outstanding cheque | 99 | 1 | 8 |
| | W. Cumb. Tech. Soc. | 2 | 10 | 0 | (52) | Subscriptions: | | | |
| | Geologists' Association | 4 | 0 | 0 | | 1965 (Arrears) | | 10 | 0 |
| (--) | Solicitors' fees for Deed | | | | | 1966 Members, 76 | | | |
| | for Edmonds Trust | 7 | 17 | 0 | | Associates, 53 | | | |
| (32) | Annual Dinner | 31 | 10 | 0 | | Institutions, 5 | | | |
| (31) | Hawse End Course: | | | | | 1967 (In advance) | | | |
| | Fees to Cumb. Ed. Cttee. | 48 | 13 | 6 | | Members, 35 | | | |
| | Coach Hire | 7 | 10 | 0 | | Associates, 17 | | | |
| (--) | Transfer to Deposit a/c. | | | | | Institutions, 2 | | | |
| | (Memorial Fund) | 80 | 14 | 0 | | | 76 | 10 | 0 |
| | Cheque Book | | 5 | 0 | (61) | Edmonds Memorial Fund | | | |
| | Bank Charges | | 5 | 0 | | (Contributions) | 6 | 13 | 0 |
| (99) | Balance at Bank | | | | (10) | Donations | 11 | 2 | 9 |
| | on 2/1/67 | 73 | 7 | 2 | (68) | Sale of Publications | 53 | 6 | 11 |
| | | | | | (31) | Hawse End Course Fees | 59 | 0 | 0 |
| | | | | | | Annual Dinner | 26 | 15 | 0 |
| | | £332 | 19 | 4 | | | £332 | 19 | 4 |

## CHARLES EDMONDS MEMORIAL FUND

| | INCOME | EXPENDITURE |
|---|---|---|
| Contributions received up to 31/12/65 | 69 17 2 | |
| Contributions received during 1966 | 6 13 0 | |
| Contributions from Society's Funds | 4 3 10 | |
| Transferred to Deposit a/c on 21/5/66 | | 80 14 0 |
| | £80 14 0 | £80 14 0 |

## CHARLES EDMONDS MEMORIAL ACCOUNT

| | INCOME | EXPENDITURE |
|---|---|---|
| Deposit a/c opened on 21/5/66 | 80 14 0 | |
| Investment: 3½% War Stock (Nominal value £146 4 11) on 14/6/66 | | 76 0 0 |
| Half-yearly interest to 3/12/66 | 2 11 2 | |
| Bank Interest to 31/12/66 | 9 7 | |
| Balance at Bank on 31/12/66 | | 7 14 9 |
| | £83 14 9 | £83 14 9 |

. . . . . .

glance at the expenditure side of the accounts will show that this £77 is balanced almost exactly by two items of expenditure which are incurred largely for the benefit of individual members, viz: the postage account (£27 - 11 - 7) and the cost of paper and material used in the production of "Proceedings", circulars and other publications (£48 - 16 - 1). Also on the income side, another welcome item is "Donations", £11 - 2 - 9, most of

STATEMENT OF ASSETS AND LIABILITIES, 2nd. January 1967.

| LIABILITIES | | | | ASSETS | | | |
|---|---|---|---|---|---|---|---|
| Subscriptions for 1967 paid in advance | 22 | 15 | 0 | Balance at Bank on 2/1/67 | 73 | 7 | 2 |
| Reserve for postage a/c for 1966 Proceedings | 7 | 10 | 0 | Duplicator, less deprec. | 20 | 0 | 0 |
| Sundry creditors | 7 | 14 | 8 | Stencils and Styli less depreciation | 4 | 0 | 0 |
| Balance, being excess of assets over liabilities | 150 | 3 | 6 | Postcards, 56 doz. approx. | 2 | 16 | 0 |
| | | | | Publications at nominal price less 50% deprec. | 88 | 0 | 0 |
| | £188 | 3 | 2 | | £188 | 3 | 2 |

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which comes from the generous gift made under covenant by Sir Frank Schon.

Sales of various publications amount to £53 - 6 - 11 more than half of which has come from sales of the "Bibliography of Lake District Geology", compiled by Dr. R.A. Smith, and now supplied to the Reference Libraries of most of the Universities and Colleges of Education in the country. These sales form a most valuable part of the income of the Society, and reflect the immense amount of painstaking effort on the part of the Editor and the Publications Secretary.

It will be noted that several items in the expenditure account are non-recurring. The Council decided to pay the legal costs involved in setting up the Charles Edmonds Memorial Trust from the Society's funds, and also made a donation of £4 - 3 - 10. Accordingly it was possible to transfer £80 - 14 - 0 to a Deposit Account, and subsequently £76 was invested in 3½% War Stock which will yield an income of slightly over £5 per annum. Contributors to the Memorial Fund will doubtless be gratified that their donations have been devoted in full to the purposes of the Fund, all extraneous expenses having been borne by the Society. The sum standing to the credit of the Fund at the end of 1966 was £7 - 14 - 9, which makes possible the award of the first Edmonds Memorial Prize during the current year.

The Income and Expenditure Account shows a balance at the bank at the end of 1966 of £73 - 7 - 2, a very satisfactory figure when compared with the £29 - 4 - 6 with which we began the year.

Next I would like to refer to the Statement of Assets and Liabilities, which is in effect a Balance Sheet. The chief assets are the duplicator and stocks of various publications, and in valuing these a generous margin has been allowed for depreciation. This seems a prudent course when it is borne in mind that the demand for several of our publications is likely to slacken as the market for them gradually becomes saturated. Even so, assets exceed liabilities by a substantial margin.

H.A. White.

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# Deglaciation in the Ennerdale Area - A Re-interpretation.

by David Huddart, B.A.

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## INTRODUCTION

At the glacial maximum during the Weichsel a combined ice-sheet, consisting of both Irish Sea and Lake District ice, covered the entire area of Ennerdale, with no nunataks projecting above its surface. The ice in the Ennerdale area formed part of a vast complex ice-sheet which reached as far as the Bar Hill - Wrexham terminal moraine in mid-Cheshire. (Worsley and Boulton, 1965.) A re-interpretation of the deglacial history of this ice-sheet in the Ennerdale area has been attempted, utilising modern ideas, which include the importance of subglacial and englacial drainage, downmelting, and a rejection of the overflowing pro-glacial lake hypothesis so widely acclaimed in the early years of this century.

The Ennerdale area can conveniently be divided into four regions for the purposes of a reconstruction of the deglacial history. These are:-

(A) The fells south of Ennerdale Lake.
(B) Lower Ennerdale (Bowness Knott to Wath Brow).
(C) The Ennerdale Bridge to Mockerkin Tarn region.
(D) Upper Ennerdale (Bowness Knott to Black Sail).

Each area will be dealt with in turn, the glacial landforms being described and a reconstruction of events based on these landforms attempted.

## (A) DEGLACIATION OF THE FELLS SOUTH OF ENNERDALE LAKE

A summary of the sequence of events suggested by Smith et al. (1931) is (a) the appearance, in the waning stages, of the higher peaks of the Grike-Iron Crag-Pillar divide as nunataks. The supply of ice from Ennerdale was largely cut off and evacuation of the ground to the south was comparatively rapid. (b) Kinneyhow Carr, a meltwater channel, is the highest of a series crossing the Ehen-Calder watershed at successively lower levels to the south, many being regarded as overflow channels from a Standingstones lake. (c) The appearance of Dent above the ice caused the ice to split into two lobes, north and south of that hill, and an enlarged Lagget Lake, dammed by the southern lobe, drained southwards by a series of overflow channels. The northern lobe rapidly retreated to a line overlooking the head of Kirk Beck and the Cockhow Delta was deposited.

I am in full agreement with (a); downmelting caused the appearance of nunataks, the first being Lank Rigg (1759'), followed by Grike (1500'), Boat How (1337'), Blakeley Raise (1250') and Dent (1131') in that order. However, the sequence of events outlined in (b) and (c) has been changed.

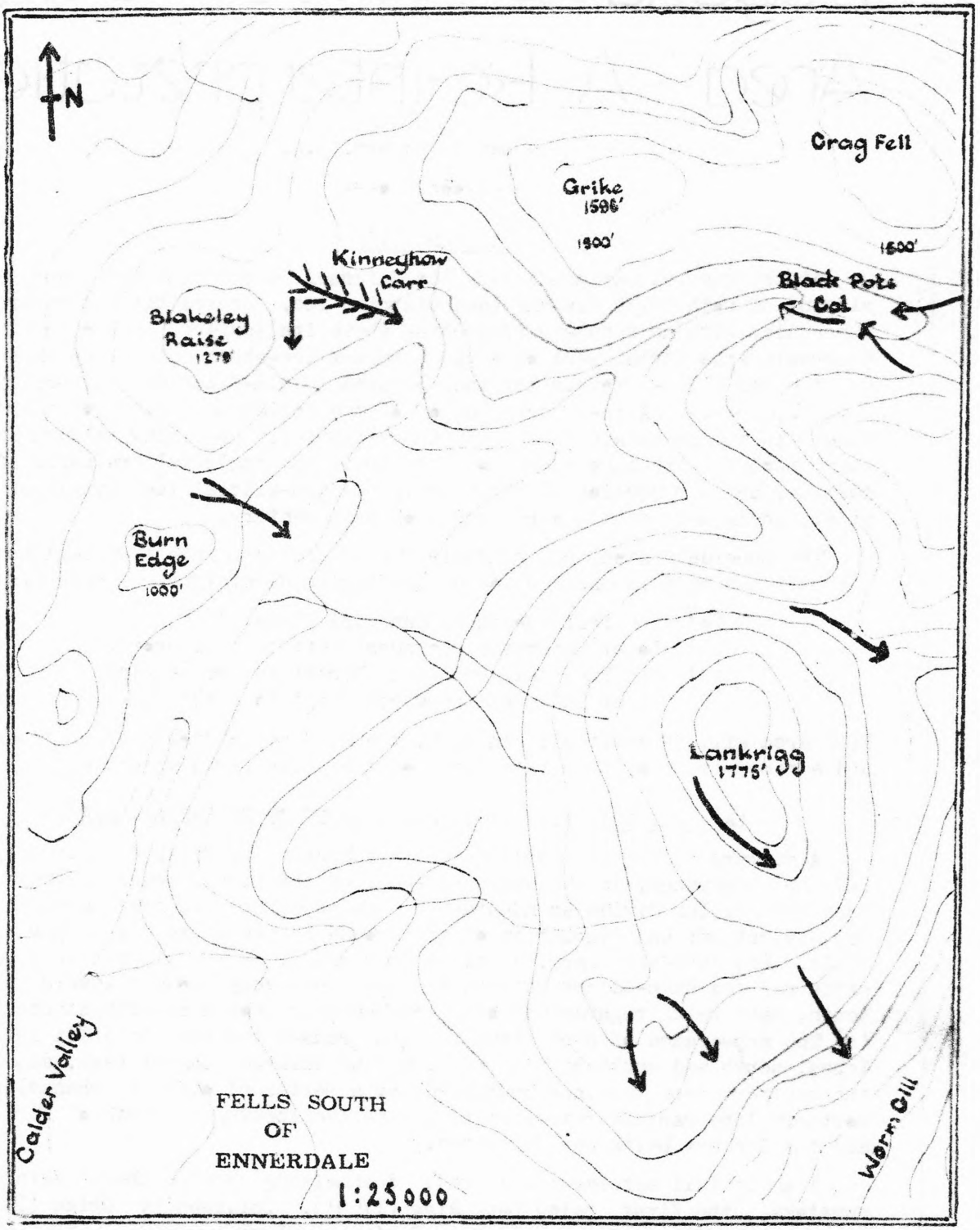



FIGURE 1.

( A key to all the figures is shown on figure 3, on page 6a. )

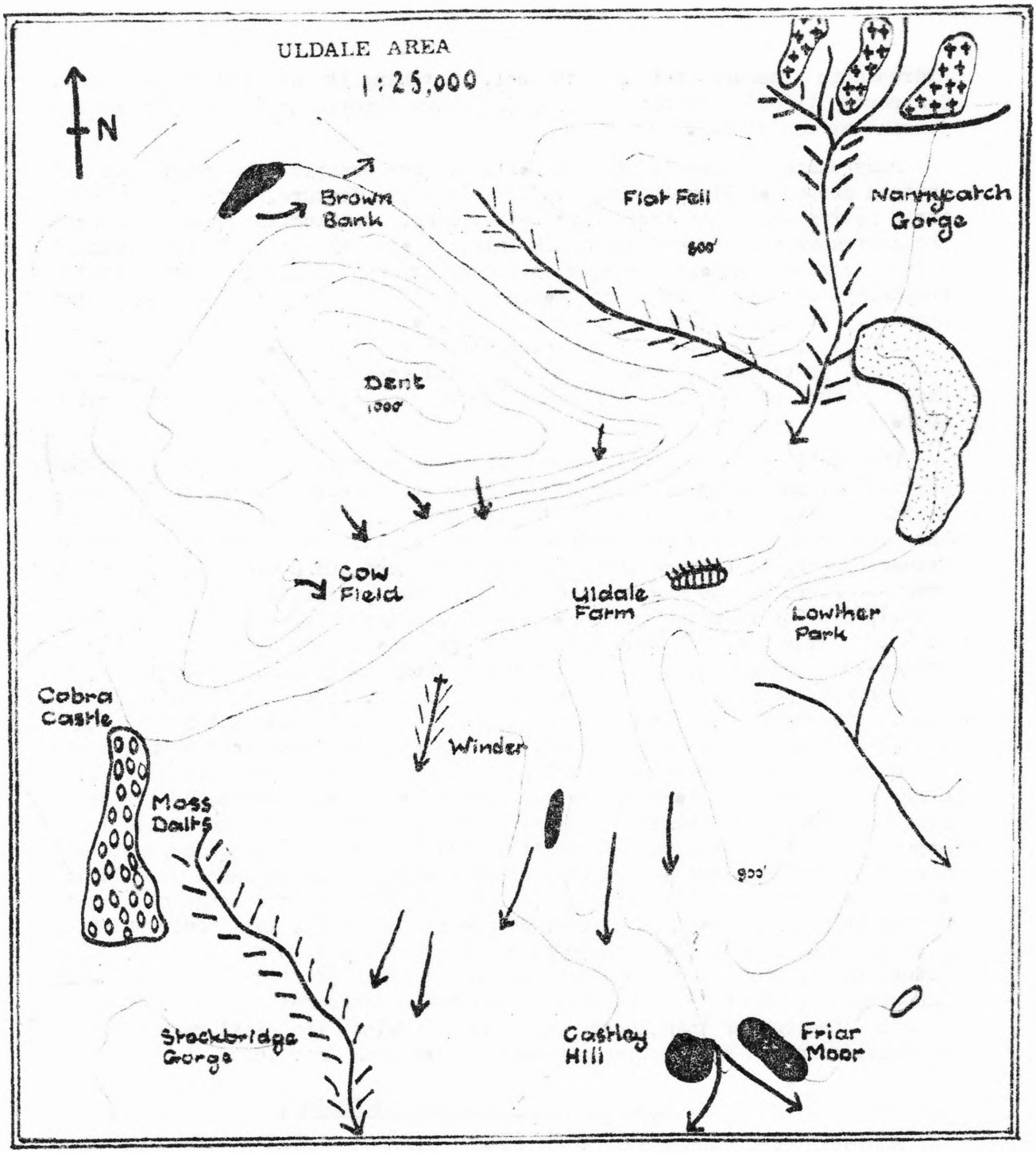



FIGURE 2.

The glacial drainage channels so common in the area have many modes of origin but none is regarded as a glacial lake overflow channel. The Binney-how Carr channel, between Lakeley Raise and Trike, is regarded as a col gully. It is dry, ten metres deep, peat-floored, and cuts across the water-shed at the lowest level. As the ice surface downwasted in the col between the two mountains, the meltwaters under the ice were forced to flow under

hydrostatic pressure through the col, notching it at its lowest point. Clapperton (1966) suggests col gullies were superimposed from former englacial stream courses.

Many channels have a marginal origin, for example the channel on the eastern slopes of Blakeley Raise. It is a small feature, three metres deep three metres wide and forty five metres long, terminating suddenly where the meltwater must have flowed back into, or onto the ice. The dry channel cutting straight across the spur at Winder rises uphill two metres at the beginning of its course, so coming under the class of an up-and-down channel. It has been interpreted as a lake overflow channel (Smith et al., 1931; Shipp, 1963, 1964) but subaerial water cannot flow uphill. It is much more probable as Dixon (1921) suggested for the Leaps Beck up-and-down channel that it was cut by a swift subglacial stream under considerable hydrostatic pressure.

The ice in this area was cut off from its sources to the north-east and north-west, and downmelting proceeded quickly, leaving masses of ice stagnating in situ in the Uldale, Calder and Worm Gill valleys. The ice must have been relatively clean and/or the subglacial and englacial meltwater streams powerful because there are not many sand and gravel spreads in the area. There was no Lagget Lake of the size postulated by Smith et al. (1931), its "overflow" channels being cut subglacially, the finest example of this being the Winder channel mentioned above. The Kirk Beck-Stockbridge-Haile channel system was cut contemporaneously as a subglacial meltwater river and not at different times (see p. 238, Smith et al., 1931). No lake deposits were pointed out by Smith et al. (1931) but Shipp (1964) postulated a large lake in Uldale, utilising the "overflow" channels and "fine-grained lacustrine deposits" as evidence. The large gravel "delta" near Uldale Farm was formed, by the lake hypothesis, because of the overflow waters from Ennerdale depositing sand and gravel in the Uldale lake. Morphologically this gravel deposit is not a delta but is a marginal kame terrace formed against an ice body or in a small marginal lake. At a little over four hundred feet O.D., the terrace is fifty metres long and twenty metres broad, the horizontal surface being due to the lake environment or because the accumulation was controlled by the level of the water table within the ice. The localised fine laminated silts are thought to represent lacustrine sedimentation in small, isolated, ephemeral lakes dammed up in stagnant ice rather than in one large Lake Uldale. The final result of ice stagnation in the area is the hummocky region near Moss Dalts.

## (B) DEGLACIATION OF LOWER ENNERDALE

A glacier-lake Ennerdale much larger than the present lake has been proposed by Dixon (1921), the levels being established from the heights of deltas formed on the northern side of the valley, overlooking the present lake. These are situated at eight hundred feet, an undetermined height well over seven hundred feet (700'+), one somewhat under seven hundred feet (700'-) and six hundred feet according to Dixon, but the eight hundred feet stage is not very clear at all. At Hunter How the deltas seem to have been formed by the now dry channels as they emptied their load into a lake. Further east the other two sets of terraced deltas occur where Croasdale and Gill Becks emerge on the hillside. At Rake Beck north of Bowness Knott

there is only the six hundred foot delta and it is probable that when the lake level stood higher it was covered by ice, although Dixon suggested that it was because the ice front had retreated further east to Rake Beck when the six hundred foot lake extended as far as here. All these deltas have flat tops, steep frontal slopes which are lobate in plan, and the higher ones are kettleholed in places.

According to Smith et al. (1931) no definite outlet for the eight hundred foot lake has been found, although it could lie across Blakeley Moss. The 700'+ lake escaped by a channel east of the Cockhow delta, the 700'- by a channel which bisects that delta and subsequently by a channel to the west of that delta. All these channels converge towards the head of Nannycatch Beck and form the great Nannycatch Gorge. Glacier-lake Ennerdale extended into the head of Merebeck as the northern ice retreated and with further recession a separate lake formed at the site of Meadley Reservoir. This was confluent with water impounded between Dent and Flat Fell when the Nannycatch Gorge was initiated. Glacier-lake Ennerdale drained into it by a series of small channels near Toddle Bank and the Thwaite Hill deltas and Cathow gravels were deposited therein. The waters of the lake escaped via the Nannycatch Gorge.

This explanation can be modified considerably, although there can be no doubt as to the former existence of a marginal lake Ennerdale. The deltas were formed by streams depositing material into the lake which drained into or beneath the ice and whose level was controlled by the englacial water table. Stone (1963) states that "most of the world's ice-dammed lakes probably empty through sub- or englacial tunnels", and the very fact that no overflow channels can be found to correspond with the 800' and 400' lakes must cast doubt on the freely-draining ice-dammed lake explanation. As the ice in Ennerdale downmelted the lake level fell, producing a series of deltas. As the lake became lower it covered a larger area and it is possible that the kames and esker near Stockhow and Bankend were formed in a lake surrounded by dead-ice masses. A 400' level of the lake is indicated by the gravel shelf on which Bowness cottage stands.

The "overflow" channels were cut early in a subglacial environment when the ice was thick. The sand and gravel deposits referred to as being formed in a lake environment probably formed as marginal deposits as the ice downmelted, and the small meltwater channels near Toddle Bank are channels that drained the ice-free land and flowed under the ice. Sand and gravel deposits at Cockhow, formerly regarded as a delta, are interpreted as deposits laid down in a subglacial tunnel. After an aggradational phase, a degradational phase ensued and the deposits were bisected by the eroding meltwater, leaving the deposit divided by a meltwater channel. Near Thwaite Hill there is a whole series of marginal gravel deposits, falling in steps to the well-marked kame terrace near Hazelholme. This terrace has a flat top with a steep ice-contact slope, being ninety metres long and fifteen metres broad. On the western slopes of Dent there are small deposits of gravel formed in a marginal environment, but it is difficult to decide whether they accumulated in small ponded lakelets or against the ice margin itself without the help of sections in the landforms. What is clear is that all these deposits formed between the hillslopes and a progressively downwasting ice mass. Erosional marginal landforms are the small "in-and-out"

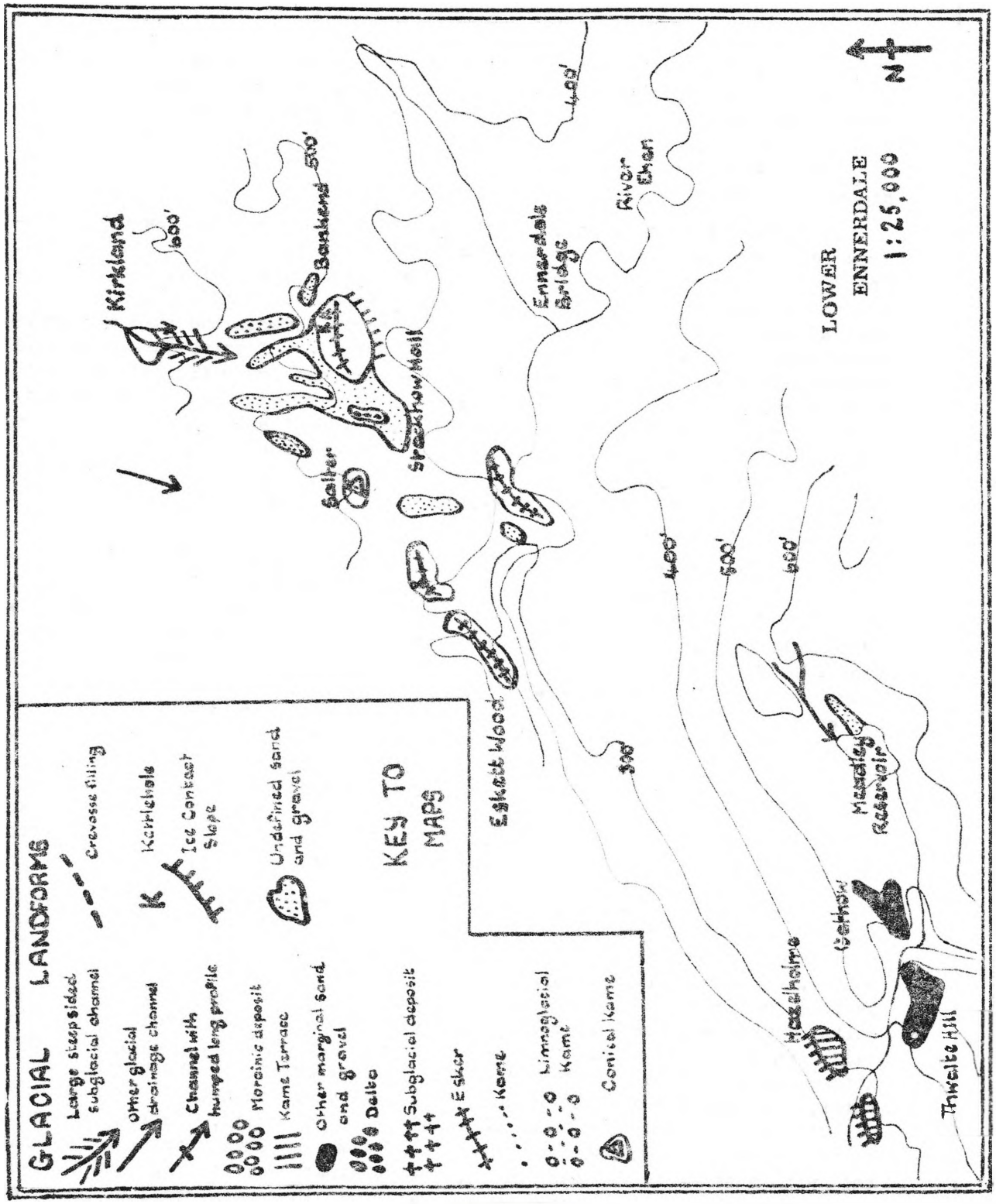



FIGURE 3.

channel east of Cleator Mill near the Flosh, whilst a much larger example occurs two hundred and seventy metres east of Row. After extending southwards for two hundred and fifty metres it leaves the slate and enters the boulder clay, in which it again turns south towards Briscoe Mill.

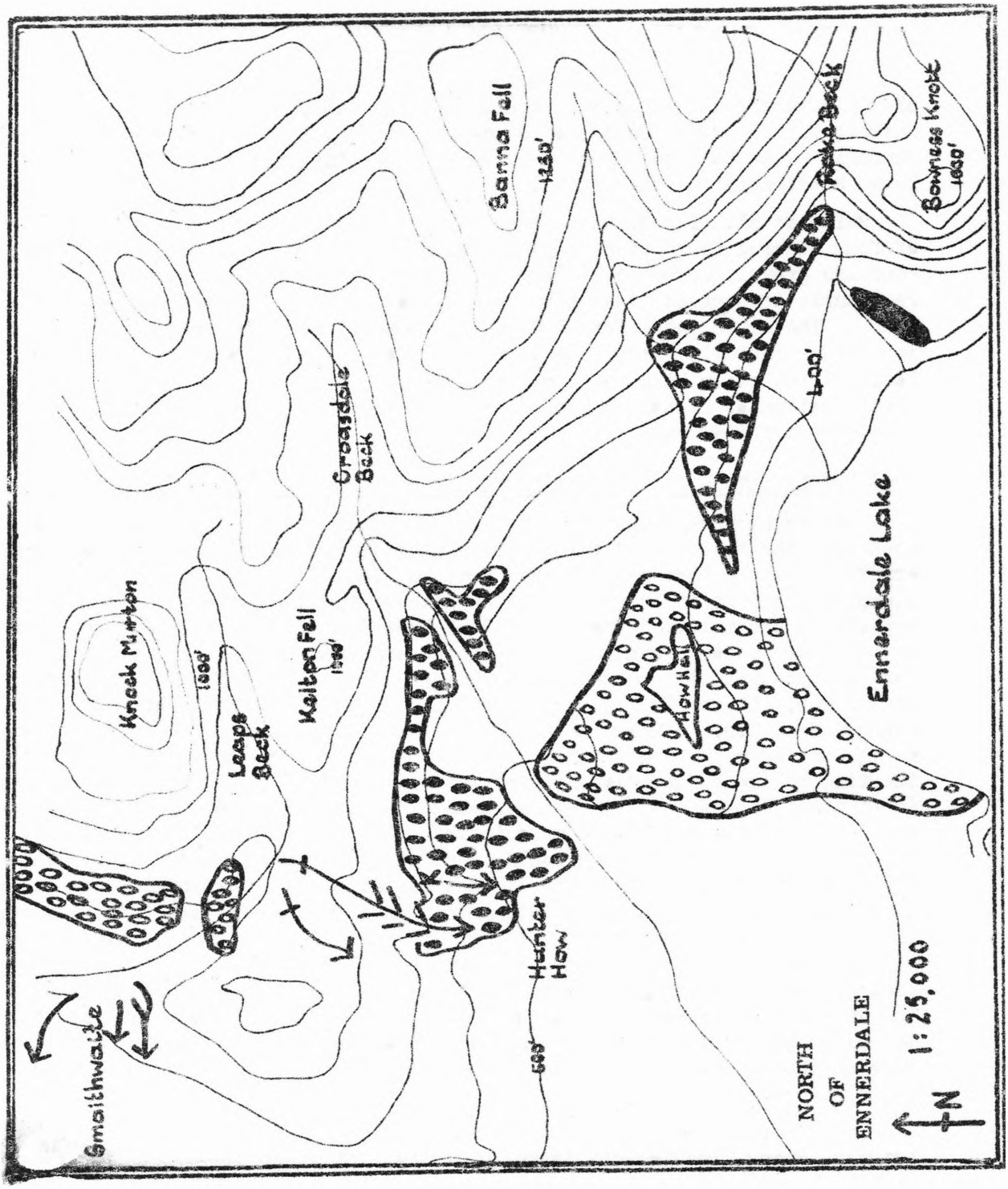



FIGURE 4.

The same complex near Stockhow Hall seems to have been fed by the dry channels south of Kirkland and Thistle Gill which deposited their material in a small lake that was choked by ice, deposition occurring around and over dead-ice blocks. This lake may have formed part of the 400' Lake Ennerdale. The kames are steep-sided, with fairly flat tops having kettles and partly closed depressions which are poorly drained today. A discontinuous esker occurs between Bankend and Eskett Wood. It is rudely and irreg-

ularly stratified, formed in a stagnant ice mass, the gaps in the esker marking places where masses of dead-ice blocked the tunnel or open-walled channel. Near Bankend it has well marked ice-contact slopes and there is a large kettlehole in its surface.

Smith et al. (1931) state that Lower Ennerdale is floored to a height of four hundred feet by an agglomeration of boulder clay, laminated clay, sand and gravel deposited by the retreating northern ice. However it seems reasonable to suggest that the area was occupied by a mass of stagnating ice. The clays were formed in small lakes, the sand and gravel being deposited fluvially either in stagnant ice or in small pools amid the dying ice. On the other hand, a revolutionary idea by Carruthers (1953) suggests the formation of a whole suite of similar glacial deposits by undermelting of a stagnant ice mass.

## (C) DEGLACIATION OF THE AREA BETWEEN ENNERDALE BRIDGE AND MOCKERKIN TARN

Between Mockerkin Tarn and Kirkland there are several types of kamiform scenery, the term "kame" being applied to mounds "composed chiefly of sand or gravel whose form has resulted from original deposition modified by any slumping incident to later melting of glacial ice against or upon which the deposition accumulated" (Holmes 1947). From Mockerkin Tarn to Lanefoot the deposits are almost continuous. These are probably limnoglacial kames formed subaqueously in what Dixon describes as a Lake Pardshaw, as they have steep, lobate fronts and fairly flat tops at a height of about four hundred feet O.D. However he states that "these are doubtfully called deltas on the map because the existence of water standing at that level at the time of their formation has not yet been confirmed". The abundance of ice-contact slopes shows that the sand and gravel was not deposited in an open lake but in intimate association with dead-ice. Kettleholes are frequent and Mockerkin Tarn itself is a fairly large kettlehole lake. Thus the evidence seems to indicate that these deposits are limnoglacial kames laid down in a small lake, existing in a mass of stagnant ice, by fluvioglacial meltwaters depositing their material. However Anderson (1931) states that "when the ice lost its movement the water-table dropped considerably, and every time the meltwater found a lower escape it dropped again. The water-table represents the upper limit of deposition of glaciofluvial material and a flat top developed upon such deposits indicates that they reached the water-table and not necessarily the surface of a lake as one might suppose."

At Mockerkin Tarn a short, steep-sided esker merges into the kame and between Snary and Tedhole Becks a narrow, steep-sided esker-like ridge commences as a spur of the kame and runs westward clear of the main mass. The sinuous crestline links it with typical eskers but its position is that of a distributary of the kame and morphologically it could be called a kame ridge. It is clear that it was formed in stagnant ice, probably in a subglacial tunnel which became choked with material.

Round, isolated kames are found at Foulknott Hill and near Beck. These can be termed conical kames and they were probably formed by a meltwater stream depositing its load in a crevasse or moulin in a dead-ice mass, but why the material and water did not run on into an outlet has never been ex-

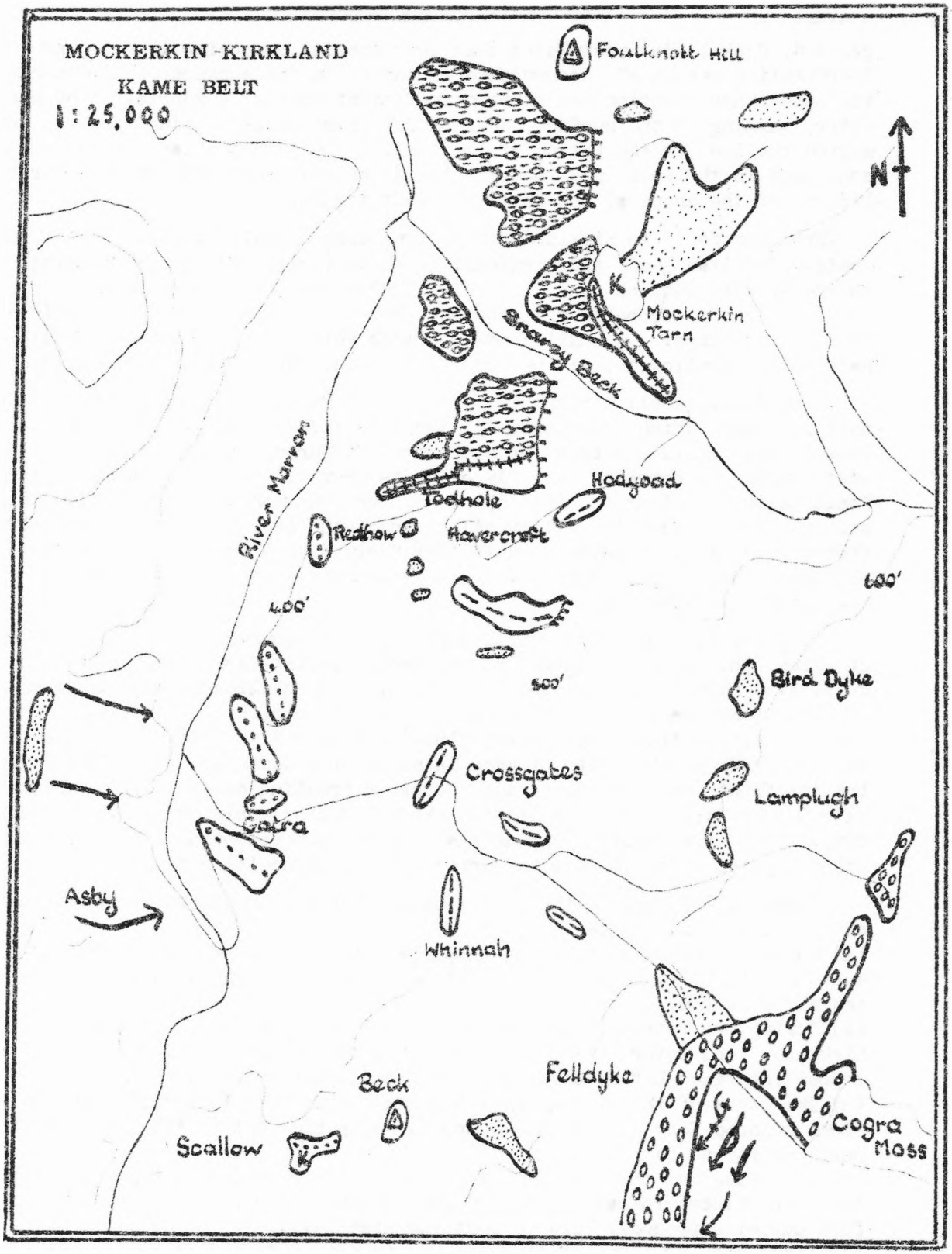

MOCKERKIN-KIRKLAND
KAME BELT
1:25,000
Foulknott Hill
N
K
Mockerkin Tarn
Smarrygill Beck
River Marron
Todhole
Hodyoad
Redhow
Ravercraft
400'
500'
Bird Dyke
Crossgates
Lamplugh
Cogra
Asby
Whinnah
Beck
Felldyke
Scallow
Cogra Moss

FIGURE 5.

plained. Cook (1946) postulated that the material composing these mounds or "perforation deposits" accumulated in pools on the surface of a stagnant ice sheet when ablation had exposed sufficient englacial debris. The pool water, warming at the surface, descended because of increasing density, and melted the ice at the bottom of the pool. In this fashion the material contained in the pool was lowered to the ground in a cone shape - a reflection of the shape of the shaft where it accumulated.

From Lanefoot to Kirkland there are three small isolated kames at Scallow, Kelton Head and Kirkland. Dixon (1921) came to the conclusion that they were outwash fans, in their elongation approaching eskers. However, it is more probable that they accumulated in a stagnant ice margin as crevasse fillings. A small dead-ice block which melted leaving a kettle-hole in the Scallow deposit was the final result of melting in the area.

Near Asby, small streams deposited their loads in channels in a stagnant ice mass which progressively decayed away leaving depressions and kames which contain debris from the Coal Measures, unlike those further east which are composed chiefly of slate gravel. The two channels near Smaithwaite, similar to the Asby ones, are subglacial chutes formed by streams flowing down the valley side beneath the ice. They are straight, five metres wide, running downhill for forty five metres, dry, and cut in Skiddaw Slate. The point where they terminate was the position of the englacial water-table.

South of Kirkland there is a system of interconnected looping channels of which the larger examples are steep-sided, flat-floored, sixteen metres deep, with misfit streams flowing in them. The shallower channels seem to be alternative courses of the larger ones, cut in higher ground, being dry and only five metres deep. Dixon (1921) attributed them to oscillations of the ice front - "the depth of each is apparently a measure of the time that the ice front has lain alongside before retreating or advancing and thus allowing or forcing the stream to take a lower or a higher path." A much simpler and more feasible explanation is the superimposing of an englacial stream system on to the ground surface during downmelting of the ice.

Dixon (1921) came to the following conclusions concerning the sequence of events in this area:-

(a) Towards the end of the glacial period the Lake District ice cap shrank away from the Irish Sea ice sheet along a line which lay along, or west of the River Marron.

(b) During its retreat, the ice cap paused along a line Mockerkin Tarn - Kirkland, and later at the foot of the fells at Lamplugh, at each pause depositing kames but no other form of recessional moraine.

(c) The level of the glacier lake Ennerdale was raised from six hundred to eight hundred feet and the lake spread over the foot of the fells to the north as far as Lamplugh.

(d) The cause of the rise of lake level was a readvance of the Irish Sea ice which closed the outlet of the lake at the lower level (the six hundred foot outlet supposedly between Dent and Flat Fell).

(e) Later the lake level fell by stages to six hundred feet again. Presumably renewed retreat of the Irish Sea ice disclosed successively lower outlets down to that formerly used.

(f) Ennerdale Water is presumably dammed by the drift-apparently a terminal

moraine - deposited by a lobe of Irish Sea ice upon its readvance.

Dixon's first point is most probably wrong but it was substantiated by Smith's (1932) conclusion that the Lake District valley glaciers and the Irish Sea ice cap separated from one another near the lower ends of Eskdale Wasdale and Miterdale. Their views resulted from an insufficient appreciation of ice thinning. The combined Lake District - Irish Sea ice sheet did not split up earlier in the south, with the separation becoming gradually later further north. It is likely that the ice sheet downmelted in situ over most of the region.

Dixon's oscillation or readvance of the Irish Sea ice is proved by the moraine and outwash deposits along the base of the fells, especially near Cogra Moss, by erratics of Carboniferous Limestone, St. Bees Sandstone and Coal Measures material along the western flank of the fells and by the How Hall morainic material at the western end of Ennerdale Lake. The problem is when did it occur and how do we fit it into the general sequence? If it came after the deposition of the Mockerkin-Kirkland kame belt, then these features should show some form of disruption. This is not the case as they are very fresh and show no signs of glacial erosion. A much more probable explanation is that a section of the Irish Sea ice overrode the Lake District ice during an early phase of the general deglaciation. This would account for the features noted above. There would follow a gradual downmelting from this maximum readvance to produce the channels at Smaithwaite, the stagnant ice topography of the Mockerkin Tarn - Kirkland kame belt and the kames, esker and heterogeneous deposits of Lower Ennerdale.

## (D) UPPER ENNERDALE

The main problem here is whether the ice in the valley stagnated in situ or retreated up-valley maintaining an active ice front. There is not much evidence to support either hypothesis but it is thought that the ice, as in Lower Ennerdale, downmelted in situ.

The moraines near the Black Sail Youth Hostel have been ascribed by Manley (1959) to a thin Liza glacier wasting away rapidly in the valley bottom. These are dated to the post-Allerod climatic recession (8800 to 8200 B.C. Zone III).

## CONCLUSION

Much evidence has accumulated in Britain recently showing that the orthodox hypothesis of ice retreat, with associated ice-dammed lakes of large size draining by overflow channels is probably wrong (for example, Sissons 1958, 1960, 1961; Derbyshire 1962; Embleton 1964; Gregory 1962, 1965; Bowen and Gregory 1965.) although there are occasional protagonists of the orthodox view (for example, Jones's Lake Teifi, 1965). The evidence presented in this paper suggests that the orthodox type of glacial retreat with freely-draining ice-dammed lakes, first elaborated by Kendall (1902), is not supported by the facts in the Ennerdale area.

If the ice-dammed lake hypothesis is untenable, it follows that the reconstruction of ice margin positions from 'overflow' channels is probably incorrect also (p. 236, Smith et al., 1931). It is preferable to reconstruct ice-margin positions mainly by attempting to determine the gradient

of the ice-margin from strictly marginal features (Mannerfelt, 1949). Postulated oscillations of an ice margin to explain the Kirkland channels based on the relative heights of the channel on the spur are invalid, for the channels were not necessarily formed in the order in which they now appear on the spur.

In the light of later knowledge it has been possible to re-interpret some of the evidence found in Smith et al. (1931) and Shipp (1963, 1964). It is firmly believed that the sequence of events presented here is correct although after much more thorough fieldwork differences in detail will, no doubt, become apparent. The main ideas which are rejected are that:-
(a) pro-glacial lake Ennerdale overflowed via the Nannycatch channel system
(b) there was a large lake dammed up in Uldale, overflowing across the spur to the south-east
(c) the Lake District and Irish Sea ice sheets split up along the foot of the fells.
The alternative suggestions put forward to replace the old ideas lay great stress on the importance of subglacial and englacial drainage, downmelting, and stagnant ice.

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# The Deglaciation of South-West Cumberland

## A RE-APPRAISAL OF SOME FEATURES IN THE ESKDALE AND BOOTLE AREAS

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The coastal tract of West Cumberland, lying as it does between the Lake District mountains and the sea, afforded an ideal site for the development of glacial landforms moulded at the time of the recession of the ice. Ice from the Lakeland mountains debouched on to the West Cumberland lowlands, particularly down the large westward facing valleys of Ennerdale, Wasdale and Eskdale. There it was under strong pressure from Scottish and Irish Sea ice pushing in from the north and west and, as a result, the combined ice sheet, moving southwards, was pressed hard against many of the westward pointing spurs of high land, overriding many cols and summits in its progress. With the wasting of the ice, great spreads of fluvio-glacial sands, gravels and boulder clays were deposited. Meltwater systems came into existence conveying meltwaters southwards in a multiplicity of channel systems, most of which were abandoned by the post-glacial streams.

A wealth of published detail concerning these meltwater movements, the creation of ice-dammed lakes, the cutting of glacial drainage channels and recession stages in the ice can be found in the literature, particularly in the works of the Survey geologists responsible for the Maryport, Whitehaven and Workington, Gosforth and Furness maps and memoirs. Working and writing in the period between the two world wars, Dixon, Eastwood, Hollingworth, Rose, Bernard Smith, Trotter and others expounded at length both in the Geological Survey literature and in several journal articles[1]. Since then, various other workers have elaborated upon details and indeed several pages of this Society's Proceedings have been taken up with discussions on these topics[3]. It is significant however, that in all this wealth of published detail the same general lines of thought persist, and the interpretations placed on many of these landforms of the deglaciation are the ones propounded by the Geological Survey workers as much as half a century and more ago.

All the published accounts rely heavily in their interpretations on the assumption that most of the glacial channels were formed by the overflowing waters of ice-dammed lakes. Very few ever resort to explanations involving meltwaters flowing under, over or through the ice; the ice being regarded always as an impenetrable barrier or dam. In the West Cumberland literature the whole sequence of the deglaciation hinges on the establishment and subsequent draining of the so-called "Lakes Ennerdale, Wasdale and Eskdale". Having subscribed to this initial assumption, channel systems are made to

fit into sequences which would explain glacier-lake drainage, and ice front positions are deduced largely from the nature of the channel intakes. Evidence to prove the existence of these large ice-dammed lakes is then sought - the greatest weight being placed on the existence of lacustrine and shoreline delta deposits. In many cases, however, it seems likely that such an interpretation would never have been put on to these depositional features if they had not been viewed in the context of lakes.

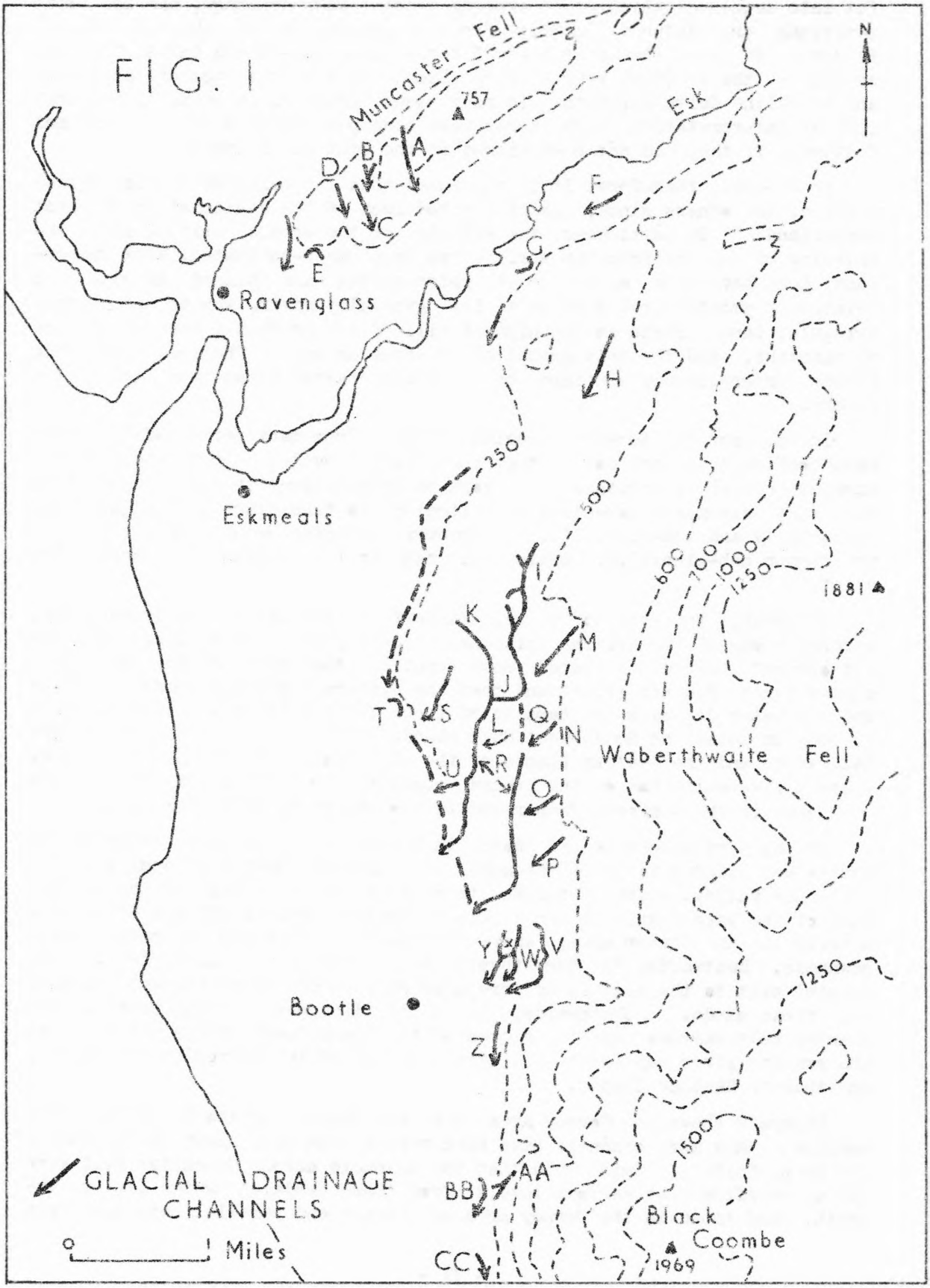
In general, therefore, it is suggested that the early Geological Survey workers, and others since, misinterpreted much of the deglaciation of West Cumberland. In particular the effects of the gradual melting down and thinning of the ice from the surface has been under-estimated. West Cumberland must have seen an ice sheet which melted and thinned in situ - a relatively smooth upper surface of ice gradually giving way to a much more irregular land surface as the highest hills first protruded through the ice as nunataks, and the enlargement of ice-free areas. The ice would then become progressively confined to the lower coastal areas and the valley floors.

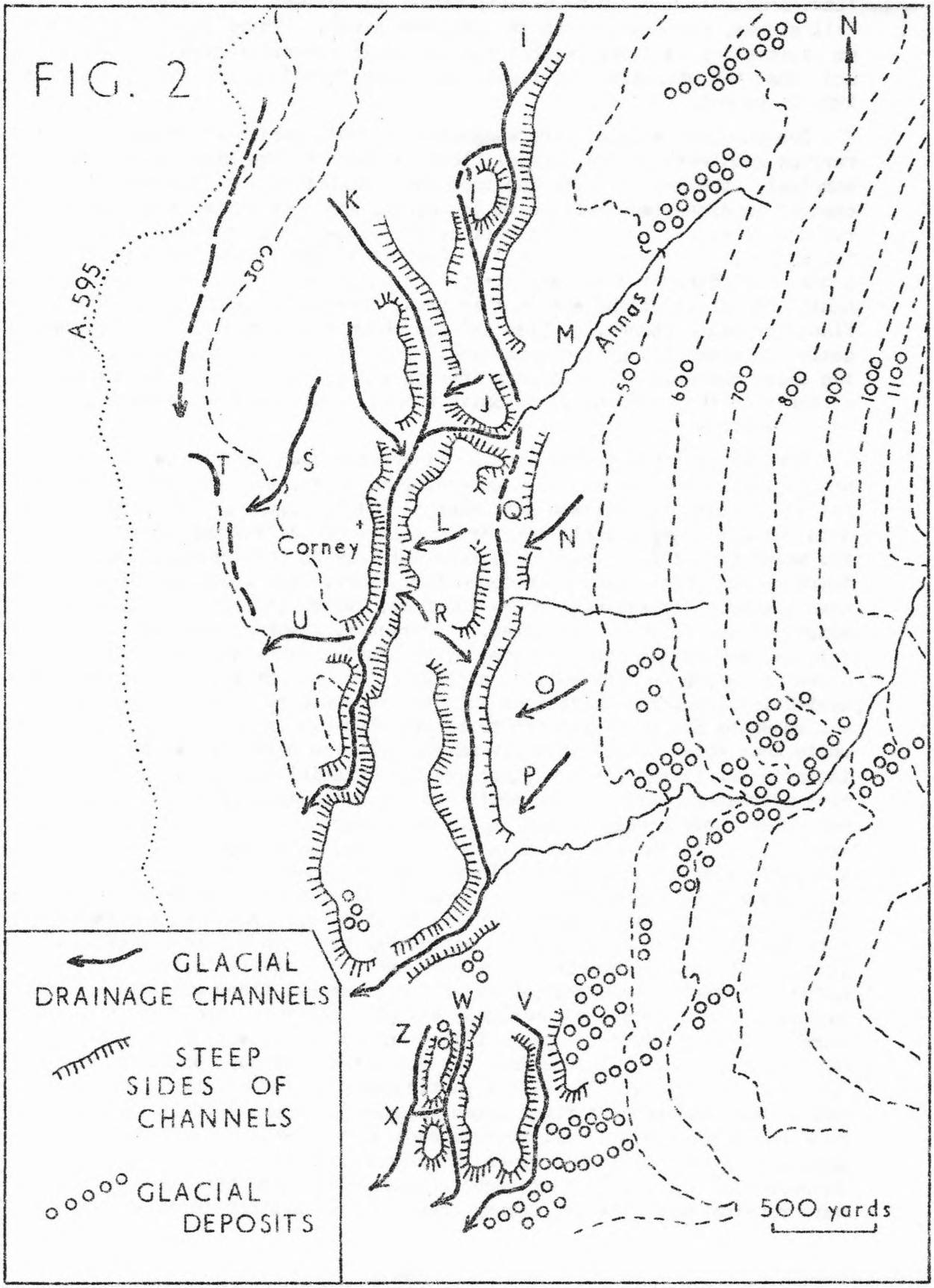
In the last few decades glacial studies from many parts of the world have confirmed beyond doubt that ice seldom provides a complete drainage barrier in such circumstances. Work on areas currently being deglaciated show that extensive movements of meltwater do take place supra-glacially, englacially and sub-glacially. Moreover extensive erosion and deposition are common sub-glacially, particularly near to the margins of a wasting ice sheet.

Following the work of Hoppe, Mannerfelt and others in Scandinavia, several areas of the British Isles have recently been re-examined. Sissons and others[4] have demonstrated most forcibly that many of the large ice-dammed lakes did not exist and that the elaborate glacial channel systems and meltwater deposits are capable of fresh interpretation. I would like to look in detail at South-West Cumberland, particularly at the lower Eskdale area and the western flanks of the Black Coombe fells around Bootle, where a re-examination of the ground suggests a re-evaluation of the work published in the Gosforth Memoir and in two papers by Bernard Smith[5].

The area of attention is shown in figure 1. The long south-west to north-east aligned ridge of Muncaster Fell (Eskdale Granite) dominates the Lower Esk valley. South of the Esk there is a distinct ledge on the seaward face of the Waberthwaite Fells (Eskdale Granite) between 250 and 500 feet - notably in the Corney area, where the ledge is furrowed by many glacial channels. Eastwards, the Waberthwaite Fells rise to over 1,800 feet. The coastal belt to the west is an irregular complex of fluvio-glacial deposits and blown sands. Southwards, the shelf disappears around Bootle, the coastal belt narrows and the slopes of the Black Coombe fells steepen as the granite gives way first to a narrow inlier of the Borrowdale Volcanics, and then to Skiddaw Slates.

Figure 2 shows the Corney Area where the channel system is particularly complex. Many more channels have been mapped than were shown by the Survey and by B. Smith. Smith held that the channels across Muncaster Fell were cut as overflows at various levels from 'Lake Wasdale' which lay to the north, and those in the Corney Area as aligned and parallel sequences from


FIG. 1
Muncaster Fell
757
Esk
N
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
Y
Z
AA
BB
CC
Ravenglass
Eskmeals
250
500
600
700
1000
1250
1881
Waberthwaite Fell
Bootle
1500
Black Coombe
1969
GLACIAL DRAINAGE CHANNELS
0
Miles


FIG. 2
A.595
300
K
I
M
Annas
500
600
700
800
900
1000
1100
N
J
T
S
Corney
L
Q
N
U
R
O
P
GLACIAL DRAINAGE CHANNELS
STEEP SIDES OF CHANNELS
GLACIAL DEPOSITS
W
V
Z
X
500 yards

'Lake Eskdale' and minor lakelets dammed up between the ice and the rising fell slopes, for example, in the Stainton Area[6]. There is nothing in such an explanation to disprove that the ice could not exist higher up the slope and that the channels might well have been formed along the hillside in tunnels beneath the ice.

Sub-marginal origins are suggested in this series of channels by the varying gradients of the channel floors - even if the more gentle ones are marginal, the more steeply inclined ones cannot be. In addition, swift changes in direction, oblique to the slope, and then suddenly down-slope at right angles, are further indications of a sub-glacial origin. The steeper the slope of the ground beneath the ice, the more chance there would be of a stream finding its way down slope and burrowing beneath the ice. This again is clearly borne out in this area, particularly in the south on the flanks of Black Coombe. Sissons[7] has shown that parallel channels can be active subglacially at the same time. In this area it is possible that the two large channels of the Corney Area (K and I) could well have functioned at the same time and not, as Smith showed, only after a recession of the ice westwards.

Several of these points can be elaborated upon if the Corney channels are looked at in more detail. According to Smith, the Barnscar channel (H) fed waters into the Welcome Nook channel (I) ".....the ground between being occupied either by a small lake or by a lobe of ice through or across which the water flowed"[8]. This would seem unlikely on many counts. Apart from there being little ground evidence for a lake, the lower end of the Barnscar channel extends well below 400 feet, which is considerably below the height of the Welcome Nook inlet. Moreover, a sub-glacial origin for the Welcome Nook system is suggested by the dual intakes at its northern end - a feature which is difficult to explain by lake overflow. The Welcome Nook system is also more complicated just to the south of Welcome Nook Farm than was shown by Smith. It has two tributary channels on its western side which unite near their heads in a low marshy col area north of How End (117928), isolating an island feature plastered with glacial material. It is clear that meltwaters were rushing southwards on both sides of this obstacle, the main flow undoubtedly being in the main channel. The flow of the main channel just to the east of this point is also quite striking. It is almost 100 yards wide, has a marshy floor, and it appears to the eye to have a slightly reversed gradient. This point clearly needs checking by careful levelling, preferably supplemented by soundings down to the rock floor beneath, but there is at least a noticeable break in the long profile here. This again is characteristic of a channel cut sub-glacially, where water under hydrostatic pressure can cut reverse channel floor gradients. Smith explains the Welcome Nook channel as being continuous southwards, almost parallel to the contours past Middle and Lower Kinmont for a distance of well over a mile. This channel is far from continuous on the ground when looked at in detail. There is a particularly noticeable break south of the point where the present river Annas crosses the channel (section Q). Again detailed levelling may well prove a section of up-hill gradient. The river Annas, from where it now crosses the channel, continues through what Smith described as the Gillfoot crosscut channel (J)[9] into the other main southward running channel - the Corney channel (K). Another 'cross-cut channel'

at Corney Hall (U) was also noted by Smith[10], this forming an exit westward into a third southerly flowing system, now marked only by vague channel remnants which again suggest that the flow was confined to a sub-glacial tunnel. There are, in fact, two other rather poorly developed 'cross-cut channels' in this system which were not recorded by Smith. They are near Miregrounds (J) and further south to the south-east of Corney Mill (R). A further example of a cross-cut channel (X) was also noted by Smith[11] in a system of channels east of Bootle. With all these channels Smith has great difficulty in finding an explanation, for, as he states: ".....were it not for the transverse valleys at Gillfoot and Corney Hall, there would be nothing inconsistent in the view that the parallel channels Kinmont, Corney and Near Bank were formed during a retreating movement of the ice. The transverse valleys, however, seem to show that different parts of the longitudinal channels were cut at different times"[12].

He finds an acceptable conclusion in a very elaborate series of small advances and retreats of the ice. All these features are easier to accept if a sub-glacial origin is considered. If these channels were cut beneath the edges of the ice sheet, the parallel Kinmont, Corney and Near Bank systems could well have been active together for some of the time. In such a situation, there would be a great tendency for sub-glacial drainage to flow down-slope at right angles to the contours seeking the lower ground to the west. These 'cross-cut channels' must surely represent points where the sub-glacial drainage found these outlets, diverting the southerly flow in the main channels down steeper gradients down-slope beneath the ice. In fact most of this system shows a west-seeking tendency, the ends of both the Kinmont and Corney channels turn westwards at their lower ends suggesting that their waters tunnelled down-slope into the ice. Channels S, V, W and Z also have similar characteristics. It must be in doubt whether these latter channels (V, W and Z) were direct extensions as aligned sequences southwards from the Kinmont system as Smith suggests. The whole system is almost identical with many on the western flanks of the South Pennines, recently described by Johnson[13].

On the fellsides to the east of these channel systems, further evidence suggesting a sub-glacial origin exists. Running down-slope at quite steep angles there are numerous channels (M, N, O, P, AA) which are fine examples of the features described as sub-glacial chutes by Sissons and others[14]. These carried waters from the open fellsides down into the ice. They have steep gradients, are usually slightly oblique to the slope, and frequently end quite abruptly or join into the lower channel systems. A particularly fine example is Tarn Dimples described in detail by Smith who was unable to attempt an interpretation[15]. Many of these chutes formed ready made channels for the post glacial streams. Associated with these chutes are extensive esker-like ridges of glacial debris - for example east of High Corney, in the Kinmont Beck valley below Buckbarrow Bridge, and at North and South Coppyhow on Bootle Fell. Practically all these features relate to deposition near to the margins of the ice and by sub-glacially plunging streams carrying debris down into their ice tunnels with them. These are the so-called sub-glacially engorged eskers.

Finally some attention must be paid to the Muncaster Fell and Lower

Eskdale areas. Muncaster Fell must have emerged as an important nunatak as the ice sheet thinned and downwasted, a fact which presents problems in explaining where any drainage originating on Muncaster Fell fed if it did not go into the ice. There is a series of channels cut across the western end of the fell which Smith has attempted to explain by an involved series of retreats of the ice involving six different still-stand positions[16]. On the south face of the fell he records a series of deposits in the grounds of the Muncaster Castle estate which he describes as 'scale deltas'. Their height and their curious arc and looped shapes did not suggest lake deltas in the true sense, but having established a glacial 'Lake Eskdale' to the south of the fell, Smith was committed to interpreting these features as deltas, although he does admit that some of them were deposited "below the surface of Lake Eskdale"[17]. The true meaning of this is illusive. Again, most of these channels represent gouges made by subglacial streams carrying debris beneath the ice - hence the lack of true deltaic bedding and the irregular shapes caused by deposition in cavities and tunnels beneath the ice. All the Muncaster Fell channels are predominantly on the southern face, falling steeply downslope. They form no obvious sequence, and have no logical continuations. It is an interesting possibility that the highest ones which cut the crest of the fell (A and D particularly) may well be examples of channels superimposed on to the emerging crest of the fell from englacial or supra-glacial streams.

On the south face of Muncaster Fell, channel E is an example of an 'in and out channel'. Other good examples occur at Howbank to the south of the Esk (G) and at Near Bank, west of Corney (T). All these were noted by Smith and the Geological Survey but were always found difficult to interpret in the light of ice retreat stages and sub-aerial drainage. These features are known elsewhere and are usually interpreted as channels cut by meandering sub-glacial streams, and thus further support active drainage under the ice in this area.

Space does not permit further elaboration of detail. There is ample evidence on the ground to substantiate a sub-marginal origin for most of these channel systems described. In other areas in Cumberland several channel systems show similar sub-glacial characteristics. For example, in the area south of Ennerdale the multiple intakes of the Nannycatch system, rapid changes of direction in the channels near the Head of Haile, and the channel patterns in the Castley Hill area are all suspiciously reminiscent of sub-glacial systems*. Further afield, the anastomosing system of channels south of Keswick around Castle Crag, and those north of Ullswater around Dacre and Mell Fell, seem worthy of a second look.

* This subject is dealt with in the preceding article by Mr. D. Huddart.

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   Other papers are number 77, 91, 94, 95, 429, 478, 479, 480, 483 and 486 in the Author's 'Lake District Bibliography', published by the Cumberland Geological Society in 1965.

2. Particularly Kendall, Marr and F.H. Smith:- papers numbered 254, 309 and 488.

3. Cumb. Geol. Soc., Proceedings 2, 1963, pp.14-17; 2, 1964, pp.10-12,25-6

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6. Op. cit., 1912, p. 425.

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10. Ibid., p. 427.

11. Ibid., p. 432.

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14. Op. cit., 1960, 1961.

15. Op. cit., 1912, p. 433.

16. Op. cit., 1937, fig. 15, p. 98.

17. Op. cit., 1932, pp. 66-67.


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# DOLOMITIZATION

## AND THE LOWER CARBONIFEROUS DOLOMITE OF THE MATLOCK AREA, DERBYSHIRE.

By R. Kay, B.Sc.

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The paper deals generally with dolomites; their occurrence and mode of formation, and goes on to deal in more detail with the magnesian limestones of South Derbyshire. Firstly their chemical properties are established and the theoretical processes by which dolomites can be obtained from compounds containing magnesium and calcium ions are ascertained. These processes are then linked to field occurrences of dolomite.

Dolomites appear as pale grey rocks on freshly-exposed surfaces but rapidly weather to a creamy brown colour when exposed to air due to the oxidation of small quantities of ferrous iron. They occur as thick bands and as thin stringers and irregular lenses. Dolomite is the double calcium magnesium carbonate $CaMg(CO_3)_2$ which contains MgO and CaO in the molecular proportions of 1:1 and exists as a crystalline mineral and massive rock. It is not a simple mixture but a definite chemical compound with properties which differ from those of its parent carbonates, e.g., it does not react with cold dilute hydrochloric acid. The magnesium is sometimes replaced by other elements within the crystal lattice such as iron. Some dolomites contain more calcium ions than the strict 1:1 ratio, and a solid solution series between calcite and dolomite probably exists. A similar excess of magnesium ions is also known although less commonly found in nature.

Jamieson thought of dolomite as the end member of two solid solution series, one a mixture of calcium and magnesium ions in planes perpendicular to the z-axis with alternate planes of calcium ions only, the other with alternate planes of magnesium ions only. Under this definition he discussed their equilibrium with a disordered calcium magnesium carbonate solid solution series and postulated formulae from the Gibbs Free Energy of mixing of each phase. There is some agreement with experimental results and it is suggested that with decreasing temperature definite free energy activation energies are required for $MgCO_3$ and $CaCO_3$ to react, i.e., dolomitization of limestone will normally occur only at elevated temperatures. The evidence is not conclusive, however, as it has also been postulated that the necessity of obtaining an ordered arrangement of calcium and magnesium ions at rapid rates of crystallization (or recrystallization) is responsible for the difficulty of producing dolomites at ordinary temperatures. With recrystallization at low temperatures cation ordering may have to take place by surface diffusion rather than by internal rearrangement, thus making dolomite nucleation and growth difficult; dolomite has never been formed by the action of solutions containing magnesium ions on calcium carbonate at ordinary temperatures and pressures in the laboratory, and hence the reaction would appear to be thermodynamically impossible under such conditions.

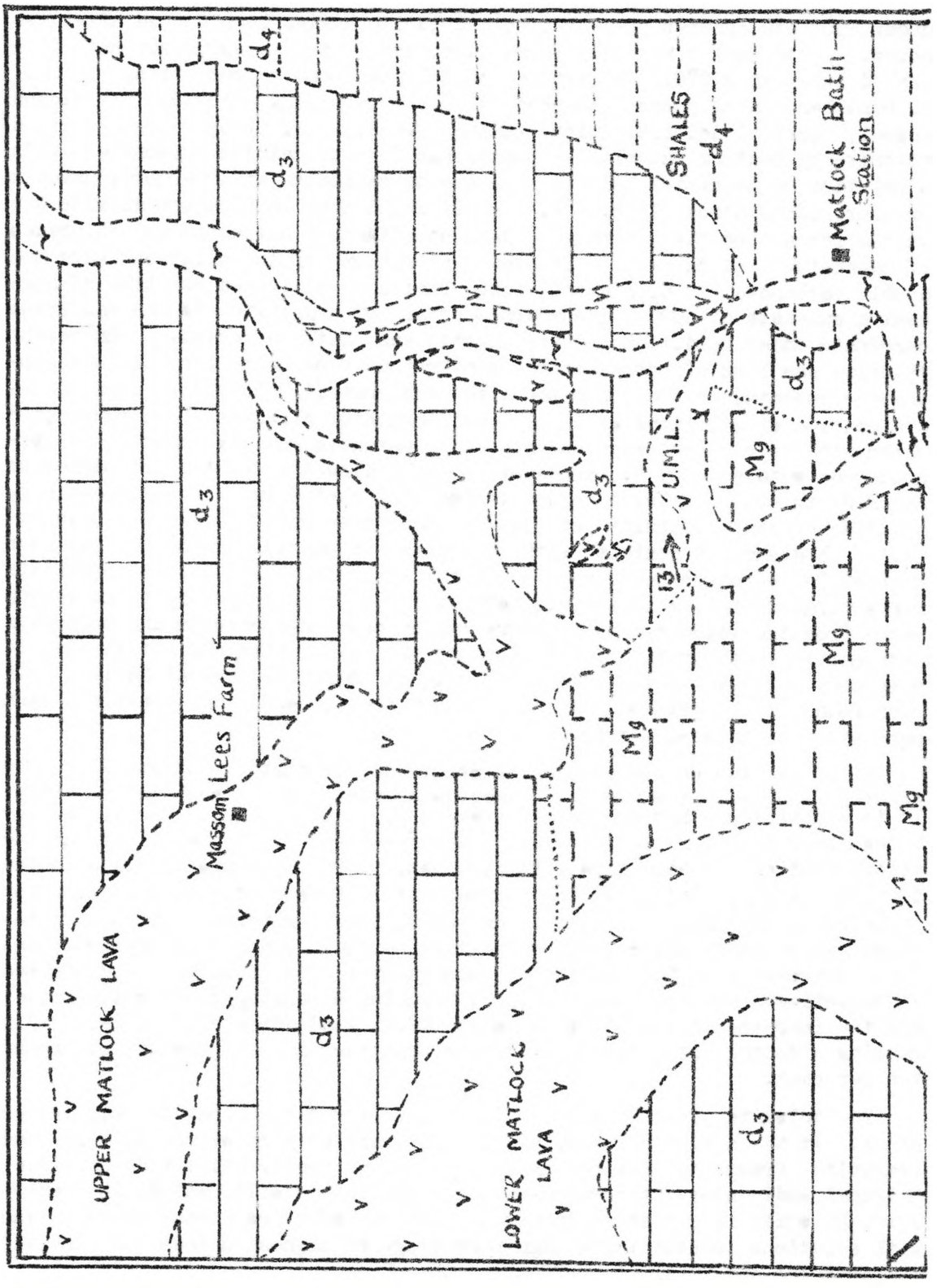
Dolomite has been produced in the laboratory in the following ways: by heating calcium carbonate with a solution of magnesium chloride at 200°C.

under 1500 atmospheres pressure, some dolomite having been formed after two hours. Von Manlet heated calcium carbonate with magnesium sulphate in a sealed tube at 200°C., a mixture of dolomite and gypsum being formed. J. Dunachen heated porous limestone with dry magnesium chloride in a closed vessel, partial dolomitization taking place. K. Spangenberg obtained dolomite by heating vaterite (a monoclinic form of calcium carbonate) with a solution of magnesium chloride and sodium carbonate at 180-200°C. under a pressure of 50 atmospheres. F.W. Pfaff found that when carbon dioxide was passed for a long time through a warm solution of sulphates and chlorides of magnesium and calcium, the slow evaporation of the solution gave the double carbonate. C. Klement found that a concentrated solution of magnesium sulphate at 60°C. transformed coral or aragonite to the magnesium carbonate under conditions where calcite was little affected. Magnesium chloride was less effective in the conversion tending to form the two separate carbonates rather than the mixed carbonate. However, spontaneous evaporation of solutions of calcium and magnesium carbonates in carbonated water with calcium chloride under no circumstances gave dolomite. No dolomite was obtained by F. Happe-Seyler who allowed a solution of magnesium chloride to act on calcium carbonate for many months in a closed container, nor did he obtain dolomite by allowing sea water saturated with carbon dioxide to stand in contact with an excess of calcium carbonate for four months. On the other hand, when sea water was heated with calcium carbonate for several months, dolomite was formed. F. van Gomys-Besery found spring water from the dolomites of the Jura which contained calcium and magnesium carbonates in the ratio 1:1 to deposit the mixed salts and not the double compound. Similarly the warm springs in the Derwent Gorge at Matlock Bath were found to deposit only calcium carbonate although they contain a high percentage of magnesium ions.

There are two possible modes of origin of dolomites; original precipitation from sea water and secondary dolomitization through metasomatism. It is doubtful whether the former process ever takes place. The latter may be considered under two heads; penecontemporaneous dolomitization and dolomitization subsequent to lithification. Penecontemporaneous dolomitization probably accounts for the majority of dolomites, dolomitization probably taking place immediately on deposition. Alternate bands of limestone and dolomite may occur, suggesting periodic changes in physico-chemical environments. Dolomitization subsequent to lithification is evidenced in selective dolomitization, original structures tending to be obliterated, and the increase in density of dolomite (S.G. 2·87) from calcite (S.G.2·71) causing a consequent decrease in volume and increase in porosity of around ten per cent.

The dolomite in the Matlock Area is believed to belong to this latter group. It has a high porosity and is only partially dolomitized, coral and aragonite fragments having presumably been preferentially dolomitized. Original sedimentary structures have generally been obliterated. The Derbyshire Dolomite is almost certainly the product of hydrothermal metasomatism with solutions containing a high percentage of magnesium ions at elevated temperatures and pressures effecting the change:

$$Mg^{++} + 2CaCO_3 = CaMg(CO_3)_2 + Ca^{++}$$




GEOLOGICAL MAP OF THE MATLOCK BATH

AREA SHOWING ZONES OF DOLOMITIZATION.

Dolomite is a low grade metamorphic mineral, confined in the area under consideration largely to a narrow strip between the two Matlock Lavas. It also borders irregularly on adjoining limestone but it is not consistent in its relations to these horizons or to local mineral veins, some of the rocks surrounding mineral veins being dolomitized, some not. Dolomites do not occur in the limestone massif north of Matlock, and their field relations in other parts of South Derbyshire have not been clearly established although knowledge of their field relations (if any) to volcanic and hydrothermal activity would be useful. From field and laboratory evidence it seems likely that dolomitization of the limestone was caused by hydrothermal solutions rich in magnesium ions (though probably containing a low percentage of sulphate ions due to the absence of any gypsum in association with the dolomite). Hydrothermal solutions undoubtedly caused mineralisation of the massif producing veins rich in fluorspar and lead ores. The temperature of these solutions would be sufficiently high to bring about dolomitization assuming a high magnesium ion content (lead and fluorspar are deposited from mineralizing solutions at temperatures between 200 and 300°C.). The absence of dolomite in limestone adjacent to many veins is difficult to explain. The confining effect of the Matlock Lavas, trapping the hydrothermal solutions and perhaps contaminating them with minerals which would catalyse the reactions, may provide an answer to the problem.

Although a process of dolomitization is not difficult to establish, the distribution of secondary dolomite cannot be explained so easily, for the hydrothermal solutions which caused mineralization throughout the massif would be expected to have similar mineral contents in equivalent temperature zones. It could be that the zones of dolomitized limestone were derived from the dolomitization of reef material which is more susceptible to alteration than normal calcite, as has previously been mentioned. This could be the case in Matlock though there is no evidence in adjoining limestone of reef structure, and dolomites nearby at Hapton are not near the edge of the massif and are almost certainly derived from massive limestone. Also this would pose the question as to why the great reefs near Castleton (themselves highly mineralized) are not dolomitized. Indeed the confinement of these secondary dolomites to South Derbyshire is still an open problem.

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Editor's Note

Dolomitization has been reported in association with reefs in the Park Limestone near Millom (C. Nicholas, Proceedings No. 2, 1963, p. 23), although it is absent at the same horizon in the Cartmel area in Furness (C. Nicholas, Proceedings No. 2, 1964, p. 23.)

# MINERALS AND MINERALIZATION

Lecture delivered to the Cumberland Geological Society by the President,

E. H. Shackleton, F.G.S.,

on Tuesday March 7th., 1967 at Whitehaven College of Further Education.

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In introducing my subject of Minerals and Mineralization I must confess that I do it with some temerity, for when one tries to unravel the complexities of the subject, one finds that there seem to be about as many different opinions as there are experts to consult. So, whilst I trust I can provide you with an interesting discourse, I ask your forbearance if I provide you with more questions than answers.

Following my usual practice I would like to devote a little time to the historical side of the subject, for without this one is apt to regard some fresh theory or point of view as a wonderful new contribution when in fact it is merely a rehash of ideas that have long been in circulation.

Firstly we had better have a definition of what is a mineral, and here we have a problem, for the definition depends very much on the person who offers it. In a popular sense almost anything qualifies that is mined or quarried, and this cheerfully includes anything from granite to fluorspar, coal, lead or limestone. The geologist does try to be a little more specific than this, but even he has his difficulties when stating that "A mineral is an inorganic substance with a definite chemical composition and usually a definite crystal structure which, given favourable conditions, produces a regular external form." In giving this definition, he has to allow considerable latitude. Zinc blende when pure, which it rarely is, consists of zinc and sulphur in definite proportions. Often, however, it contains a little cadmium, and far more commonly appreciable amounts of iron; the more iron the darker the blende, but it is still accepted as zinc blende. A further complexity arises when the same chemical substance gives rise to two or more distinct minerals. For instance, carbon is found as diamond and graphite, whilst calcium carbonate can occur as aragonite or as calcite.

Whilst possible combinations and variations seem endless, and something not far short of two thousand minerals have been described, it is still true that a list of two hundred would cover not only all the common ones but also practically all the minerals of economic importance. But here again we are on somewhat shaky ground, for what was useless a short time ago may now be of great importance. Who was particularly interested in beryllium, cadmium, selenium or zirconium a few years ago?

Without bothering his head how minerals came into existence, man has been using them for very much longer than most people think. The searches for minerals, and the struggles to possess them, have greatly influenced the course of history. I suppose the first mineral man mined with a purpose was flint, and underground excavations for this in chalk, as typified by Grimes Graves in Norfolk, date back thousands of years. Perhaps the first large scale mineral industry was the digging of clay for pottery, the beginnings of which go back to Palaeolithic times, and which by Neolithic

times had become almost universal. By 7,000 B.C. man was using at least a dozen different kinds of semi-precious and decorative stones. The ancient Egyptians mined copper and turquoise in Sinai and emeralds on the shore of the Red Sea. By contrast, the diamond finds little mention before 700 B.C. and did not become an article of commerce until about 600 A.D.

Salt played a very significant part in the trade of ancient times and was often a cause of strife. The German salt mines are amongst the oldest mines in Europe and bitter wars were being fought for their possession between the Germanic tribes in the days of the Romans. Metals seem to have attracted primitive man first as ornaments; it is certain that Neolithic man discovered gold as gleaming nuggets in the sands and gravels of streams and its ductility and resistance to tarnish made it one of the most sought-after metals. Copper, which is often found "native" at or near the surface was also used for decoration, although man soon found that it could be hardened by beating and thus fashioned into useful tools. This art was certainly practised by the Chaldeans, 6,500 years ago.

It would seem to be not more than 5,000 years ago that man made the stupendous discovery that some rocks, on heating in a fire, would produce metal. I have often wondered how, when, where and by whom the discovery was made. It may interest the ladies to learn that the beauties of ancient Egypt used powdered malachite as make-up: did some angry beauty of long ago throw her powder jar and its contents on the fire, producing copper? Silver, too, is a soft and easily-worked metal, and the art of shaping silver vessels was well advanced by 2,500 B.C. In the ruins of Hissarlik, the city that later became Troy, lumps of lead were found that must date back at least as far as this. It is on record that the Chinese were using lead to debase their coinage before 2,000 B.C.

It is well known that long before Roman times the Phoenicians came to Cornwall for tin. What is not so commonly known is that in Cornwall, as in Bohemia, tin and copper were often found in close association; smelted together their ores would give the much superior metal branze. It has been established that bronze was in use before 2,000 B.C. Tin, which is never found native, was not smelted from its ores for at least another five hundred years. In a similar way brass was known and used both for ornaments and utensils long before it was realized that the metal was an intimate mixture of copper and zinc. The metal zinc was not discovered until 1509 A.D. but brass bracelets found on the island of Rhodes date back to at least the sixth century B.C.

Iron is really a modern metal but it was known and highly prized, even more so than gold, by the Egyptians some 5,000 years ago. Knife blades made from meteoric iron date back to at least 1350 B.C. but not for another hundred and fifty years did man discover how to make even a spongy iron that could be beaten into shape. To smelt the metal so that it could be poured and cast needs temperatures approaching 1,500°C. and this was beyond our early ancestors.

The lure of mineral wealth has coloured history for thousands of years, and I think it is true to say that civilization has advanced along with metallurgical skill. Egypt came to the height of her wealth and power under Amenhotep III about 1,400 B.C. when her exploitation of minerals and metals

was at its height - gold from the mines of Nubia, copper and turquoise from Sinai, emeralds from the Red Sea and lapis lazuli from Afghanistan. It was the search for metals that led the Cretans, and later the Phoenicians, to dominate the Mediterranean for nearly two thousand years before the Christian era. The power of Tyre was founded upon the mineral wealth of Spain. The Carthaginians, following their Phoenician ancestors, used the silver of Andalusia to hire mercenaries to fight their Punic Wars with Rome, and when they lost, their power declined. It was the possession of these Andalusian silver mines which led to the long struggle between Carthage and Rome, for the Romans wanted the silver both for currency and for trade with the East.

The prosperity of Greece during the Golden Age was founded not on gold, but on the exploitation of the silver mines of Laurium. "Laurium was a fountain running silver, a treasure in the land", sang one of the ancient Greek poets. It was this silver that enabled Themistocles to build the fleet with which he defeated the Persians at the famous battle of Salamis in 480 B.C., whereby the Mediterranean was saved from domination by the Persians. Some hundred and fifty years later the gold of Mount Pangaeus in Macedonia enabled Alexander the Great to conquer the then known world. If the Roman Empire was gained largely by the sword it was maintained by the flow of mineral wealth from the tributary lands. By defeating Carthage she obtained the gold, silver, copper, iron and mercury of Spain. By conquering Britain she acquired the copper and tin of Cornwall, the lead of Somerset and Alston Moor. Gradually, from one cause and another, these supplies dwindled, her great trade with the East was lost and the decline and fall of Rome followed.

For at least four hundred years the Dark Ages covered Europe and nothing is heard until Charlemagne began to exploit the gold, silver and lead of Central Europe. In the tenth century the conquests of Otto the Great were financed by the discovery of the rich silver veins of Goslar in the Harz Mountains. The Harz Mountains were the cradle of modern mining. Around 1170 Saxon miners from this area led a migration eastwards to the mineral field of Freiberg. The expanding output from these mines assured Germany of a commercial supremacy throughout mediaeval times.

It was partly the search for precious metals that led Columbus westward in search of a new route to the East. Some twenty years later Cortes led his conquistadores to the "Rape of Mexico" and Montezuma's wealth. These expeditions culminated in Pizarro's conquest of Peru and the discovery of the fabulous silver veins of Potosi. Upon these riches was founded the might of Spain until the piratical efforts of the "Dogs of Devon" brought the flow almost to a standstill. If this impoverished Spain, the diverted wealth helped Elizabeth to build the navy which in 1588 defeated the Armada. It was during Elizabeth's reign that the rejuvenation of mining began in England, and we all know that much of this effort was centred in and around Keswick.

When Daniell Heckstetter of Keswick died in 1581 an inventory of his effects was made, and amongst these was a treatise upon mines and mining by Georges Agricola of Augsburg (1494-1555). Besides much practical information on the working of mines and the assaying and smelting of ores, this work contained a discussion on the nature and origin of mineral veins. As

far as I know, Agricola was the first man to put into writing a reasoned theory of the origin of ore deposits. "Ore veins" he said "originated by the deposition of minerals from solution in erosion channels." The "juices" were assumed to have been formed from surface water which had seeped down to great depths and, under the influence of heat, had taken the minerals into solution.

From the time of Agricola to the late 1700's practically all writers on the subjects of mining and minerals were German, and we must not forget that even in Elizabeth's day, Germany already had a flourishing School of Mines. Becher and Henkel writing in the early 1700's attributed the origin of veins to the action on pre-existing stony matter of subterranean vapours which arose from "fermentations" in the bowels of the earth. In 1749 Zimmerman ascribed veins to the transformation brought about by the action of solvents, particularly when heated, which found their way through cracks and crevices in the rocks. Fissures, according to him, had no part to play in the process. J.D. Kendall, writing in the 1890's, had much the same idea, being very insistent that veins were not infilled fissures. Nevertheless, von Oppel writing in 1749 showed that veins were often filled faults.

Gerhard, in 1781, thought that waters circulating in the rocks adjacent to veins became charged with metallic and earthy substances and, passing through minute crevices, deposited their burden in the fissures to form veins. This is, of course, the forerunner of the present-day "Lateral Secretionist" theory.

At the end of the eighteenth century all geological thought was dominated by the Neptunist Theory of the famous Freiberg professor, Abraham Gottlob Werner. According to him all the rocks of the earth's crust had been secreted in succession from the primeval ocean as precipitates. Veins he said were simply pre-existing fissures filled by minerals which had been deposited from the all-pervading ocean. These views were attacked and overthrown by James Hutton and his Plutonist School. "The minerals that fill veins" wrote Playfair "have been melted by heat and forcibly injected into clefts and fissures." If for a time the Plutonists carried all before them a reaction set in and the current of opinion swung once more in favour of deposition from waters which, descending from the surface, picked up heat and metals to fill the veins. Discussion waxwd fast and furious for upwards of half a century on the respective merits of the Ascentionist, Descentionist and Lateral Secretionist theories. Was the mineral burden carried down from the surface rocks, was it concentrated from rocks adjacent to veins, or did it come from deep-seated sources?

The Lateral Secretionist theory was ably expounded by Bischof in the mid-1800's, and he was well supported by Dieulafait. However, the results of practical work in the Przibram area of Bohemia and amongst the lead-zinc veins of Saxony failed to bear out the thesis. The work was taken up by von Beust and Scheerer who were convinced that all these veins had been filled by thermal solutions bringing up mineral matter from below. Another school, whilst agreeing with this, argued that ground water descended by capillarity to great depths, thus acquiring high temperatures and pressures and a vastly increased solvent power when passing through the rocks and

taking up mineral matter. Moving laterally these solutions would ultimately find open conduits where on a fall of temperature and pressure the minerals would be deposited.

In my time such geologists as Vogt, Lindgren, Spurr and Rastall have maintained that at least some mineral deposits are the direct result of magmatic segregation prior to and during consolidation. They are the people who have advocated the important role to be played by "Mineralizers" such as fluorine, chlorine, sulphur, phosphorus, silica and boron. Whilst these elements can form volatile compounds with the metals it is still considered that water is all-important as the agent of ore concentration. Separating from the silica melt as the magma cools these thermal waters pick up the elements that are more soluble in water than in the melt. Suess, in 1902, drew attention to the connection between hot springs, vulcanicity and ore deposits. He it was who coined the term "Juvenile" for waters coming from the depths of the crust. These, he pointed out, were the last survivors of vulcanicity. They usually contain soluble compounds of the alkali metals together with compounds of sulphur, chlorine and carbon dioxide, the less soluble metal compounds having already been deposited at lower depths.

Although many of the ideas mentioned and discussed in the preceding paragraphs can be fitted to particular circumstances, it would seem that even after hundreds of years of investigation and reasoned argument there is as yet no general theory sufficiently flexible to cover all aspects of mineralization.

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After an adjournment for refreshments, the lecture was continued with the President showing slides to illustrate the connection of mineral fields with several types of igneous intrusion, referring to the Bushveld in South Africa, Kiruna in Sweden, Cornwall, the North Pennines and the Lake District. The President pointed out that much expensive foreign ore was being imported whilst our home deposits, although much exploited and depleted in the past, have manifestly not had their potential fully explored. Turning from economic considerations to more fundamentally scientific arguments, the President outlined, with the aid of well-chosen slides, some of the possible means by which certain elements, in some cases occurring as only a fraction of a percent in the earth's crust, have been formed as minerals and concentrated into workable deposits.

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## THE ANNUAL DINNER

Held at the Miota Restaurant on Friday, March 10th., 1967.

The Guests of Honour were Dr. and Mrs. A. G. Lunn of the University of Newcastle upon Tyne. Dr. Lunn, stating that he was a geomorphologist rather than a geologist, expressed pleasure in noting the continued progress of the Society. He stated that he was concerned to preserve the natural history of the country, many aspects of which are in danger of being eroded and destroyed by man's activities. He was anxious, he said, to make the public aware of its heritage, and in this such societies as the Cumberland Geological Society are playing an important part.

At the Dinner the first Charles Edmonds Memorial Prize was presented to Mr. Clive Nicholas, who, as a postgraduate student, made a special study of the Carboniferous Limestone - on which Charles Edmonds was a recognised international authority. At present Mr. Nicholas is employed as geologist to the United Steel Companies' mines in the Egremont area, the area where the man the prize commemorates started work well over half a century ago.

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## EXCURSION TO THE ELTERWATER DIVISION OF THE BROUGHTON MOOR GREEN SLATE QUARRIES, WESTMORLAND.

Thursday 30th. March, 1967. Director: Mr. Baines.

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Twenty three members of the Society visited the cutting and polishing sheds at Elterwater, and the nearby Spout Crag Quarry. We were shown round by Mr. Baines who was in charge of production. Mr. Baines claimed that the slate is superior to and harder than the Honister Stone, and much better than the Norwegian Stone which had been used at Keswick Police Station in the 1930's and which was now having to be replaced.

Labour at the quarries and cutting sheds was reasonably easy to obtain, although it was claimed that the stone was being sold cheaply in view of the fact that wages had risen at least fourfold whilst best roofing slate was being sold at rather less than three times its pre-war price.

The stone is used as roofing slates, cladding, dry wall construction, flooring and crazy paving. A recently erected show house at the works demonstrates these various uses. The stone is either cut and polished or riven, i.e., split, and left with a natural rough surface. Production is running at the rate of 140 tons of riven stone a month, and 300 tons of polished stone. Only about 20% of the material in the quarry is actually used, the remainder is dumped as waste.

The excursion party walked up to the Spout Crag Quarry which is about a mile from the main works. There are several quarries in the immediate vicinity in the 2000 feet or so thickness of Ordovician Slate, but only two are being worked at present. The main methods of winning the slate were explained; blasting with black powder, and wire rope sawing.

The slate appears to have originated as a fine volcanic mud on the bed of some early sea, cemented into a solid mass with a typically sedimentary stratification. Subsequent earth movements have left the deposits with a general N.E. dip of about 40° in this area, and considerable lateral pressure associated with mountain building movements has induced slaty cleavage genarally at a steep angle to the bedding.

The party returned to the cutting sheds at Elterwater, and after watching demonstrations of cutting, polishing and riving, thanked the representative of the Broughton Moor Green Slate Company for making possible such an interesting visit.

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VISIT TO MILLYEAT, NEAR FRIZINGTON, TO INVESTIGATE THE SPIRORBIS LIMESTONE

Saturday, 13th. May, 1967 Director: H. Bland.

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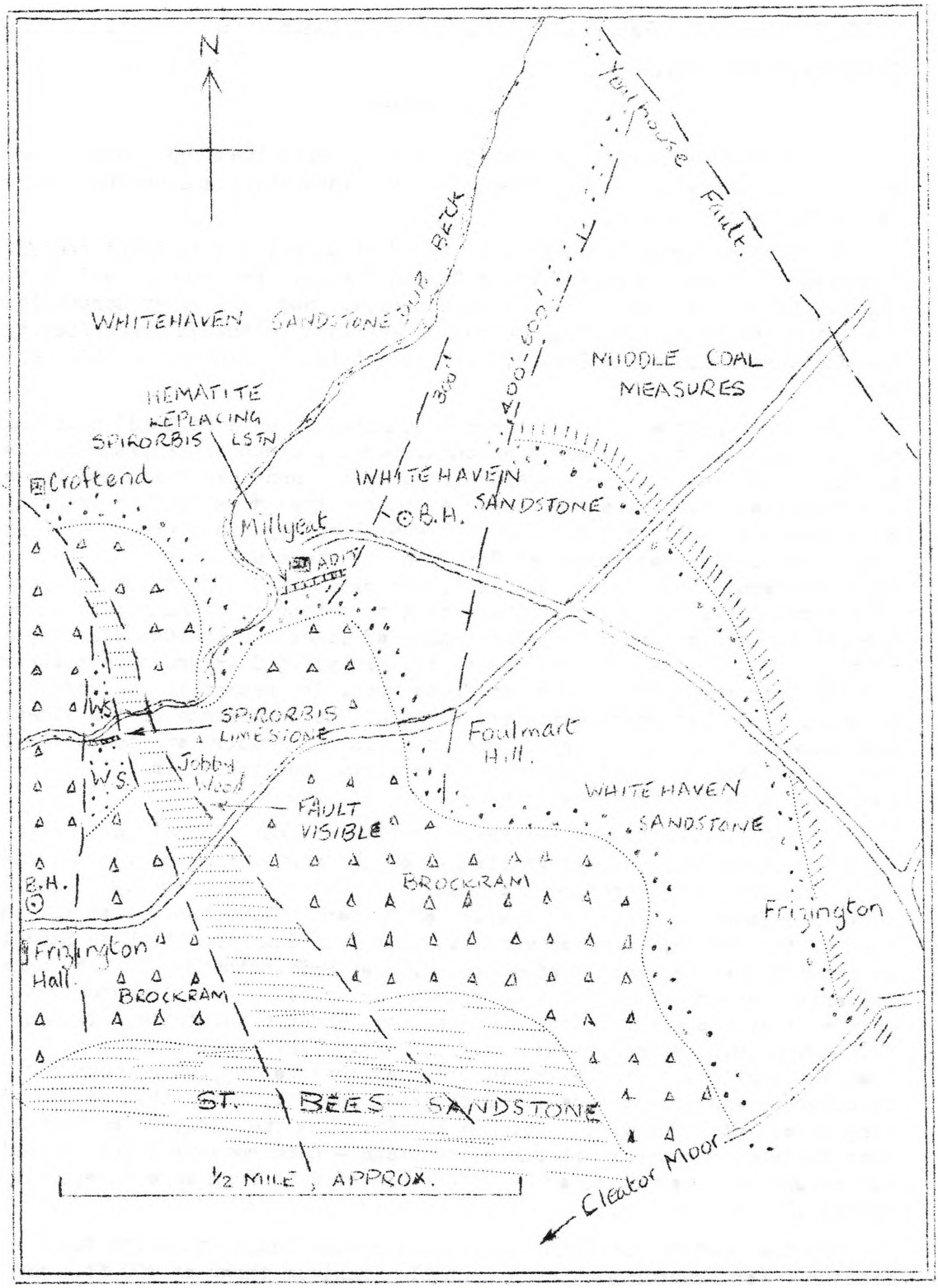
Eleven Members turned up for this visit, which was made under very wet weather conditions. The geology of the locality is described in the following paragraphs.

The Carboniferous formations in the West Cumberland district consist of limestones and shales of the Lower Carboniferous, followed by a thin shaly representative of the Millstone Grit Series, and the Upper Carboniferous consisting of productive Coal Measures overlain with some unconformity by the Whitehaven Sandstone Series, having a total thickness of 700 feet or more.

The lower part of the Whitehaven Sandstone, as developed near Whitehaven, consists chiefly of sandstones, purple, brown or greyish in colour, but higher in the sequence shales predominate and thin coals and bands of limestones occur. Two thin bands of these limestones with spirorbis and ostracods were first noted in the Millyeat locality in a borehole at Frizington Hall, these occurring at depths of 115 feet and 263 feet. The upper band was found to outcrop on the south side of Dub Beck, north-east of Frizington Hall. At Millyeat there is a thin deposit of haematite which is thought to have replaced the higher band of limestone (metasomatic replacement). The shales associated with the ore yielded Anthracomya phillipsi, but the Spirorbis annelid was not found here. The haematite was worked from an adit, traces of which can still be seen. The occurrence of the limestone and haematite are noted by T. Eastwood in the Memoir of the Geological Survey (Whitehaven and Workington District) published in 1931, and the following details from that publication are relevant.

"In that stream (Dub Beck) between Millyeat and Weddicar Hall there are repeated exposures, due to faulting, of the higher beds of the Whitehaven Sandstone Series beneath the Brockram. These beds are mostly of shale of various colours. The best exposure of Spirorbis Limestone is on the south side of the stream, west of a fault that lets down the St. Bees Sandstone at a point about a quarter of a mile N.E. of Frizington Hall. The annelid Spirorbis occurs here, but sparingly as usual. The limestone varies from a cream to a purple tint and appears about 6 in. thick, though the Frizington Hall boring proved a bed of 3 ft. 9 in. in thickness at 115 ft. from the surface. The lower limestone of that boring, which does not come to outcrop, was a white bed 1 ft. thick at 263 ft., three thin coals occurring below at 298 ft., 317 ft. and 407 ft. from the surface respectively. Near Millyeat the upper Spirorbis limestone - here converted into haematite and at one time worked as ore - though expected to form an outcrop, is not visible." (It now is.)

"To the east of Millyeat there is a trough fault in which the western fracture (or fractures) has a probable maximum throw of 300 ft. and the eastern one of at least 400 ft. and possibly as much as 600 ft. The Millyeat boring was put down in this trough. The upper Spirorbis limestone is not recorded, but the lower bed, 2 ft. in thickness was encountered at




SPIRORBIS LIMESTONE MILLYEAT CUMBERLAND

343 ft. This borehole was put down to 618 ft. (all in Whitehaven Sandstone Series) without bottoming the series, neither were any coal seams recorded".

Although, apparently, the outcrop of haematised limestone was not visible at the time of the Geological Survey, an exposure can now be seen in the south bank of a stream on the west side of the old adit which is now filled in. Good samples of the ore and partially haematised rock can also be picked up from the stream below the exposure. The thickness of the best ore at the exposure is only 3"-4", set amidst grey and reddish shales or marls. The Spirorbis band is not visible at the western side of the trough fault, neither is the fault plane itself visible in the stream. The top Spirorbis band, not recorded in the Millyeat borehole, would be expected in the trough at about 200 ft. from the surface. Perhaps it has thinned out at this point, or it may have been missed due to the borehole being in faulted ground.

The Whitehaven Sandstone Series exposed further up the stream consist of variously coloured marls and shales forming the higher beds of the Series. Two small 2" seams of coal occur. Higher still up the stream, nearer Foulmart Hill but still apparently within the south-east side of the trough, purple-red sandstone forms the bed of the stream. This seems to be above the shales and coal seams, but this point will require further investigation.

The other section of Spirorbis Limestone mentioned in the Geological Survey as being 6" thick on the south side of Dub Beck, N.E. of Frizington Hall, does not now appear to be visible. Probably the ground surface has slumped and covered the exposure during the last 40 years or so. One piece of weathered limestone was, however, picked up from the surface in this vicinity and in appearance it tallies with the description of the Spirorbis Limestone.

The wedge of St. Bees Sandstone trough faulted between Rheda and Croft End is interesting. The eastern fault plane is visible in the ghyll at the top of Jobby Ghyll Wood.

The exposures of the Brockram here and on both sides of Dub Beck at the old weir below Millyeat are particularly fine, and passage from Whitehaven Sandstone to the Brockram is visible a few yards above the weir. The various fragments included in the Brockram are of interest, including limestone and pieces of what appear to be Ennerdale Granophyre.

H.B.

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## EXCURSION TO DEVOKE WATER AND THE WATER CRAG GREISEN

Sunday 11th. June, 1967. Director: M.F. Burton.

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Devoke Water lies partly on the junction of the Eskdale Granite with the Borrowdale Volcanic Series. This area of the granite mass reveals exposures exhibiting "end-stage" features of the final consolidation of the granite magma, along with micro-granites, granite porphyries and similar marginal facies.

The excursion party met at Eskdale Green and proceeded by car over Birker Moor to the Waberthwaite footpath signpost, where the vehicles were parked. From there they made their way towards the lake, avoiding the marshy ground on its shore by going westwards over higher ground towards Water Crag which lies to the north-west.

En route the party intended to examine the "Quartz-sericite rock", but its exact location was missed on this trip. The whitish, granular quartz sericite was however observed from the south side of the water on the return journey. This rock is comprised only of quartz and sericite, the latter mineral being the final alteration product of a feldspar formed during the hydrothermal stage of the residual magma. F.W. Clarke has explained the production of sericite from orthoclase by the operation of high temperature, chemical activity of water (hydrolysis) and mechanical stress acting together, resulting in the production of muscovite, free quartz, and the leaching out of potassium silicate. In the case of plagioclase Clarke gives a formula which, however, is not proved. Sericitization of orthoclase could be illustrated by the equation:-

$$3KAlSi_3O_8 + H_2O = KAl_2(Si_4Al)O_{10}(OH)_2 + 5SiO_2 + K_2SiO_3$$

Taking into account its position in the field, it is difficult to imagine that stress played a major part in the formation of the Devoke Water quartz sericite rock. The writer would not like at this point to give an opinion of what quantity of free silica in this mass was derived directly from alteration of the feldspars as mentioned above, and how much, if any, was deposited from an earlier magmatic source.

The party proceeded further westwards towards the summit of Water Crag. This is bounded eastward by a fault cliff marking the Devoke Water Fault which has a N.N.W.-S.S.E. strike. This dextral wrench fault (Firman 1960) has displaced a small pocket of granite to the south side of the water which was visited later by the excursion party.

The exposure of greisen could be seen in the rocks on the summit of Water Crag and was more in evidence on the lower south-west slope. Several members of the party obtained contact specimens of the Eskdale Granite with the B.V.S. and collected specimens from the lens of hornfelsed Skiddaw Slate also on the Crag. The greisen is conspicuous in the field by its brilliant milky-white colour. It has a splintery fracture and it appears in general to be allotriomorphic, although members found the occasional crystal faces in one or two of the boulders examined. These crystals were of the same colour as the mass itself and may be of topaz. Simpson mentions

the presence of andalusite and rare fluorspar in addition to the main constituents of quartz and topaz. Pinkish inclusions were noticed in the rock and these could well be crystals of andalusite filled with haematite or fine dust. Simpson gives the specific gravity of the greisen as 2·88. A sample taken from the lower part of the exposure by the writer had a specific gravity of 3·02. This figure should be compared with the specific gravities of granite, 2·7; quartz, 2·65 and topaz, 3·5-3·6.

By its composition and mode of occurrence the exposure suggests that it is metasomatic and possibly pneumatolytic in origin. This type of greisen is developed extensively in only a few areas, and usually extends only a short distance from the granite mass. Topaz is an almost constant accessory and in some specimens is an important constituent. The end product of this line of variation is a topaz-quartz rock in which the former occupies nine-tenths of the mass. This has been termed a "topazfels" and can be found in the tin mining area of Erzgebirge in Saxony.

The quartz-mica greisen of Grainsgill in the Carrock Fell area of Cumberland is of a different type. This much larger body of greisen occurs as an apophysis of the main granite mass. In a comparative analysis with the Skiddaw Granite it has been found to contain a much larger amount of silica than could be attributed to hydrothermal action. It has been suggested that the greisen crystallized from a particularly acid fraction of the magma which was separated from the main granite and driven northwards by a sort of filter-press action. As the greisen yields evidence of the replacement of the original feldspars, however, it is probable that two processes have been involved: firstly, differentiation of the magma as mentioned above, and secondly deuteric alteration by an active residuum.

With further reference to the andalusite in the Water Crag greisen, it would be expected that this mineral would normally occur as a product of the assimilation of argillaceous material. However, the pure whiteness of the greisen and the absence of any extensive dark inclusions points away from the idea that pelitic material could have been captured. It has been suggested that the andalusite arose through the break-up of aluminium halides, alkali aluminates and similar compounds contained in the residual portions of the granite magma. In this respect, reference has been made to the sillimanite-bearing granites of the Strath Hallidale Complex and to certain muscovite-sillimanite veins in the Loch Choire Complex. In these mafic-poor rocks the necessary aluminium would seem to have been supplied from the residuum.

Following lunch in the warm sun at the foot of Water Crag, the party moved round the western end of the lake. After crossing Linbeck Gill which drains Devoke Water into the Esk through a "green" granite (Simpson 1934), the andesites altered by the granite mass were traversed. A specimen from this area showed conspicuous spots of epidote. This was the best example of epidotization observed on this journey round the lake.

The "cake" of granite (Green 1917) displaced by the Devoke Water Fault was located by the party as lying roughly between two becks on the south side of the water. This thin sheet of granite lies on top of the andesite, the underlying andesite being exposed in Rigg Beck, the second of the two streams visited. A sample of rock was taken from this beck which could

only have been a metre or so below the sole of the granite (Green 1917), and was found to be a porphyritic augite-andesite without a trace of thermal action. This fact proves that the junction here must have been a fault.

The excursion party, after resting at Rigg Beck, returned to the Waberthwaite track and so back to their vehicles.

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M.F.B.

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## THE SUMMER CAMP

Friday, July 21st. - Sunday, July 23rd., 1967

The Camp was held this year at Bolton Mill near Appleby, a delightful site on the banks of the Eden. The Excursion Secretary is to be congratulated on finding such a pleasant place, for making the arrangements for the weekend's camping and geology, and not least for providing fine weather.

## VISIT TO THE CROSS FELL INLIER

Saturday, July 22nd. Director: R.S. Arthurton, B.Sc., F.G.S.

Eighteen members set out from Ousby, in glorious weather, to explore the complexities of the Pennine Fault Area. A series of roughly parallel faults running down the western side of the Pennines constitute one of the really old geological structures of the North of England. This fault structure has had a great influence on the development of the area over hundreds of millions of years. A dramatic west-facing scarp slope exposes the older Palaeozoic rocks as an inlier between the New Red Sandstone of the Eden Valley and the Carboniferous Limestone of the Pennines.

After crossing a stream where an exposure of Penrith Sandstone (the lowest member of the New Red Sandstone) was observed, the party ascended Muska Hill, noting en route the drainage channels on the hillside left by sub-glacial meltwaters. Lunch was taken at a fine viewpoint near an exposure of quartz conglomerate. The party then continued climbing to the top of the scarp slope in the vicinity of the Maiden Way from where they observed the line of the Great Sulphur Vein of Alston Moor. Turning in a northerly direction towards Melmerby Fell they crossed an outcrop of Melmerby Scar Limestone, the lowest and thickest of the Carboniferous Limestone sequence in the area, and observed an intrusion of the Whin Sill. The underlying Basement Series is obscured by talus from the Melmerby Scar Limestone along much of its outcrop. The route then dropped steeply down to the col between Melmerby Fell and Cuns Fell, where specimens of dolerite were obtained.

After a short relatively level walk along the fellside the party descended a steep slope into the upper part of Rake Beck where the Skiddaw Slate was examined for fossils. Lower down the beck the leader pointed to an exposure of polygenetic conglomerate resting unconformably on Skiddaw Slate.

The excursion terminated at Melmerby, after a hearty vote of thanks to the director for a magnificant and interesting day.

G. Wood.

VISIT TO THE BROMLEY (OR BROMLEY) HILL MINE, NENTHEAD, NEAR ALSTON

Sunday, July 23rd. Director: N. Lupton.

This mine, now disused, worked Bromley Hill North Vein, Bromley Hill Vein, North Middle Vein, Middle Vein and Sun Vein. About a dozen members visited the two main levels into the mine - High Level and Horse Level. Both connect with the veins, the workings being extensive and mainly sound.

The minerals worked were galena and sphalerite. Quartz, chalcedony and fluorite (according to Forster 1821) also occur quite commonly in the mine. There is an upward transition from fluorite to barytes as dominant gangue mineral. Interesting minerals of minor occurrence in the mine are hydrozincite, alstonite and secondary gypsum. Hydrozincite is a secondary zinc carbonate and forms a white, grey or pale yellow coating; it can also form rimstone pools. Alstonite (bromlite) was first described by Thompson(1837). Secondary gypsum occurs as efflorescences in the mine.

Production statistics for the mine are incomplete, but from 1848 to the closure of the mine in 1886 14,732 tons of lead concentrates were produced. From 1872-76 1,197 tons of zinc concentrates were produced. According to Smith (1923) an average of 5 oz. of silver per ton of lead was obtained between 1854 and 1884.

The ground at Bromley Hill between the two main levels has been very thoroughly explored. A good plan exists in Nenthead, but no section, so it is not known if trials were made below the Great Limestone at the mine.

Reference

Dunham, K.C., 1948. Geology of the Northern Pennine Orefield, Vol. I.

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Whilst the mine visit was in progress, a number of members, led by the President, visited a disused limestone quarry at Keisley, and afterwards a small party led by Dr. Harpum visited the Great Whin Sill at High Cup Nick.

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OTHER FUNCTIONS HELD DURING 1967

Lecture VOLCANOES

Tuesday, January 10th. R. Gowing, M.A.

Mr. Gowing gave a vivid description, illustrated by magnificent slides, of his recent stay in Japan. Although his lecture was devoted mainly to volcanoes and volcanic features such as hot springs and mineralization, he also showed some interesting shots of Alaskan glaciers and Middle Eastern deserts taken from the aeroplane during the outward and return trips.

Excursion THE CARBONIFEROUS - PERMO TRIAS UNCONFORMITY, BARROWMOUTH.

Sunday, April 16th. T. Shipp, B.Sc.

The excursion party visited the unconformity on the seashore at Barrow-mouth Bay, near Whitehaven, where the Director explained the succession and spoke about the conditions under which the various rocks were formed. The party also visited the adjacent disused gypsum workings in the cliffside. Underground this gypsum passes into deposits of anhydrite now worked for the manufacture of sulphuric acid and cement. Concern was expressed lest the tipping of industrial waste on the clifftop should cover this classic geological feature.

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Lecture and social evening at the Queen Elizabeth Grammar School, Penrith

Tuesday, April 18th. E.H. Shackleton, F.G.S. T. Shipp, B.Sc.
J.R. Harpum, Ph.D., F.G.S.

After a welcome from Dr. Harpum the Head of the Geology Department at the school, Mr. Shipp gave a short talk, illustrated by slides, on the subject of exploration for oil and gas in the North Sea. Mr. Shackleton followed this with a talk on the development of mining and some comments on formation of minerals. Dr. Harpum in a humourous talk entitled "We can't win" listed the theories which have been propounded regarding the expected future of life on earth. Apparently we shall go out in a blaze of light or in frozen gloom if we first do not approach extinction from loss of oxygen or meteoric impact which could occur any time from this instant to a few billion years hence - all very depressing! After refreshments and a look round the Department and the displays of specimens, the President thanked the staff and pupils of the school for their hospitality.

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Excursion OPENCAST COAL MINING

Sunday, September 24th. R. Kay, B.Sc.

Mr. Kay, with two colleagues from the N.C.B. showed the three phases of opencasting. The first, near Asby, involved putting down a grid of bore-holes to prove the existence and continuity of coal seams, and to establish the ratio of overburden to coal which determines the profitability or other wise of subsequent operations. An opencast site in full production, the Blooming Heather site near Maryport, was inspected and the sequence of removal of soil, subsoil and rockfill was explained, the heaps of various materials being put back in the correct order to provide good agricultural land. The worked-out site at Branthwaite Crossroads was visited to see the manner in which the land is restored to agricultural use. It was explained that substantial improvements in drainage and fertility were usually made as a result of opencasting operations.

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Lecture THE MOUNTAINS OF NORTH WESTERN AMERICA

Tuesday, October 10th. Prof. F.J. Monkhouse.

The lecturer took his audience, with the aid of colour slides, on a tour of exploration of the varied features of the Rockies, showing how mountain form depends on type of rock, manner and speed of uplift, and type of erosion, whether by ice, running water or blown desert sand.

Lecture — GEM IDENTIFICATION

Tuesday, November 14th. — J.S. Harris.

By means of specimens, optical instruments and colour slides, many of which were taken through his microscopes and other instruments, Mr. Harris showed how a great variety of gems could be identified and distinguished from imitations by their physical and optical properties.

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Lecture — THE DEGLACIATION OF EAST CUMBERLAND

Tuesday, December 12th. — R.S. Arthurton, B.Sc., F.G.S.

Modern theories of deglaciation had been applied to the many geomorphological features to be found between the Lake District and the Western Pennines. The lecturer showed maps and slides of a number of meltwater systems, explaining how older theories of subaerial drainage along an ice front had been modified to include a large measure of subglacial, englacial and supraglacial drainage. These modifications have to be made to explain such features as humped channels formed under hydrostatic pressure, and the many erosion channels. Many depositional features were also examined in the lecture, including kames, eskers, boulder clays, and the occurrence of pockets of contorted silt within the boulder clay. No evidence had been found which would prove more than one period of glaciation in the area.

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## GEOLOGY IN SCHOOLS

A little over twelve months ago a sub-committee was set up by the Council of the Society to contact local schools. Meetings were arranged between this committee and staff from Primary and Secondary Schools and the College of Further Education. From these meetings the following scheme was planned

1. To provide a geological information and identification service.
2. To prepare "loan kits" of rocks, minerals and fossils which could be borrowed by schools.
3. To help the schools in building up their own collections of rocks, minerals and fossils. This to include an exchange scheme between schools.
4. The preparation of geological fieldwork itineraries to be distributed for use in the schools.
5. The preparation of sets of colour slides to supplement the itineraries and as a teaching aid. The collection to be catalogued and available for loan to schools. As far as possible, illustrations of geological features to be taken from our own county.
6. To arrange the exchange of information on books, ideas and teaching methods
7. To encourage younger members to be active in the work of the Society.

This work quickly got under way, and an "identification" meeting was held to which teachers brought specimens and problems. Six itineraries were produced and distributed to Secondary Schools in the Whitehaven area. More itineraries are at present in preparation. Colour slides of the Lake District area and surrounding countryside have been taken and preliminary discussions have been held to decide the best method of cataloguinig. A grant has been promised for procuring duplicates and storage boxes.

In the initial stages the work went ahead quickly, but the discovery of a wonderful collection of minerals at Cleator County School channelled our energies towards item 2. This Cleator collection has now been sorted, cleaned and catalogued, and a permanent display is being arranged together with a loan set to schools. Now this work is nearly completed we can once more direct our energies to the completion of the rest of the plan. Very soon we hope to have established a useful service for teachers of Geology and Geography in Cumberland Schools.

If any members of the Society would like to help in this work, would they please contact me, or come along to Cleator County School from 7 p.m. to 9-30 p.m. on the second Friday of each month.

H.H. Walmsley.

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RECENT GEOLOGICAL FINDS IN CUMBERLAND AND WESTMORLAND by W.F. Davidson.

A number of interesting minerals and fossils have been collected during the past three years and I think it proper that these should be recorded.

Identifications have been made by the British Museum, The Royal Scottish Museum and Dr. R.A. Howie (University of London, King's College).

Fossils. Calyces of the following crinoids from a quarry near Caldbeck (Carboniferous Limestone):-

Phanocrinus c.f. calyx (M'Coy)
Tyrieocrinus laxus (Wright).
Platycrinites gigas (Phillips).

Also feeding arms of:-

Anemetocrinus biserialis (Wright) Loc. as above.

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From Howgill Head Quarry, Whitehaven (Coal Measures), an opercular plate and median abdominal appendage of Adelopthalmus (Eurypterid).

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From the Carboniferous Limestone of Ash Fell, Ravenstonedale:-

Pygidium of Weberides sp.,

and the following fish remains:-

Rhabdoderma (Coelacanth) - a gular plate.
Ctenocanthus major (Agassiz) - piece of fin spine.
Cochliodus sp. - numerous palatal teeth.
Cladodus mirabilis (Agassiz) - tooth.

The last specimen was described as "particularly fine" by the British Museum and was embedded, point down, in a piece of limestone. They were able to extract it from the matrix by skilful use of acid. C. mirabilis was the fiercest shark of the Carboniferous seas.

Minerals. From the Caldbeck Fells:-

Brochantite - one specimen, Sandbed Mine.
Tetrahedrite - three specimens, Sandbed Mine.
Covellite - numerous examples, Sandbed Mine.
Linarite - Roughtongill Mine.
Cornwallite - a number of nice specimens obtained when the old dump was removed, Potts Gill.

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