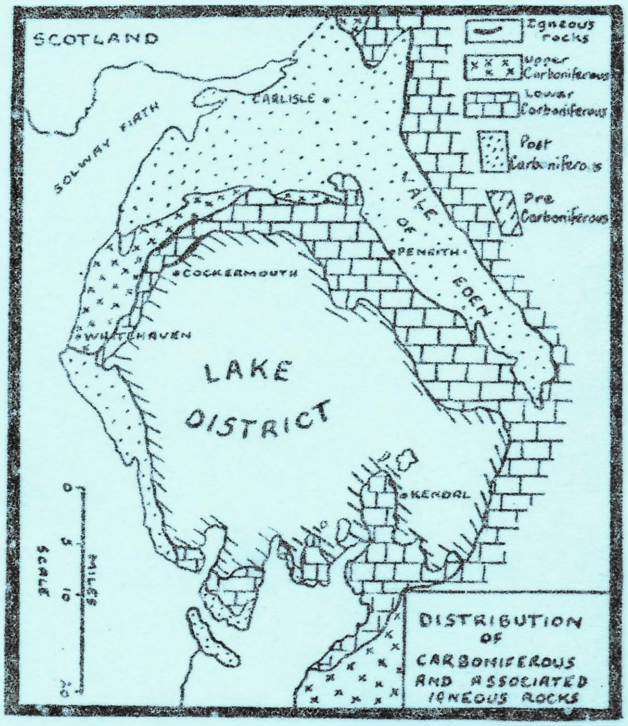
CUMBERLAND GEOLOGICAL SOCIETY



PROCEEDINGS

VOLUME 2. PART 1.

- 1966 -

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FIVE SHILLINGS

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T H E C U M B E R L A N D G E O L O G I C A L S O C I E T Y

President:

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

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PROCEEDINGS

VOLUME 2: PART 1.

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GENERAL SECRETARY: PUBLICATIONS: EDITOR:

R.E.O. Pearson, K.R. Baker, T. Shipp, B.Sc.,

[redacted] [redacted] [redacted]

EDITOR'S NOTE

It was decided early this year to make the first eight issues of the PROCEEDINGS OF THE CUMBERLAND GEOLOGICAL SOCIETY into Volume 1. This caused a slight difficulty because these PROCEEDINGS were published in the first instance purely for the benefit of the Membership of a very small Society. Between 1962 and 1965 membership of the Society has increased fourfold, activities have multiplied, and consequently, the PROCEEDINGS, like Topsy, "just growed".

Because we had no idea how successful these written records of the activities of the Society were going to be, each issue of PROCEEDINGS was treated as a separate entity. This caused problems in the compilation of an index, as each issue started at page one. However, Mr. G. S. Gowing nobly undertook the task of producing an index which has now been published separately.

The present issue is the first of Volume 2, and succeeding issues will have the pages numbered consecutively. Members will also have noted that it is now being issued only once per year. Compilation of two issues yearly was becoming too much of a burden for the Editor. We have attempted to improve the style and content of text and diagrams, including not only reports of Society activities but also articles of geological interest submitted by Members.

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THE FIFTH ANNUAL GENERAL MEETING OF THE CUMBERLAND GEOLOGICAL SOCIETY

Held on January 12th. 1966 at Whitehaven College of Further Education

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The President, Mr. E.H. Shackleton, F.G.S., took the chair and called upon the General Secretary, Mr. R.E.C. Pearson, to read the minutes of the previous Annual General Meeting. These were adopted.

The President called upon the General Secretary*, the Treasurer*, and the Excursion Secretary to present their annual reports. These were accepted by the meeting, the President expressing appreciation of the hard work done on behalf of the Society by the elected Officers.

In accordance with Rules 23, 24, and 25 of the Society, the following Officers of the Society resigned, but were nominated for re-election. This was approved by the meeting:

President:	Mr. E.H. Shackleton, F.G.S.
General Secretary:	Mr. R.E.C. Pearson.
Treasurer:	Mr. H.A. White, B.A.
Excursion Secretary:	Mr. R.H. Hewitt.
Editor:	Mr. T. Shipp, B.Sc.
Librarian:	Mr. M.F. Burton.

The retiring Vice-President, Mr. G.S. Gowing, M.A., F.G.S., after three years in office, did not wish to stand for re-election. The position of Vice-President was taken by Mr. H.A. White, B.A.

Mr. D.C. James, B.Sc., Mr. S.H. Gate, M.Sc. and Miss V. Beer retired from Council. The following were nominated by Council, and since there were no further nominations from Members, they were elected to serve as Ordinary Members of Council:

Miss E. Pimblett, B.A.
Mr. H. Bland.
Mr. H.H. Walmsley.
Mr. H.C. Stone, B.Sc.

This concluded the formal business of the Annual General Meeting.

* Reports appended below.

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THE GENERAL SECRETARY S REPORT

I wish to deal firstly with the membership, which stands as follows:

116 Ordinary Members
60 Associate Members
6 Institutional Members
1 Honorary Member.

In spite of losing a number of members by resignation or failure to renew subscription, these numbers represent gains of 25 Ordinary Members, 5 Associate Members and one Institutional Member. There is in fact a large turnover of Associate Members, as a good many of these are students at local schools, who, leaving for College or University lose touch with the Society. Happily there are exceptions to this trend, a notable one being Mr. A.G. Fox who joined the Society in 1961 whilst at Workington Grammar School, and kept up his membership whilst at Bristol University where he

obtained a degree of B.Sc. this year.

Apart from excursions and mine visits to be dealt with by the Excursion Secretary, the Society's activities have included a Week-end School in Geology for teachers, held at Hawse End, and an Introductory Course in Geology at Wyndham Centre, Egremont. A further very worthwhile venture was the publishing of A Bibliography of Lake District Geology and Geomorphology compiled by Dr. R.A. Smith. To date we have sold 237 copies of this, and had to reprint only four months after it was first published. I regret to have to say that only 20 of these were sold to Members of the Society. The majority have gone to Public Libraries and Booksellers. To anyone with an interest in the natural history of Cumberland this book is invaluable, presenting a comprehensive list of publications on the geology of the area. At five shillings it is good value.

I shall end on a personal note. I have been General Secretary for five years. The sure way for a Society to become moribund is, in my opinion, for its Executive to be in office for too long. I would therefore urge that Members be willing to join the Council, and I hope that eventually someone will relieve me of my job. R.E.O. Pearson.

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THE HONORARY TREASURER'S REPORT

The financial affairs of the Society continue to be in a satisfactory condition. Reference to the Income and Expenditure Account will show that we commenced the year with a total of £42 including cash in hand as well as our balance at the bank. Nearly £9 of this, however, consisted of contributions to the Charles Edmonds Memorial Fund, so that the sum actually standing to the Society's credit was £33.

We closed the year with a balance at the bank of £99 - 1 - 8, of which £69 - 17 - 2 is due to the Edmonds Memorial Fund, leaving £29 - 4 - 6 to the Society's credit. This represents a fall of about £4 during the year, which at first sight might suggest a rather disturbing situation. Actually the state of affairs is more favourable than it seems. Our subscription income in 1965 totals £52 as compared with £45 - 14 - 0 in 1964. Moreover, many members paid their subscriptions for 1965 in advance, so £24 - 8 - 0 was paid on this account before the end of 1964. It will be seen that the corresponding sum for this year was £18 - 15 - 0, due to the fact that it was not necessary to request pre-payment of subscriptions, as was done towards the end of 1964.

It will also be seen that materials for our publications (chiefly duplicating paper) have cost £79 during the current year as against £47 in 1964, and postages have risen from £13 to £24 - 10 - 9. These substantial increases are due to the publication in April of the "Bibliography of Lake District Geology" compiled by Dr. R. A. Smith of Padgate College of Education, and produced with meticulous care and much labour by our Editor. The demand for this publication from libraries and colleges all over the country exceeded expectations, and a substantial reprinting was called for. Several back numbers of the Proceedings were also reprinted so that we have stocks of most of our publications on hand.

Proceeds from the sale of publications thus total £68 - 5 - 4 compared

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDING 1st. JANUARY, 1966.

1964	EXPENDITURE				1964	INCOME			
(47)	Publications	£78	19	5	(30)	Balance at Bank on 1/1/65	£38	7	10
(13)	Postages	24	10	9	(5)	Cash in hand on 1/1/65	3	12	3
(8)	Subscriptions etc. Lake District Naturalists' Trust	1	1	0	(21)	Subscriptions (1965) 45 Full Members	22	10	0
	W.Cumb.Tech.Assoc. affiliation fee		10	0		4 Institutions	2	0	0
	175 Programmes	5	9	4		35 Associates	8	15	0
	Geologists' Assoc.	4	0	0	(24)	Subscriptions (1966) (paid in advance)			
(--)	Annual Dinners 1965	30	17	0		30 Full Members	15	0	0
	1966		17	6		1 Institution		10	0
(--)	Hawse End Course (students' fees)	31	10	0		13 Associates	3	5	0
(2)	Refreshments at Soiree	2	5	0	(17)	Sales of Publications Proceedings and Limestones	12	12	3
(--)	Hire of room at Wyndham Centre		5	0		Postcards		19	0
(2)	Bank charges		5	0		Library Catalogues	4	1	0
	Cheque book		5	0		Bibliographies	50	13	1
(4)	Cash in hand		nil		(23)	Annual Dinners 1965	7	10	0
(38)	Balance at bank on 1/1/66 after making provision for outstanding cheque	99	1	8		in advance 1966	4	15	0
					(9)	Donations, etc.	10	7	9
					(2)	Sale of refreshments at Soiree	2	10	6
					(--)	Hawse End Course	31	10	0
					(9)	Charles Edmonds Memorial Fund	60	18	0
		£279	16	8			£279	16	8

THE CHARLES EDMONDS MEMORIAL FUND

Contributions received up to 31/12/64	8 19 2
Contributions received during 1965	60 18 0
Total at 31/12/65	£69 17 2

with £17 in 1964. It should be noted that a proportion of our publications is sold through booksellers at a discount on the published price, and in many other instances the sum received by the Society includes charges for postage.

The Society was pleased to receive a further covenanted donation of £5 - 5 - 0 (plus tax rebate) from Mr. Frank Schon.

The Charles Edmonds Memorial Fund now stands at £69 - 17 - 2 including a generous donation of £50 from the National Union of General and Municipal Workers. It was not thought necessary to open a separate bank account for this Fund, as further donations are not expected after today, and the Fund will soon be invested by the Trustees in suitable securities.

STATEMENT OF ASSETS AND LIABILITIES, 1st. JANUARY, 1966.

LIABILITIES		ASSETS	
Subscriptions for 1966, paid in advance	£18 15 0	Balance at Bank 31/12/65	£99 1 8
Charles Edmonds Memorial Fund	69 17 2	Duplicator (cost price £50 less depreciation)	30 0 0
Annual Dinner, 1966 payments in advance	4 15 0	Stock of stencils, styli and stencil fluid, approx	4 10 0
Excess of Assets over Liabilities	185 14 6	Stock of duplicating paper 10 reams approx	5 0 0
		Stock of postcards 60 doz. approx.	8 0 0
		Stocks of publications	
		Bibliographies, 430 @ 5/=	107 10 0
		Proceedings, 200 @ 2/6	25 0 0
	£279 1 8		£279 1 8

WEEKEND COURSE IN GEOLOGY

Organised on behalf of Cumberland Education Committee at Hawse End Centre, April 2nd. to 4th. 1965

EXPENDITURE		INCOME	
Accommodation at Hawse End for 14 students @ £1 2 6 per person per day	£31 10 0	Fees from 14 students @ £2 5 0 each	£31 10 0

Under the heading of "Subscriptions to other Societies" there is an increased payment to the West Cumberland Technical Societies in respect of their programme brochure, copies of which were sent to all our members.

Turning finally to the Statement of Assets and Liabilities it will be seen that the excess of Assets over Liabilities is now estimated at a total of £185 - 14 - 6, compared with £110 - 18 - 4 a year ago. This is partly due to our large stock of Bibliographies which have been valued at their selling price of 5/= each. It is anticipated that there will continue to be a steady demand for this useful publication.

I am of the opinion that in spite of the rather modest balance at the bank at the turn of the year, the financial condition of the Cumberland Geological Society is sound.

H.A. White.

TIME MEASUREMENT AND THE FOSSIL RECORD

PRESIDENTIAL ADDRESS TO THE CUMBERLAND GEOLOGICAL SOCIETY

Delivered by E. H. Shackleton, F.G.S. at the Workington College of Further Education on February 8th., 1966.

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Once again I find myself faced with the increasingly formidable task of delivering a Presidential Address, and since this is the fifth year in succession perhaps I may be forgiven if I return to a subject I have touched upon before, at least in part. In 1963 I found myself tucked up in bed recovering from my sojourn in hospital when the time for the annual address came round, and on that occasion our worthy editor, Mr. T. Shipp, deputised for me on the subject of "The Age of the Earth" from a lecture I had given some years before. Inevitably, in the circumstances, that lecture had to go practically unrevised and any success it had leaned heavily on Mr. Shipp.

Now it so happens that a year ago the Geological Society of London held at Glasgow University, along with members of the Scottish Geological societies, a symposium on the subject of "The Phanerozoic Time Scale". As we shall see in a moment, whilst the subjects of this symposium and the theme of my 1963 address were not identical, they had a good deal in common, even though in 1963 I was the complete amateur grappling alone with a highly technical subject, whereas in Glasgow were gathered together some of the world's experts. At the symposium, these eminent men were able to present and review the state of knowledge of the record of earth history which is contained in the rocks in the form of readily recognisable fossils, which is really what the impressive title means.

In this Address I would like to give you as clear a picture as I am able of the conclusions recorded in the excellent volume produced by the Geological Society on the subject of time and its relation to the fossil record.

The volume opens with a tribute to that doyen of geochronologists, Professor Arthur Holmes. I feel that many of you will have in your hearts the same warm spot for the Professor that I have myself. A fellow North Countryman, he was born at Hebburn-on-Tyne in 1890, six years before Becquerel made his great discovery of radioactivity that founded what has almost become a science in itself. By 1897 Lord Kelvin, from his research into the heat flow of the earth, was putting its age at somewhere between 20 and 40 million years. This in itself was a shock to a generation brought up on Archbishop Ussher and his "4,004 B.C." but, as I described in my last lecture on this subject, this did not satisfy the geologists. Men like Geikie and Joly, faced with the immense thickness of stratified deposits and believing these to have been accumulated by the action of forces still at work around us, were already thinking in terms of 100 million years, whilst J. G. Goodchild, that same Goodchild I suspect who once played so prominent a part both as geological surveyor and leader of scientific thought in Cumberland, came up with the remarkably prescient guess of 704 million years from the base of the Cambrian. Kelvin's estimate of 20 - 40 million years was also too short a time for Darwin; his theory of evolution demanded a far longer period to account for the proliferation of species.

During his schooldays Holmes, we are told, had already looked askance at the Archbishop's "4,004" and whilst in the sixth form some enlightened schoolmaster had encouraged him to read Kelvin and Suess. As an undergraduate he began his formal studies at Imperial College in 1907, the year Boltwood was calculating approximate ages of uranium minerals from their lead contents. After working with Strutt on the dating of minerals from their uranium/helium ratios Holmes published his first paper on the subject in 1911 in the Proceedings of the Royal Society. In this he upset some geologists of the day by what seemed to them to be rather extravagant estimates, figures nevertheless little removed from those now established firmly. Since then the Professor has made over fifty contributions on the subject of radiometric dating.

It should not be thought however that this theme has been his only concern. During a very active career he has investigated the geology of many parts of the world. Besides building up the Geology Department at Durham University from scratch he occupied the Chair of Geology at Edinburgh for thirteen years, and for a further six was Emeritus Professor there. Along with his distinguished geologist wife he has influenced geological thought on many often controversial subjects. But perhaps most of us will remember Professor Arthus Holmes with a deep sense of gratitude for the beautifully-written textbooks that stir our imaginations on so many and various topics from granites to orogeny, from the origins of igneous rocks to continental drift. I might also remind many of you that although you may never have read Holmes, you are still in his debt, for in the preparation of my own lectures on geology over many years his works have always been my first reference.

The work of the Glasgow Symposium was opened by the late Professor Lawrence Richard Wager. Perhaps I may be forgiven a personal reference. His sudden death came to me as something of a shock for only as late as last September I visited the Professor's department at Oxford to see something at first hand of the work being done there on radiometric dating. At Glasgow Professor Wager covered the same historical background as I did myself in my last lecture and then went on to review radiometric methods and the attempts that have been made to relate the dates determined to the maximum thickness of deposits and to the fossil record. After Wager's introduction various experts dealt at length with the different techniques used at the present time, and as briefly as possible I would like to summarize these.

THE URANIUM-THORIUM/LEAD METHODS

There are three naturally-occurring isotopes of uranium, U^{238}, U^{235} and U^{234}. The last is very rare and need not concern us further. The second, whilst famous (or should I say infamous?) now as the raw material of atomic bombs, for long escaped detection. This, perhaps, is not surprising as the present natural proportions of these two isotopes are 99·27% of U^{238} to 0·72% of U^{235}. Of these two isotopes U^{235} decays the more rapidly, its half life being 713 million years, whilst the half life of U^{238} is 4,510 million years. Thus the ratio of U^{235} to U^{238} has decreased throughout geological time to a present day relative abundance of 1:137·7. Both of these isotopes as well as the element thorium have well-known decay series.

In the case of U^{238} there are 14 unstable nuclides before the stable end product, Pb^{206}, is reached. In the case of U^{235} there are 12, ending in Pb^{207}, whilst in the thorium series there are 10 unstable stages with Pb^{208} as the end product. The naturally-occurring thorium isotope has an atomic weight of 232 and an exceptionally long half life of 14,200 million years. The decay of one atom of U^{238} to Pb^{206} involves the production of eight alpha particles. U^{235} produces seven alpha particles and Th^{232} six. Since alpha particles are helium nuclei, this forms the basis of a cross-check method for U/Pb ratios by determining also U/He. The method was suggested by Lord Rutherford himself and worked on diligently for many years by Holmes, although in the early days the results were invariably most disappointing. Perhaps it will do no harm to hark back to those early days if only to appreciate the patience and determination then required.

When it was first realised that in radioactive minerals there was a relationship which approximated to: $\frac{U + Th}{Pb} = \text{Time}$, the only means of establishing this ratio was by chemical analysis. Apart from the fact that the conception of isotopes was then in its infancy, this chemical method had many limitations. In the first place appreciable amounts of mineral were required, and the mineral must have a high radioactive content. It took much time and frustrated effort to realise that this distinctly reduced the possibility of using uranium/helium ratios as a cross check because in richly radioactive minerals the gas pressure due to accumulating helium became so great that loss by diffusion was almost inevitable. It became obvious that weakly radioactive minerals were preferable for this purpose if only they could be analysed successfully - but how?

The answer to this question came as a result of the improvement by Paneth in 1928 of the mass spectroscope. This instrument, devised by Aston about 1920, could sort out ions according to their different masses, whilst Paneth's improvement allowed the detection of helium in quantities no greater than a millionth of a millilitre. Further modifications of the instrument make it possible to deal with samples containing as little as 50 micrograms of uranium or lead, Zircon concentrates totalling no more than 0·2 milligrams can now be effectively dealt with. To use a rather crude analogy: today we can manage quite comfortably on a thimbleful where once we needed a tubful.

The decay of the uranium and thorium minerals involves many intervening stages, and daughter products of decay begin to accumulate from the moment of formation of the mineral. The members of these various series of unstable isotopes have differing half lives and there must consequently be a time interval between the decay of the parent atom and the decay of its daughter products until eventually the series in each case attains a state of equilibrium. For uranium this takes about one million years, but for thorium minerals only about thirty years is required. Since parent and daughter elements all contribute to the total radiation, each with beta and gamma radiations in differing proportions, for any given series in equilibrium the ratio of beta to gamma is fixed, and can be measured. This is really important because it permits the immediate recognition of specimens that have for one cause or another lost some of their decay products. For any disintegration series in a state of equilibrium the relation between the number of parent atoms and the number of atoms of daughter decay pro-

ducts now can be calculated, and this ratio is itself a measure of time. This relationship is well established for the series U^{238}/Pb^{206}, U^{235}/Pb^{207} and for Th^{232}/Pb^{208}, provided that there has been no gain or loss of decay products, this being a most important provision.

Since the time that has elapsed since a radioactive mineral was formed is measured by determining, amongst other things, the various isotopes of lead present, it is a dangerous pre-supposition to assume that there was no lead in the sample at the time of its formation. It is known that lead has many isotopes, some of which, such as Pb^{206}, Pb^{207}, Pb^{208} or Pb^{210} have direct or indirect radioactive ancestors. There is, however, one isotope of lead, Pb^{204}, which has no such ancestor on earth, as far as can be ascertained. This occurs in 'common lead' consisting of isotopes 204, 206, 207 and 208. The isotopic proportions can be cross checked from outside our planet, for lead from the famous Canyon Diablo Meteorite shews:

Lead isotope 204	2·0%	Lead isotope 207	20·6%
" " 206	18·8%	" " 208	58·6%.

From this it follows that any mineral sample that shews Pb^{204} in greater proportion than 2% of total lead is at once suspect, and probably better thrown out.

It is possible because of the differing disintegration rates of U^{238} and U^{235} to use the ratio Pb^{206}/Pb^{207} as a measure of time, as well as the two uranium-lead ratios. After years of patient work, the degree of uncertainty of radiometric dating using U^{238}/Pb^{206} is very small, and this may be due as much as anything to the fact that Pb^{206} constitutes 95% of all lead derived from uranium. The ratio Pb^{206}/Pb^{207} is the least reliable method of radiometric dating, and becomes progressively less reliable from the Cambrian onwards. With some mineral samples, all three methods have been used to give complementary results and in such cases it is agreed that the margin of error must be extremely small.

THE POTASSIUM/ARGON METHOD

Whilst the uranium/lead methods already outlined are now well established and give good results with the refined techniques of measurement of radioactivity now available, there are drawbacks. For one thing, usable minerals of this series with well-authenticated cross correlations are by no means as common as we would like them to be. But if we turn our attention to the element potassium we have a completely different picture, for this element is commonly present in a great many rocks. In igneous rocks it is present in felspars and micas, occurring not only in granitic rocks, but also in some lavas, tuffs, dykes and sills. Often it is much easier to relate a lava or a tuff to a well recognised fossil horizon than it is a granite. The method has been tried also on sedimentary rocks containing such potassium-bearing minerals as glauconite and bentonite.

Potassium/argon (K/A) determinations depend on the radioactive decay of the isotope K^{40} to the inert gas A^{40}. K^{40} decays in two different ways, by the process of K-electron capture (the letter K in this case having nothing to do with the chemical symbol for potassium!) giving argon, and also by beta emission resulting in the isotope of calcium, Ca^{40}. This rather complicates the fixing of the half life period, a constant most important in all time/decay calculations. Sad to say, no finality has been reached on

this. To use the ratio K^{40}/A^{40} as a measure of the age of rocks or minerals, it must be assumed that initially there was no A^{40} present and that none has been gained or lost since. The first may be logically conceded, but the rest is not so easy for the gain or loss of matter from a rock or mineral depends a great deal upon the geological conditions to which it has been subjected since its emplacement or crystallisation. Nevertheless, because potassium is present in reasonable quantities in many rocks and minerals, and because its radioactive isotope, K^{40}, has a half life of about 1,300 million years, it can be used for age determinations from the older Pre-Cambrian down to about one million years. Should it be possible to surmount all the technical difficulties involved in the method, it promises to be a very useful tool indeed.

Briefly the technique is this; the sample is placed in a vacuum and slowly heated to drive off all gaseous impurities. An accurately measured quantity of A^{38} (known as a 'spike') is added and the sample fused. The resulting gas mixture obtained is passed over a red hot titanium sponge to remove all further impurities except water vapour and most of the hydrogen. The water vapour is removed in a U-tube cooled in liquid nitrogen, and the hydrogen adsorbed on active charcoal cooled in the same liquid. The residual gas is then passes to a mass spectrometer which determines the argon ratios from which the weight of radiogenic argon per gramme of sample can be calculated. The potassium content of the sample is usually found by making five or six determinations, either by careful analysis or by flame photometry. Potassium-bearing minerals such as muscovite, biotite, phlogopite and lepidolite have all been used very successfully in this method of dating. Amphiboles and pyroxenes have also been used, but their low potassium content makes accurate determination of age by their use rather difficult at present. Felspars have, on the whole, proved unsatisfactory. Of the felspars, sanidine seems to be the most useful, particularly in the younger rocks. Glauconites too have been used, especially from Mesozoic rocks, but the results seem to be rather doubtful, due perhaps to loss of argon.

The technique of K/A determination applied to whole-rock specimens, as distinct from minerals derived from rocks, was first tried at Cambridge in 1962. This is of special interest to us in the North of England because six of the first specimens to which the method was applied came from the Rookhope borehole into the Weardale Granite, and one from a surface outcrop of the Whin Sill at Housesteads. The geological horizon of the Whin Sill is fairly well established, as it is intruded into various levels of the Carboniferous up to the Coal Measures, whilst pebbles of its dolerite have been found in the Upper Brockrams of the Permian. Various workers, from Holmes to Dunham, have investigated the Whin Sill, concluding that whilst absolutely fresh specimens give dates of the same order, many specimens of the rock, even though at first sight they appeared to be fresh enough, gave dates that were far too low. One specimen of the Sill was apparently only 130 million years old as compared with the accepted age of 300 $\pm$ 10 million years. A great deal of research followed on what came to be known as 'age discrepancy' and it was seen that weathering alone was not a sufficient answer. Eventually it was found that not all minerals in a rock sample had the same argon retentivity. Biotite for example if subject to any heating or stress readily loses some of its A^{40}, and in some cases the dates found

were not the dates of formation but those of subsequent metamorphism. Rocks badly affected by cleavage could very well have lost all their radiogenic argon, having had their 'radioactive clocks' re-set. In conclusion, all workers in this field understand the need for a complete geological and petrological examination before K/A can be used as a satisfactory cross-check for the older methods of dating.

THE RUBIDIUM/STRONTIUM METHOD

Perhaps the latest method of radioactive dating is the one that depends upon the decay of Rb^{87} to Sr^{87}. This decay series is very involved, with a whole spectrum of very weak beta particles, making direct half life determinations very difficult. Various methods have been tried and differing constants found, but the most successful seems to be to establish the Rb/Sr half life by a cross check against well-established uranium series dates. This, I realise, looks rather like putting the cart before the horse, but if a satisfactory half life constant can be established, the rubidium/strontium method may yet prove to be one of the most useful dating tools. For one thing, the two methods K/A and Rb/Sr can often be applied to one and the same specimen. The latter method does not of course depend on potassium, but minerals rich in this element usually carry rubidium also. The micas are very suitable subjects, and if the cross check on a mica specimen shews discrepancy then the dating is probably suspect. On the other hand if the two ratios give dates that agree it is very unlikely that daughter decay products have been lost since the mineral was formed. For two such dissimilar elements as argon gas and the solid rubidium to leak away from a crystal at the same rate is highly improbable. Minerals like orthoclase, for some yet unexplained reason, give unsatisfactory K/A dates. They are usually about 25% too low. But the mineral is quite suitable for the Rb/Sr method, enabling the ages of many granitic rocks to be checked.

LINKS WITH THE STRATIGRAPHICAL COLUMN

Those of you who recall my earlier lecture will remember that in the early days of speculation about geological time much play was made about maximum thicknesses of deposits. Arthur Holmes, in common with Kulp, Schuchert and others, made repeated attempts to relate radiogenic dates to the sedimentary pile from the Cambrian onwards. Why from the Cambrian? Because only from the Cambrian can a relative succession be established, based on the fossil evidence. Of late, with increasing frequency, microfossils and algae have been reported from the Pre-Cambrian but it is likely to be a long time before these widely scattered finds can be used to give a stratigraphical column of the Pre-Cambrian, if ever. Back in 1933, Holmes was trying to tie his radiometric age determinations to the stratigraphical column and attempting to use as a cross reference the maximum thickness of deposits. Although few firm dates had been established upon which to base his findings, it seemed to Holmes that there has been a definite increase in the rate of deposition of sediments with the passage of time. His conclusion may well have seemed obvious thirty years ago but how does it stand today? Holmes thought one reason why Palaeozoic strata had taken longer to accumulate than more recent deposits was due to a preponderance of limestones. This may indeed be true, but how may it be assessed?

One illustration of this may be given by the Carboniferous Limestones of which there are many varieties, some macroscopic in texture, some micro-

scopic. If it takes 'x' years to build a bed of crinoidal limestone, the constituent fragments of which can be seen with the naked eye, how many years does it take to build a bed of the same thickness, but composed of nothing bigger than foraminifera? In the Avon Gorge there is a well-known sequence of rather more than 3,000 feet of rocks, mostly limestone. In the Pennines there is a matching sequence of coarse Millstone Grit, 3,000 feet thick. Is it to be suggested that one is the time equivalent of the other ? One must admit that this conception of 'maximum thickness' turns out to be anything but a simple proposition. To have deposition at all presupposes subsidence but there is an added time factor; subsidence without sufficient time for accumulation of sediments is unlikely to produce a thick deposit. The immense variation in possible thickness of deposits, as checked against the bio-stratigraphical record has been shown very frequently. For example 40,000ft. of Lower Palaeozoic rocks in the Welsh Borderlands are equivalent to 1300ft. in the Baltic Provinces which accumulated in the same geological time. Recently, members of the Cumberland Geological Society visited the Southern Uplands of Scotland to look at some of the localities unravelled by Professor Lapworth. We were fortunate on that occasion to be taken over some of the ground by Mr. Eckford, late of H. M. Geological Survey. Recent Scottish studies seem to shew that the degree of folding postulated by Lapworth may have been excessive, and as a consequence the Ordovician of Scotland may be much thicker than was thought. Much the same sort of evidence is to hand from Ireland also. Nearer home in the Lake District there is at the base of the Silurian a sequence of rocks known as the Skelgill Beds, dark mudstones and shales in which a prolific fauna has clearly registered the change in life forms. It would appear from a study of the accepted zones of the Silurian as a whole that one of two things happened. Either the Skelgill Beds were deposited so slowly that there was more time for change of life forms than there was during the deposition of the overlying thousands of feet of strata from the Brathay Flags to the top of the Kirkby Moor Flags, or (and this seems improbable) the rate of evolutionary change was stepped up during the deposition of the Skelgill Beds. It is evident from all this that insufficient is known about the finer points of our subject. Perhaps the evidence for maximum thicknesses is easier to assess in recent deposits than in ancient ones. Maybe the suggested increase in the rate of deposition is more apparent than real. It seems to me that a long hard look is required at evidence already gathered, and for this a hammer, a stout pair of boots and a great deal of patient fieldwork will prove more useful than a computer!

How well do radiometrically dated rocks and minerals fit into the stratigraphical background? How well does the geological succession so painstakingly worked out in the field tally with the dates determined by patient laboratory investigations? There is, to put it mildly, a good deal of uncertainty and perhaps as good an illustration as we could wish to find of the difficulties encountered can be found quite close to home, in fact no further away than Shap. From the most recent assessment by Holmes and Kulp the base of the Devonian is placed at approximately 400 million years and the top of the Devonian at about 350 million years. Previous work by Kulp in 1961 in trying to relate geological time to maximum thicknesses in the Upper Palaeozoic gave age determinations of the Shap Adamellite which would place it anywhere in the Devonian. Further determinations give a date of 395 $\pm$ 5 million years. What is the purely stratigraphical evidence for the age of the Shap Pluton? Members of this Society will recollect that on

our last excursion to Shap we examined the Granite Quarry itself, and then went on to the Blue Rock Quarry where we saw Borrowdale Volcanic Lavas highly altered by the heat of the intrusion. Obviously the plutonic episode was post-Ordovician. On Pack Horse Hill, Upper Silurian grits have been altered to quartzite, so the event was post-Silurian also. Whilst I do not remember anyone going to Shap Wells on this occasion I have on previous visits taken some of you to see the conglomerate which there underlies the Solenopora Beds of the Lower Carboniferous. This conglomerate lies upon the upturned edges of the older rocks and contains pieces of unmistakeable felspar from the granite in quite a fresh condition. Not very far away in Ravenstonedale there are Carboniferous beds in Pinskey Gill which are generally held to be older than the conglomerate at Shap Wells, but shewing no trace of Shap detritus.

We know that towards the end of the Silurian the great Caledonian Mountain Building movements began. These folded the Lakeland strata, and continued well into the Devonian when the Shap Pluton was emplaced. For the latter event there is now a firm radiometric date of 395 (±5) million years ago. How does this fit into the relative time sequence, and where? Can one use the date mentioned as fixing the base of the Devonian? If I understand the theory correctly the date given is the time when crystals of biotite became a closed system, but how long after the emplacement of the pluton was this? Whilst the field relations at Shap are somewhat ambiguous perhaps they are as well established as in most such cases. There is also another way of looking at this. The Shap Pluton was intruded into Ordovician and Silurian rocks. It seems that the actual time of exposure can be reasonably well fixed against the fossil time scale to between the Pinskey Gill Beds and the conglomerate at Shap Wells. One wishes that the age correlation of the granite itself with the fossil record could be as clearly defined.

I have used the example of the Shap Granite because it is well-known to you, but also because I wanted to emphasise this difficulty of fitting a date of which the accuracy is not in question to the right horizon. Perhaps it is no wonder that practically every speaker at the Glasgow Symposium emphasised the need for the most meticulous fieldwork in all cases. As one works up the geochronological scale towards the present, things become a little easier, for there are in more recent rocks many instances of interbedded lavas and tuffs, of which the geological horizons are clearly fixed. Also these rocks are young enough to have escaped the revages of time. It is a pity that many are basic rocks, poor in radiogenic elements, but I have every faith that improving laboratory techniques will surmount this.

In conclusion, I believe I have expressed on a previous occasion the opinion that geology is, first and foremost, the concern of the geologist. Whilst welcoming the great advances made in techniques of radiometric age determination, the dates of individual rock and mineral samples found by the use of these techniques leave us no nearer a final evaluation of the stratigraphical column. Knowledge of these dates often creates as many problems as it solves, problems which will only be rationalised by geologists, professional and amateur, reviewing field relationships with the utmost care and attention to detail. This, I feel, is an activity which can and should be undertaken by this Society in our own small corner of the British Isles.

Oil & Natural Gas Exploration in the Eastern Irish Sea

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C. V. KNIPE, B.Sc., F.G.S.

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The last two years have seen considerable activity in the North Sea by a dozen combines of major oil companies (see 'Drilling for oil and gas in the North Sea', Proceedings No. 2, 1965), culminating in the discovery of a number of large gas shows. These promise radically to alter the relative importance of coal and gas or oil as sources of energy in Britain. Already development wells are being sunk and pipelines laid to bring gas ashore.

The stimulus of this activity and its success has naturally led to the search being widened for other potential oil or gas fields. The Irish Sea east and south east of the Isle of Man is one such area being explored at the moment.

CLUES

For many years oil seepages have been known in a peat moss at Formby in West Lancashire. The oil is believed to have escaped upwards through the Permo-Trias and boulder clay to the surface from an original reservoir in the Carboniferous. The D'Arcy Exploration Company drilled a number of shallow holes in 1939 near the main seepages east of Formby. These found oil in the thin sandstones (Waterstones) at the base of the Keuper Marl and at the top of the Keuper Sandstone. Since then, many more shallow holes have been sunk by British Petroleum ranging from 65 feet to over 1150 feet in depth, and a number of deep borings made in unsuccessful attempts to find the primary reservoir.

Some of the shallow wells are still in production but make a very small contribution to the total United Kingdom indigenous oil output - in 1965, 122 long tons out of 82,419 - and even less compared with the amount of crude petroleum we have to import, over 66 million tons in 1965. However, the oil is there and it is a pointer, a hint that more oil or gas may exist under the neighbouring part of the Irish Sea.

THE STRUCTURE OF THE IRISH SEA BASIN

A gravity survey (Bott, 1964) made five years ago has suggested the basic structures of the rocks underlying the Irish Sea. Areas where the gravitational attraction is comparitively low are thought to be filled with Carboniferous and New Red Sandstone rocks and areas where the attraction is stronger are thought to be where the denser Lower Palaeozoic slates, grits and volcanics come closer to the surface.

This work indicated the existence of a number of deep basins, in some cases filled with up to 8,000 feet or more of rocks (see Figure 1). The general way in which they came into existence is as follows: during the Lower Carboniferous the eastern Irish Sea was probably a shallow sea in which the Mountain Limestones were deposited. During the deposition of the Millstone Grit and the Coal Measures the area was still shallower, being at about sea level for much of the time, so there is a good chance that coal swamp forests covered large areas of the eastern Irish Sea. Towards the close of the Carboniferous the floor of the Irish Sea started to subside in an irregular pattern of basins. As fast as the basins subsided, Permian and Triassic sediments, derived from the nearby upland areas, poured in so that the surface remained generally at about sea level, or a little above. The process may have gone on intermittently for more than 100 million years so that there was plenty of time for 8,000 feet of sediments to be deposited. *

There is, then, quite a possibility that coal may be preserved extensively in the basins, and also that great thicknesses of salt cover wide areas in the New Red Sandstone as they do in the very similar Cheshire Basin.

Other geophysical methods of investigation have been used to determine the broad geological structure of the Irish Sea area, notably seismic shooting (which is mentioned later) and the use of airborne magnetometers. The latter work has been done by two specialist companies on contract to the Geological Survey. The results of this have been published in map form (Ordnance Survey, 1965). 'Highs' on the map imply that the magnetic basement rocks are relatively shallow, as for example along the east side of the Isle of Man. 'Lows' suggest the basement rocks are much deeper as they would be under sediment-filled basins, and under granite masses.

The aeromagnetic map shows fairly good correspondence with the gravity anomaly map except along a 20 mile zone trending north west, roughly midway between Fleetwood and Ramsey, where there are sharp changes in magnetic values. This could possibly represent a dyke, but the anomalies are so strong that they are probably caused by a much more complex structure.

OIL OR GAS TRAPS

For oil or gas to be found in economic quantities it must have collected in the pores of some suitable 'reservoir' rock, escape upwards to the surface being prevented by a suitable impermeable 'trap' rock.

But what of the original source of the fuel? Most of the discoveries in Britain so far are thought to represent oil or gas which was generated in rocks of Carboniferous age and which has not migrated far from these source rocks. In the East Midlands most of the strikes have been in sandstones of the Millstone Grit Series or the Coal Measures.

However, in the case of the Formby oil and the North Sea gas the fluids have migrated upwards from Carboniferous into Permo-Triassic beds. There seem to be a few likely situations of this type which might be encountered in the Irish Sea (Figure 2). The most likely reservoir rock is the Collyhurst Sandstone at the base of the Permian and equivalent to the Rotliegendes Sandstone of Holland (in which is the largest natural gas field in

* See addendum at end of article.

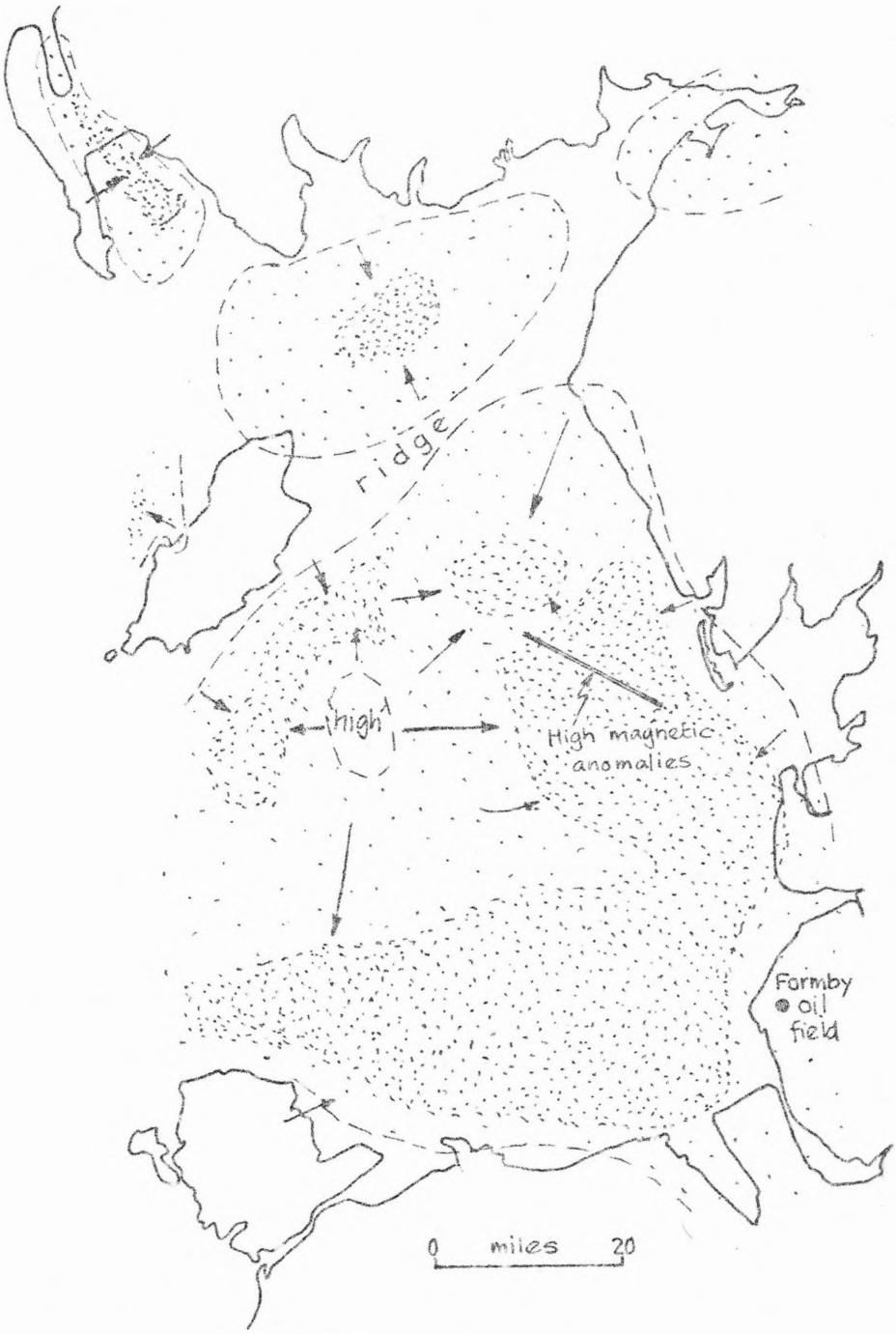


Figure 1: SEDIMENTARY BASINS

The stippled areas represent sedimentary basins; the deeper parts are more closely stippled. Arrows indicate transport of sediment. Northern part based on Bott, 1964, southern part on Aeromagnetic Map.

the world, the Groningen field). The Collyhurst Sandstone is a windblown deposit and it varies considerably in thickness. Formby No. 1 borehole penetrated 2,345 feet, but in the Manchester area it is sometimes absent. Since it was deposited on a most uneven land surface it is found banked up against post-Carboniferous/pre-Permian hillsides and fault escarpments (Figures 2a, 2b). It is overlain by up to 750 feet of the impermeable Manchester Marls which would form a good cap rock.

If oil or gas were to occur in the Collyhurst Sandstone it is most likely that suitable structures would be found near the margins of the sedimentary basins.

It is also possible that fuel reserves may be associated with thick salt deposits (Figure 2c) as in the North Sea. The salt would form an excellent cap rock for Permian sandstones below. Where the salt has been buried beneath a considerable thickness of sediments it can flow under pressure and rise upwards in the form of domes or columns (diapirs) often four or five miles across. This movement may draw up the sandstone below into an ideal oil or gas reservoir. Salt domes are now thought to be fairly common under the North Sea and it is quite probable that they will be found in the sedimentary basins of the Irish Sea.

EXPLORATION

Practical interest by oil companies started in 1965 with a seismic survey carried out from March to May over most of the Irish Sea east of the Isle of Man, an area of about 1000 square miles. The work was undertaken by Signal Oil & Gas Co. on behalf of a consortium comprising Signal, Amoseas, Burmah Oil, B.P., Shell-Esso, Phillips and Gulf Oil. It involved setting off explosive charges in the sea and picking up the sounds reflected by different rock layers by the use of floating hydrophones. From the records a picture of the probable underground structures emerged.

In August 1965 the Irish Sea east of the meridian 5°W was designated under the Continental Shelf Act 1964. The Ministry of Power invited applications for production licences covering blocks of approximately 100 square miles (Figure 3). So far Gulf Oil (Great Britain) Ltd. has taken five blocks north of Liverpool Bay. Much more detailed geophysical work needs to be done before actual drilling can start; Gulf intends continuing its survey during the 1967 season.

The waters round the Isle of Man are a special case. The concession out to the three mile limit rests with Isle of Man Petroleums Ltd., but this company's chief activity is the planned installation of a refinery on the island and there seems little likelihood of finding oil or gas close to the shore anyway.

PROSPECTS

It seems quite likely that either oil or gas may be struck in the next few years under the eastern Irish Sea, probably in the south eastern sector off the Lancashire coast. It is an unexplained fact that oil is more likely to be found than gas as one approaches the Pennines, and gas is more probable as one moves away from them. This is no doubt related to the history

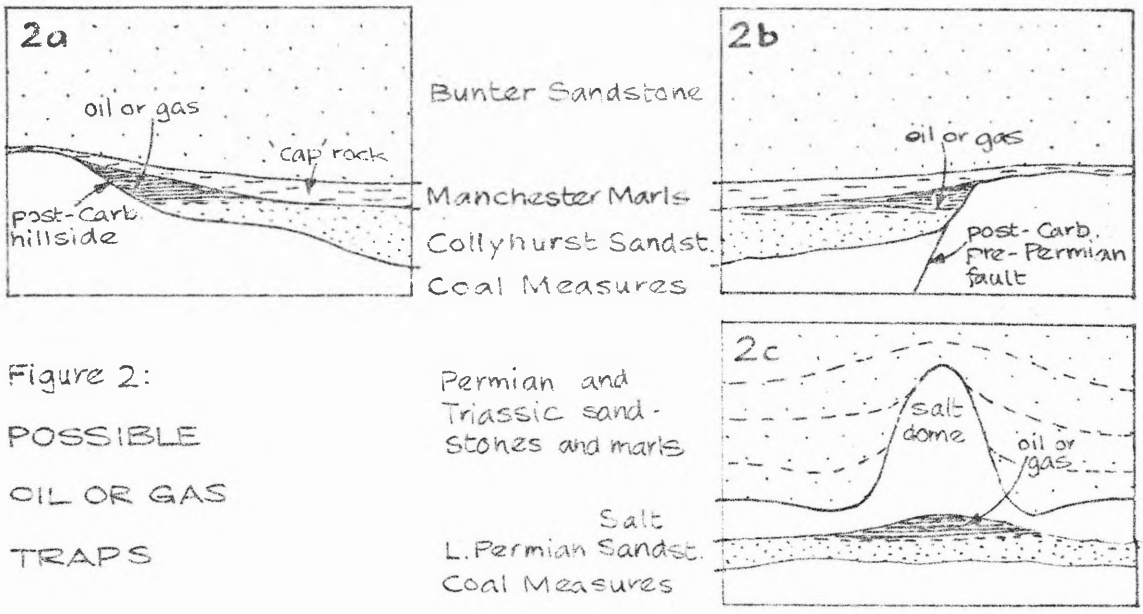


Figure 2:

POSSIBLE

OIL OR GAS

TRAPS

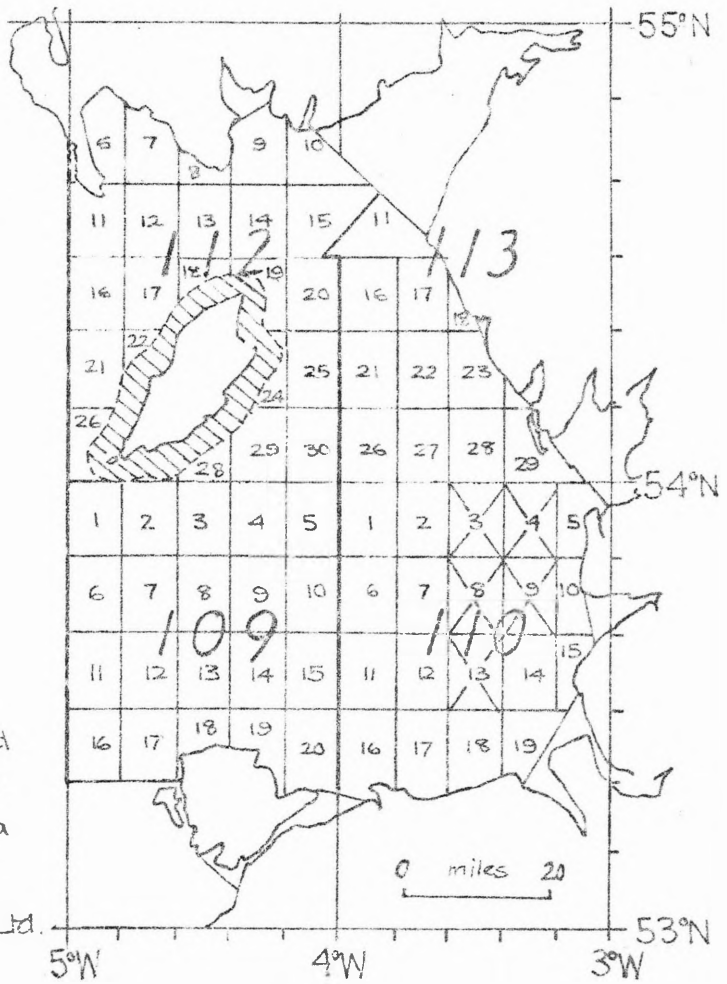


Figure 3:

OIL AND GAS

LICENCE AREAS

Blocks 110/3, /4, /8, /9 and /13 awarded to Gulf Oil (Great Britain) Ltd; area around Isle of Man to Isle of Man Petroleums Ltd.

of sedimentation during the Carboniferous and Permo-Triassic periods, when the Pennines rose as a landmass above the sea.

It is this sedimentation history which raises some doubts. The potential reservoir rocks vary considerably in thickness and there was a long time interval during which the likely Carboniferous source rocks were exposed to erosion above the sea before the Permian sands were deposited.

However, the most likely factor determining whether Irish Sea oil or gas will be exploited is the economic one. With the promise of abundant North Sea gas, will it be able to compete? Will the incentive remain?

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ADDENDUM

Paragraph 1 on page 14 continues:

Moreover sedimantation almost certainly continued through the Jurassic and Cretaceous periods since there are indications that the Chalk was laid down somewhere between the Isle of Man and the Cumberland Coast.

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This is the third article in the series on celebrated geologists whose names are connected with the Lake District

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Robert Harkness, F.R.S., F.G.S.

"Robert Harkness might fairly have laid claim to have known more about the geological structure, the fossils, minerals and the natural features of Cumberland and Westmorland than any one man possessed before his time, or, it may be safe to prophesy, than any one man even in these days of facile locomotion will ever possess again."

So wrote J.G. Goodchild of the Geological Survey when the Professor unexpectedly departed this life in October of 1878. This, it may be felt, was a remarkable claim, but one which the following facts may do something to justify.

Robert Harkness was born on the 28th. July 1816 at Ormskirk in Lancashire. He was educated first at home and later in Dumfries at the home of Dr. Duncan who was minister of Greyfriars. From there he went to Edinburgh University where he attended the lectures of the well-known Wernerian geologist, Professor Jamieson, as well as those of Professor J.D. Forbes. Back in Ormskirk he gave his attention to local geological problems with such zeal that in 1843 he was reading his first paper to the recently-formed Manchester Geological Society. The paper dealt with the climate of the Coal Period with remarkable insight. In these days of easy communication and travel it is not easy for us to appreciate the difficulties under which the early geologists laboured. To a large extent what a worker found out, he found out for himself. Textbooks were few, and geological maps were virtually non-existent. Of every half dozen fossils found there was a distinct possibility that one had never been named or described before. A student of today might easily assimilate more during a few years intensive study than a man of Harkness's day might compass in the years of a long and active life. This should never be forgotten. Metaphorically, we stand on the shoulders of those who have gone before.

In the year 1845 Harkness, along with E.W. Binney, was contributing to the Geological Society on such widely divergent topics as the Fossil Trees of St. Helens, and on fossils found in the Boulder Clay, the latter being in those days a highly controversial subject.

In 1848 Robert Harkness moved with his family to Dumfries and at once began an extensive study of the rocks of the area. Amongst other places that attracted him was Moffat and its graptolite bearing shales. This was a locality which apart from a few rapid traverses by Sedgwick was entirely new. In 1850 the British Association held its meeting in Edinburgh, and Harkness, attending for the first time, found an exhibition of graptolites put on by Adam Sedgwick. The two met, immediately became friends, and to Harkness's delight he was introduced to John Ruthven of Kendal, Sedgwick's celebrated fossil collector. In all probability it was due to this meeting with Sedgwick that Harkness began to refer his finds to J.W. Salter for identification.

In fact it was the year before this meeting that Harkness first visited Cumberland in pursuance of the similarities he found between the New Red rocks of the Solway Basin and those of the Lancashire Plain where he was born. The outcome of this was a paper read to the British Association on the fossil footprints of the two localities. In 1851 he contributed a paper to the Geological Society on the Silurian Rocks of the Solway Basin, a paper that was so successful that it brought him letters from many of the leading geologists of the day and the gift of a collection of graptolites from no less a person than the celebrated Joachim Barrande of Bohemia.

About this time Harkness applied for the Chair of Geology at the University of Cork and, supported as he was by many eminent geologists, he got it. In the same year that he took up his professorship in Ireland he was elected a Fellow of the Geological Society, an honour which in those days was by no means lightly bestowed. In 1854 Harkness was elected a Fellow of the Royal Society of Edinburgh and in the same year Sir Henry de la Beche offered him the professorship at Roorkee in Northern India. After very careful consideration this offer was declined. The reasons for this action casting not a little light on the personal character of the subject of these notes.

Harkness said that his objections were threefold:-
(1) Whilst he was greatly attracted to the possibilities of such a virgin field he felt he would have hated to find himself coming back to England old before his time and alienated from his homeland, as so many Anglo-Indians seemed, in his observation, to be.
(2) Whilst the opportunities were great the restrictions were great also, for he could not imagine a life isolated from minds actively pursuing like objects with his own. Such fellowship was a reward not likely to be forgone.
(3) Lastly, and perhaps most importantly, he had always made his home with his sister. To live in India without her company was something he could not relish; to endeavour to persuade her to accompany him would be to do her a great injustice.

One can only assume that from then on Harkness was far too busy ever to have time to regret his decision, for in 1856 he not only published six papers, but he was elected to the scientific elite of the country as a Fellow of the Royal Society. Some of his papers concerned the geology of Cumberland and Westmorland. With Jonathan Otley just dead and Sedgwick too old and infirm for further work in the rough hill country of Lakeland, the opening was ready for Robert Harkness to apply his keen mind to some of the vexed problems of Lake Country geology. His purpose was strengthened in two ways. He received encouraging letters, full of suggestions, advice and questions so long as Adam Sedgwick could wield a pen. Since Harkness's nearest and dearest relative came to live in Penrith, what better place had he to spend his out-of-term time.

Between the British Association meeting of 1857 where he gave papers on the geology and mineralogy of the Caldbeck Fells, and 1862, he was very active in our area. Whilst he collected fossils from the Skiddaw Slates, and minerals as well, he returned again and again to the great problem of unconformity. According to the best estimates there was in and around Lakeland a gap between the Lower Palaeozoics and the Upper Palaeozoics which elsewhere was filled by approximately five miles of Devonian strata.

These missing rocks he sought and studied in other places, visiting Hugh Miller's country, where he was helped by letters and maps from Lyell and Murchison. The latter's assistance was not entirely without self-interest, for if he was still fighting a rearguard action in his claims to most of Adam Sedgwick's Cambrian, he might claim that what some people classed as Lower Devonian should be Upper Silurian and the Upper Devonian should belong to the Carboniferous! Perhaps we see a remnant of these views in the fact that up to a decade or two ago our own Mell Fell Conglomerates were called Carboniferous Basement Beds.

In 1863 Professor Harkness published a paper on the Skiddaw Slates, with notes by Salter on the graptolites. In the same year he completed his work on the Palaeozoic rocks of the Pennine Fault area between Gamblesby and Warcop. This piece of mapping, which was entirely his own work, had never been attempted before. It was carried through with such amazing accuracy that the Survey, under Goodchild, later adopted it with little amendment.

It was about this time that Robert Harkness met for the first time one of Penrith's notable sons, H. Alleyne Nicholson, Professor of Natural History at Aberdeen. The two joined forces to work first on the Skiddaw Slates and later on the rocks of the Coniston Limestone group.

Perhaps one might be forgiven for thinking that here was a man enjoying a sinecure for eight or nine months of the year and working off loads of surplus energy during his vacations. In fact, nothing could be further from the truth, for although he was Professor of Geology at Cork he found himself responsible for the teaching of geography, botany and zoology as well as his own geology and mineralogy. Not surprisingly Harkness found these multifarious duties a bit too much of a burden so he applied for the Chair of Geology at Edinburgh. Unfortunately this appointment did not materialise so the ever-willing Professor carried on doing several people's jobs and in the meantime when he might have rested, working out the geology of the Isle of Man, looking for geological links between the Lake District and Ireland.

Between 1866 and 1870 Harkness and Nicholson published jointly no less than four memoirs on the older rocks of Cumberland and Westmorland. These were rewarding years. In 1867 J.G. Goodchild and his Survey team first met Harkness and with the bravado of youth assailed some of the Professor's theories and maps. Goodchild said later that Harkness, instead of meeting these criticisms with the impatience that nearly twenty years of work would have excused, listened patiently and quietly, smilingly refuting some of their more outrageous suggestions. It was this aspect of the Professor's personality, every bit as much as his scientific distinction, which made him such a popular figure amongst the scientists of his day. His popularity culminated in his election as President of Section C of the British Association Meeting at Exeter in 1869. On this occasion his Presidential Address was devoted to the Devonian and its associations, appropriately enough. About this time he was writing to John Phillips ("Strata" Smith's nephew) about the distribution of the Shap erratics, and working with Dr. Hicks on the fossils of the Menevian Beds. Together they wrote a paper on this subject, a paper which could not be expected to endear them to Roderick Murchison.

The long years of a very active life on top of the cares of three men's jobs were beginning to tell, and in 1877 Robert Harkness decided to leave Cork, settle in Penrith with his sister, and devote the rest of his days to the study of the area he had come to love so well. With this decision made he crossed to Cork late in 1878 to bid farewell to his colleagues and friends, when suddenly, on the fourth of October, he collapsed and died of heart failure. His body was brought back to his sorrowing sister, to be buried in Penrith churchyard. At a later date she gave all the Professor's collections to Carlisle Museum and there they remain to this day, a fitting memorial to a great geologist.

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

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THE OCCURRENCE OF CALAMITES FOSSILISED IN SITU IN THE COAL MEASURES AT BRANSTY CLIFFS, WHITEHAVEN.

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R. E. O. PEARSON

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The Coal Measures exposed in the cliffs north of Whitehaven may be approached through the yard of the now-closed William Pit, and by following the disused waggon way towards Parton. The sandstone cliffs forming the coastline north of Whitehaven belong to the Lower Division of the Sandstone Series, known locally as the Whitehaven Sandstone. That portion which extends from William Pit to Parton consists of a yellowish-grey to whiteish freestone, used extensively in and around Whitehaven, notably in the building of the harbour. The sandstone contains layers of argillaceous rocks with haematite and coal.

The cliffs average more than 100 feet in height, and at William Pit the Sandstone Series extend to some 120 feet below sea level.

Good specimens of Coal Measures fossil flora may be collected from the

friable shales which alternate with massive freestone along the exposure. The thickness of the shales where the best fossils may be obtained varies between 50 and 80 feet. The sandstone also contains some fair impressions, mainly of Sigillaria.

It may be of interest to note that the earliest record of fossils in this area comes from John Woodward's "Catalogue of English Fossils", published in 1729. The fossils in question are those of nearly complete Calamites found in a section of the Bransty Cliff exposure. The fact that they are upright, in the position of growth, raises the question of how they were fossilised in this attitude when fossilisation is known to be such a slow process. For fossilisation of the type in question to occur, the plant tissues must be replaced by silt before the plant has time to disintegrate due to decay.

There are three main ways in which plant remains are preserved:

IMPRESSIONS result from the transport of plant fragments by water. The softer tissues decay after a time, and gradually the gases imprisoned in the plant cells are replaced by water, causing remains to sink to the bed of river, lagoon or sea. Here they are rapidly covered by layers of sand, silt or mud. Individual leaves and smaller fronds, because of their shape and size, lie flat on the bottom, their tissues being altered during the lithification of the sediments to thin films of carbonaceous material. These are termed "Impressions", and locally are best seen at the Whitehaven Brickworks Quarry.

The larger stems and trunks decay unequally, the pithy inner tissues disappear rapidly whilst the more resistant bark takes longer. When the inner pith decays it is replaced by mud resulting in so-called "pith casts". The sediment enclosing the outside of the stem takes on the inequalities of the surface of the resistant bark hardening in course of time into a mould.

MUMMIFICATION involves the whole or part preservation of the actual plant tissue, and is caused by the rapid covering of plant fragments by very fine clays which by the nature of their closeness of texture exclude all air and keep decay to a minimum.

Thirdly, PETRIFACTION occurs when plant remains are preserved by water charged with minerals, chiefly lime or silica. In this manner an exact replica of the specimen is preserved in stone. The occurrence of plant remains in limestone concretions known as "coal balls" has given a great deal of information about tissue structures of Coal Measures plants.

The explanation of the occurrence of the fossil Calamites under consideration appears to be that the plants were rapidly inundated by a rise of mud, brought in perhaps by the breaking down of a nearby river bank in time of flood.

To quote from an article in the German magazine 'Natur und Volk' written by H. Klusemann and R. Teichmüller. "When such a 'bark tree' stands upright in a very fine-grained sandstone, we have to admit that something like this happened. Firstly layers of mud accumulated around the still-living tree, with the result that it finally choked. Its trunk rotted inside. The crown of the tree fell to pieces and in the hollowed-out trunk mud slipped down from above, the same mud as that which settled around the trunk. All this cannot have lasted a long time: perhaps just a few months.

maybe a few years, but certainly not longer, otherwise the stump would have decayed under the warm humid climatic conditions prevailing in Coal Measure times, before a mould could have formed."

The article then goes on to explain the phenomenon with the Ruhr Coalfields in mind. Since it is likely that conditions would have been similar in the Coal Measure forests in our part of the world, I can do no better than to continue quoting from the same article.

"This mud must therefore have been deposited rapidly, much more rapidly than is generally admitted for mud layers in the Ruhr Coalfield. This is based on the following considerations. Supposing the Westphalian epoch lasted about twenty million years, as is generally admitted, and that the thickness of the beds deposited during that time amounts to 2,500 metres. The soil can have subsided during this space of time at the rate of not more than 0·1 to 0·2 m.m. per annum. The layer of mud deposited annually must have had a corresponding thickness."

"This does not exclude the possibility that in a dell (depression), mud may have accumulated at a much greater rate - for instance the case of river loam filling in and burying the forest in time of flood."

Such then must have been the conditions prevailing at the time of formation of the Calamite fossils in the Bransty Cliffs. Examination of the rock types at this site, together with the shales worked by the Whitehaven Brick and Tile Company in their quarry at Low Road, Whitehaven adds further weight to the theory. The Bransty rock is of an arenaceous nature, indicative of the faster-flowing water consistent with flooding. The Brickworks rock is argillaceous and the fossils found are mainly leaflets and small fronds. This does, I think, point to a slow-running inwash area where the mass of small debris from the forest collected in a backwater. The small leaves settled on the mud, and being small and flat, were covered by fresh mud quickly enough to stop decay. The rate of deposition of mud would, however, be too slow to preserve large pieces, and it is rare to find anything of size at this site.

I would ask readers of this article to treat the Bransty site with care since places where good geological phenomena may be examined by the serious student are becoming fewer each year. It is up to local geologists to keep a careful watch on what is left.

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ZEOLITES

Lecture delivered by Dr. G. McL. Biggar of Edinburgh University on March 15th. 1966 at Whitehaven College of Further Education.

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Dr. Biggar commenced by defining zeolites as a group of hydrous alumino-silicate minerals, and describing their occurrence in the field. The first area studied was that of the Antrim Plateau Basalts of Northern Ireland, and slides were shown of the basalt lava flows covering Cretaceous sediments, of the famous columnar structures in the Giant's Causeway, and of a geological map of Northern Ireland to show the extent of the basalt cover. G.P.L. Walker has painstakingly examined the Antrim basalts which contain some zeolites in the body of the rock but which in addition contain abundant zeolites in amygdules. These amygdules are blow holes in the lava probably formed by gas boiling out during solidification, and they have subsequently been filled by secondary mineralisation. Walker records details of the minerals present in more than 750 amygdules.

One of the zeolites found abundantly in Antrim, gmelinite, is rather uncommon on a world-wide scale. In Northern Ireland it occurs only in the eastern zone from Glenarm to Island Magee. Gmelinite occurs as crystals up to 1 cm. long in the amygdules. Analcime, one of the common zeolites, occurs with the gmelinite, but in an unusual habit as small transparent crystals and not in its more usual habit as large dull-white crystals. The gmelinite is confined to the lowest lavas, and its occurrence has been mapped as a dome-shaped zone 50 ft. high at the edge and up to 500 ft. high at the middle.

Walker also succeeded in mapping other zeolite zones to the west, away from Island Magee. The lowest of these zones is one of analcime and natrolite, which although occurring in the same locality are seldom both found in the same amygdule. This zone is succeeded upwards by one of thomsonite and chabazite. In the south of the district there is a small zone of intense late zeolitisation where some remarkable crystals of chabazite have been formed by replacement of an original gmelinite compound twin. These chabazite replacements have no less than fourteen crystals intertwinned, and as each individual crystal has eighteen faces, this makes a total of two hundred and fifty two crystal faces.

Further mapping has shown that the habit of the crystals varies from the bottom to the top of a zone, an interesting point illustrating that the shape or habit is not just a random assemblage of crystalline faces, but it is controlled by the physical and chemical environment at the time of crystallisation, in this case, some variation in temperature or pressure between the base and top of a zone.

Although at first sight the zeolite zones appear to conform to the layering of the lavas, this is not the case. The zones have been found, by careful mapping, to transgress the lava flows showing that they are not contemporaneous. It is believed that the zeolites formed as a result of zoning in a waterlogged pile of basalts.

After this description of zeolite zoning in the basalts of Northern Ireland, Dr. Biggar showed some interesting photographs of vulcanicity in

Iceland, a present-day expression of the sort of volcanic outbursts that gave rise to the rocks and minerals under consideration.

At this point the lecturer referred to the geology of New Zealand in order to give further examples of the use of zeolites in the zoning of lava flows. The geology of New Zealand is dominated by the New Zealand geosyncline and to the south, the remnants of the older Southland geosyncline. The areas under consideration are at Taringatura in Southland and the Otago chlorite schists.

At Otago the chlorite schists grade eastwards into unmetamorphosed rocks or semischists and extend northwards as the basement of North Island. The characteristic minerals of these semischists allow them to be divided into two zones known as the prehnite zone and the pumpellyite zone. To the west the usual higher metamorphic sequence is exposed, zones of biotite, garnet, staurolite, kyanite, sillimanite, etc.

In Taringatura the prehnite zone is also exposed, although not in the same rocks as in the north, for this is a different geosyncline. In this case the higher zones are not exposed, but an extremely interesting set of lower zones is shown, and these zones have been defined on the basis of the zeolites present in the rocks. These zeolites occur in volcanic ash beds and in andesitic lavas which are members of the sedimentary sequence. The zeolites have been formed by the alteration of fragments of volcanic glass, and significant mineralogical changes, starting with the least altered rocks, gives the following zones:

Heulandite and analcime.
Laumontite.
Pumpellyite.
Prehnite.

The minerals in these zones form a dehydration series, as might be expected in rocks being successively heated and compacted by the accumulating sediments above them.

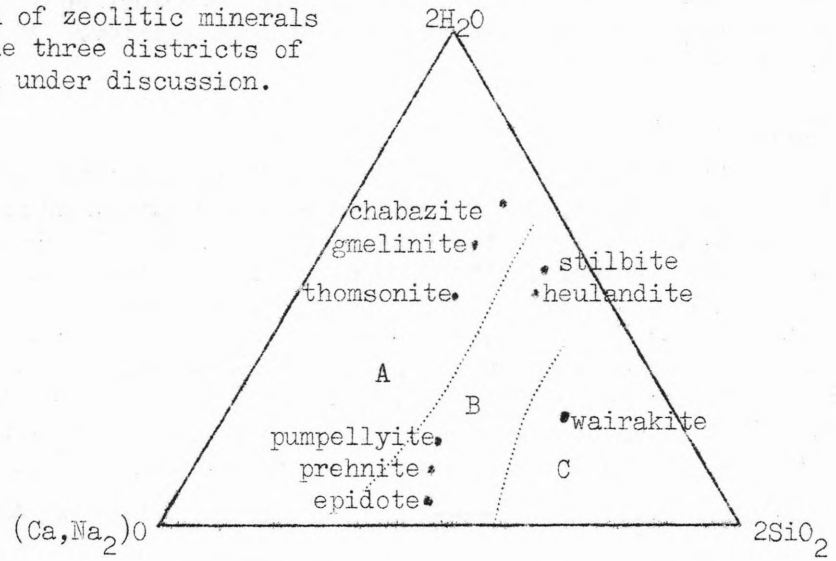
In a zone of crushing and faulting at Otama the detrital plagioclase of the sedimentary rocks has reacted and been replaced by zeolites. It is likely that the crushing has allowed free access of water to the rock, and it may also have increased the surface area, for zeolitisation is fairly complete. Normally the process of zeolitisation is confined to alteration of volcanic glass, this being more reactive than a crystalline compound, although as just mentioned, under favourable conditions the less reactive crystalline plagioclase may be transformed. In North Island it is possible to observe active zeolitisation. In the boreholes that have been put down to provide the inhabitants with hot water, a zeolite called wairakite has been recorded as an alteration product of volcanic glass. Here the waters, at temperatures up to 250°C. under pressure are supersaturated with silica. The relationships of the three zeolite occurrences have been summarised in Figure 1.

Zeolite Facies

Based mainly on the work in New Zealand, a proposal has been made to establish a zeolite metamorphic facies. Metamorphic facies represent different ranges of temperature and pressure to which rocks have been

FIGURE 1.

Composition of zeolitic minerals found in the three districts of New Zealand under discussion.



Area A. At Otago in North Island, the zeolites occur in altered alkali basalts, an environment poor in silica.

Area B. At Taringatura the zeolites occur in andesites and rhyolites, both richer in silica as reflected on the composition diagram.

Area C. In a region of the North Island known to be silica-saturated, the silica-rich zeolite wairakite is found.

subjected. The zeolite facies bridges the gap between sedimentary rocks and the previous lowest grade of metamorphism, the greenschist facies. Increasing metamorphism gives rise to such rocks as glaucophane schist, almandine-amphibole, granulite and eclogite. Generally the temperature and pressure involved in the zeolite facies would be up to 300°C., and 4,000 atmospheres. It is possible to deduce the chemical changes that occur as sediments are heated and compressed over this range:

i. The reconstitution of clay minerals and the recrystallisation of volcanic glass.

ii. The destruction of detrital grains of high temperature minerals, notably plagioclase on which hydrated reaction rims may develop.

These changes result in the progressive crystallisation of the following mineral assemblages:

a. Quartz, albite, heulandite.
b. " " laumontite.
c. " " pumpellyite.
d. " " prehnite.

In the next metamorphic facies, the greenschist facies, the process of destruction by dehydration occurs. Sodium zeolites give albite, and calcic zeolites give epidote. Thus the occurrence of zeolites is confined to the zeolite facies.

One point of supreme importance is that only rarely is the process of zeolitisation taken to completion, as for example in the fault zone at Otama. Normally the rocks do not attain chemical equilibrium, the most common evidence for this being the continued existence of detrital plagioclase with reaction rims.

Experimental Work

Synthesis of most zeolites is a relatively easy task using hydrothermal conditions of up to 4,000 atmospheres of water vapour pressure and temperatures up to 400°C. The determination of stability fields has, on the other hand, proved difficult, the reason being apparent from previous remarks about disequilibrium in natural rocks. The experimentalist has found that different minerals are stable under identical laboratory conditions, depending on the reactivity of the starting materials. Oxide mixtures, gels, glasses and pure natural minerals have all been tried as starting materials as has the seeding of mixtures with different minerals. One series of experimental reactions shows successive dehydration and desilicification:

$$\underset{\text{Heulandite}}{Ca_2Al_4Si_{12}O_{32}.12H_2O} \longrightarrow \underset{\text{Laumontite}}{Ca_2Al_4Si_8O_{24}.8H_2O} + 4H_2O + 4SiO_2$$

$$\underset{\text{Laumontite}}{Ca_2Al_4Si_8O_{24}.8H_2O} \longrightarrow \underset{\text{Anorthite}}{2CaAl_2Si_2O_8} + 8H_2O + 4SiO_2$$

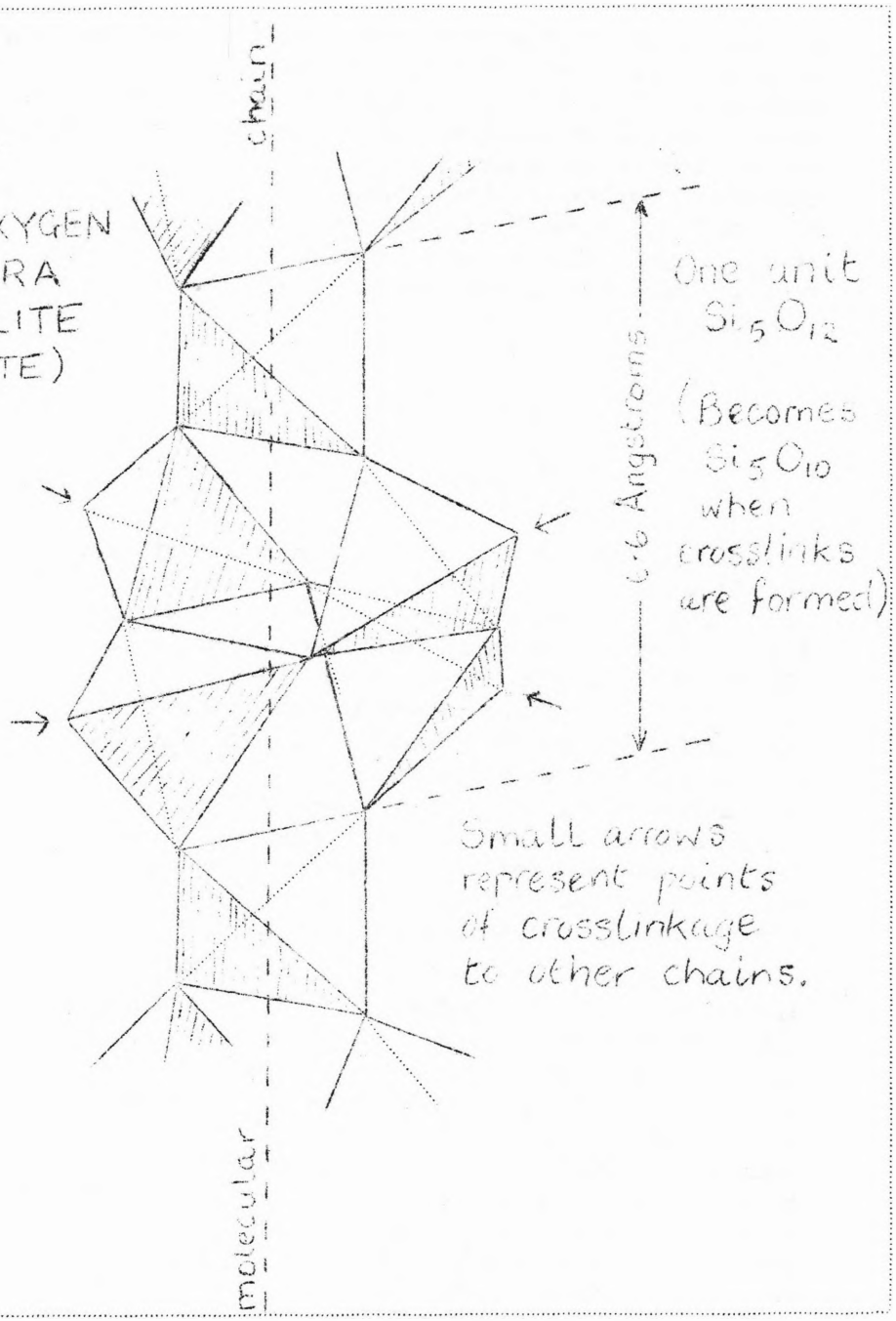
It has been suggested that the mechanism by which volcanic glass is converted into a zeolite is a sort of ion exchange reaction in which hydrogen ions attack the glass and liberate sodium ions. The resulting sodium hydroxide solution then leaches silica out of the glass. From the experimentally determined corrosion rates of volcanic glass in water it has been calculated that the average size of volcanic glass particle would take between 300 and 3,000 years to dissolve, given suitable geological conditions.

The lecturer went on to illustrate linking of single SiO_4 tetrahedra to form chains which in turn constitute the framework of many silicate structures. He demonstrated, by using models, the various ways of linking these tetrahedra apex to apex to form a great variety of units and chains; simple chains with varying degrees of "twist", double chains and multiple chains all occur. A model of one unit of a complex chain (Figure 2) was shown, and it was seen to contain five tetrahedra linked apex to apex; the complete chain would be made up of a great number of these units, each of which is 6·6 Ångstrom units in length. Such a chain is merely one thread running through the crystal structure. The complex crystalline framework is obtained by crosslinking the chains by means of the free apices of the tetrahedra, but a further complication is here introduced, as it will readily be seen that there are several methods by which this crosslinking may be effected, either with the chains running parallel or counterparallel to each other. Whatever the arrangement at the molecular level in zeolite structures, it will be appreciated that the structure is very open, and the spaces or channels running along or across the chains have widths which vary with the actual zeolite and depend on the details of its structure.

A number of modifications to the basic silicon-oxygen tetrahedral

Figure 2.

A TYPICAL CHAIN OF SILICON-OXYGEN TETRAHEDRA IN A ZEOLITE (NATROLITE)



structure were next discussed.

i. Silicon can be replaced by aluminium in a tetrahedron, giving an increased negative charge. However, the ratio of SiO_4/AlO_4 cannot be less than unity.

ii. The cations, typically Na^+ or Ca^{2+}, about 1·0Å in size, lie recessed in the channels of the structure.

iii. The "free volume" available in the channels is normally completely filled with water molecules, occupying anything from 10-50% of the overall structure.

iv. The fibrous nature of many zeolites, e.g., natrolite, is due to the existence of few crosslinks between chains.

Dr. Biggar developed the principles of zeolite structures by referring to natrolite, a simple chain structure, phillipsite, a double chain, and mordenite with a very complex structure. The mordenite group is interesting as it contains particularly wide non-intersecting channels running parallel to the crystallographic c-axis. The numerous ways of crosslinking the chains of complex zeolites present a challenge to the chemist who, whilst able to "tailor make" complex organic polymers, finds it rather more difficult to synthesise these inorganic zeolite polymers. Still, a great many zeolites have been synthesised some of them having no natural counterparts. By substituting ions of similar charge but different sizes the chemist can change the dimensions of the channels and apertures in zeolites. The chief substitutions are:

Germanium for silicon.
Gallium for aluminium.
Rubidium, caesium, ammonium or methylammonium for sodium.
Strontium or barium for calcium.

Having outlined some of the structures of zeolites the lecturer shifted his emphasis to the channels and windows in the structures, showing by means of slides and models some of the many shapes and sizes of these cavities and apertures in different zeolites. It is from the natures of these windows and channels that the most useful properties of the zeolites stem. Water is not the only molecular species that can fill the free volume of the cavity; it can be replaced by a great many fluids, a property for which the zeolite family finds commercial applications. The water can be removed by heating or by outgassing under vacuum, and the dry zeolite can then absorb a great variety of guest molecules, but in a highly selective manner with the windows acting as guards to prevent absorption of any molecules too large to pass through. The zeolite is then acting as a "molecular sieve", and in fact this term is often used to describe zeolitic compounds.

The remainder of the lecture was devoted to the subject of molecular sieves and their applications. Of a mixture of hydrocarbons for example, only the straight-chain molecules can be absorbed by the zeolite chabazite. Molecules with branched chains, cycloparaffins and aromatic hydrocarbons pass by unabsorbed. Methanol can be separated from acetone by absorption in the same zeolite. The state of the liquid absorbed in a zeolite is unusual. Since the cavities are linked, the liquid can be imagined as a tenuous filament woven into and around the zeolite framework. The liquid behaves as a gas in the sense that the liquid molecules are distributed throughout the available pore space just as gas molecules distribute themselves in a flask. The liquid is subject to the usual effects of thermal expansion and the number of absorbed molecules decreases as the temperature rises. In a saturated zeolite, the packing density of the guest molecules approaches that of the bulk liquid but never quite reaches it, due to small steric effects. On the other hand, the mobility of the liquid molecules is severely limited by the restricted channels and by weak chemical bonding to the zeolite structure, and in this sense the liquid has some of the attributes of a solid, in particular, a very low self-diffusion rate.

The guest molecule in a zeolite therefore does not "feel quite itself", and its behaviour and properties are considerably modified. For example,

in the zeolite cavities, liquid molecules are subject to attractive forces which affect their bond strengths, often resulting in such processes as catalytic oxidation, "cracking", polymerisation and disproportionation. Representative reactions are:

$$4NO \quad \text{-----} \quad N_2O + N_2O_3$$

$$CH_3.CH_2Cl \quad \text{-----} \quad CH_2{:}CH_2 + HCl$$

$$CHCl_2.CFCl_2 \quad \text{-----} \quad CCl_2{:}CCl_2 + HF$$

The last reaction is interesting in that the hydrofluoric acid produced by the catalytic effect of the zeolite attacks its silicate structure, a self-destructive process.

The "windows" of the zeolite structures, being the entrances to the molecular sieve, are worthy of study. They are bounded by puckered (or occasionally planar) rings of oxygen atoms and are able to distort slightly to admit a molecule that might, on purely geometrical considerations, be considered too large to enter. Several factors, apart from basic molecular structure, have a control on the window size:

i. Temperature and the effects of thermal expansion and contraction.
ii. The size of the univalent or divalent ions (usually Na^+, K^+ or Ca^{2+}) which partly block the windows.
iii. The numbers of ions, for example the substitution of one Ca^{2+} ion for two Na^+ ions. In most cases the calcium zeolites have the larger effective windows.
iv. Changes in zeolite composition, particularly the substitution of (Na + Al) for Si.
v. Water, or any other strongly absorbed solvent, can be used to restrict the available free space and window size.

In concluding, Dr. Biggar summed up the uses of zeolites. From the chemical point of view, zeolites are useful drying agents, particularly for ketones and alcohols. They can be used in analytical procedures, selectively removing or sieving water, ammonia or certain hydrocarbons. In the geological field they are useful in the zoning of volcanic lavas, and may serve to zone low grade metamorphic rocks if the zeolite facies gains recognition. The main drawback to this is the practical difficulty of recognising zeolites in the field, or even in the laboratory by their optical properties. X-ray diffraction techniques are required for certain identification.

After Dr. Biggar had answered a number of questions put by the audience and passed round some excellent specimens from the Currie Collection, the meeting was concluded.

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MINE VISIT - THE LONG MEG ANHYDRITE MINE

On Saturday, 12th. March, 26 members visited the Long Meg Mine at Little Salkeld and were shown round by the Mine Manager, Mr. B. Cowan, F.G.S. The mine is worked by British Gypsum Limited and is of similar formation and age, namely Permian, to the Solway Chemicals Anhydrite Mine at Whitehaven. The Long Meg Mine is worked for both anhydrite and gypsum which are used in the manufacture of sulphuric acid, cement and plaster. The gypsum and anhydrite are found in the St. Bees Sandstone and Shale which lie above the Penrith Sandstone. These rocks are covered at the surface by deposits of boulder clay. It was interesting to see the equivalent of faulting in the anhydrite known as "rolls", the biggest roll seen being of considerable thickness and depth.

There are four beds of anhydrite, labelled "A", "B", "C" and "D". Bed "A" being the lowest and 100 feet in thickness is not found in the mine but is shown by boreholes to commence at Kirkby Thore at the nearest point, some nine miles away. The "B", "C" and "D" beds are found in the mine. Beautiful specimens of satin spar and selenite were obtained, as well as massive gypsum and anhydrite. Each bed shows an irregular alternation of anhydrite and gypsum (cf. Proceedings No.1, 1963, p. 19) with the gypsum being more plentiful in areas where groundwater has gained access.

After thanking Mr. Cowan for an excellent visit, the party dispersed, some for food, and some to pay a call on Long Meg and her Sisters.

R.H. Hewitt.

Dent Excursion, continued:
an old glacier lake, and fine sections of lake bottom sediments were seen in the banks of Kirk Beck. Just before Uldale Farm, a rising track through the trees was followed to a junction where a fine view across the valley can be had. A single dyke has been exposed at this point. At the water-tank above the forest a faint track going W.N.W. to the summit of Dent brought the party to a group of three dykes of altered basaltic material, not too well exposed near the western end of the summit plateau.

Having seen the many dykes, some noted by the Geological Survey, and others exposed since by the activities of the Forestry Commission and brought to the notice of the Society by Mr. Bland, the party made its way down to the road and so homewards.

EXCURSION TO THE INTRUSIVE ROCKS IN SKIDDAW SLATES OF THE DENT ANTICLINE

Sunday, 17th. April, 1966 Director: H. Bland.

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Geological Features

The general structure of Dent is that of a much denuded anticline in the Skiddaw Slate series, being the westerly end of the major E.N.E.-W.S.W. anticline extending through the Lake District from Skiddaw to Dent and formed chiefly as a result of the Caledonian movements which took place at the end of the Silurian. The axis of the anticline in the Dent locality appears to pass through Flat Fell and the summit of Dent in the direction of Row Farm (south of Black How) and is pitching in a westerly direction.

The younger beds of the Skiddaw Slate series (Mosser-type slates) appear in the north, west and south-west, encircling the core as exposed on Flat Fell. The major anticline was at a later date subjected to intense pressure at a slight angle to its axis resulting in numerous smaller folds and corrugations being superimposed on the major anticlinal fold. The stresses were sufficient to cause intense crumpling and brecciation in places, but they did not induce cleavage to any extent.

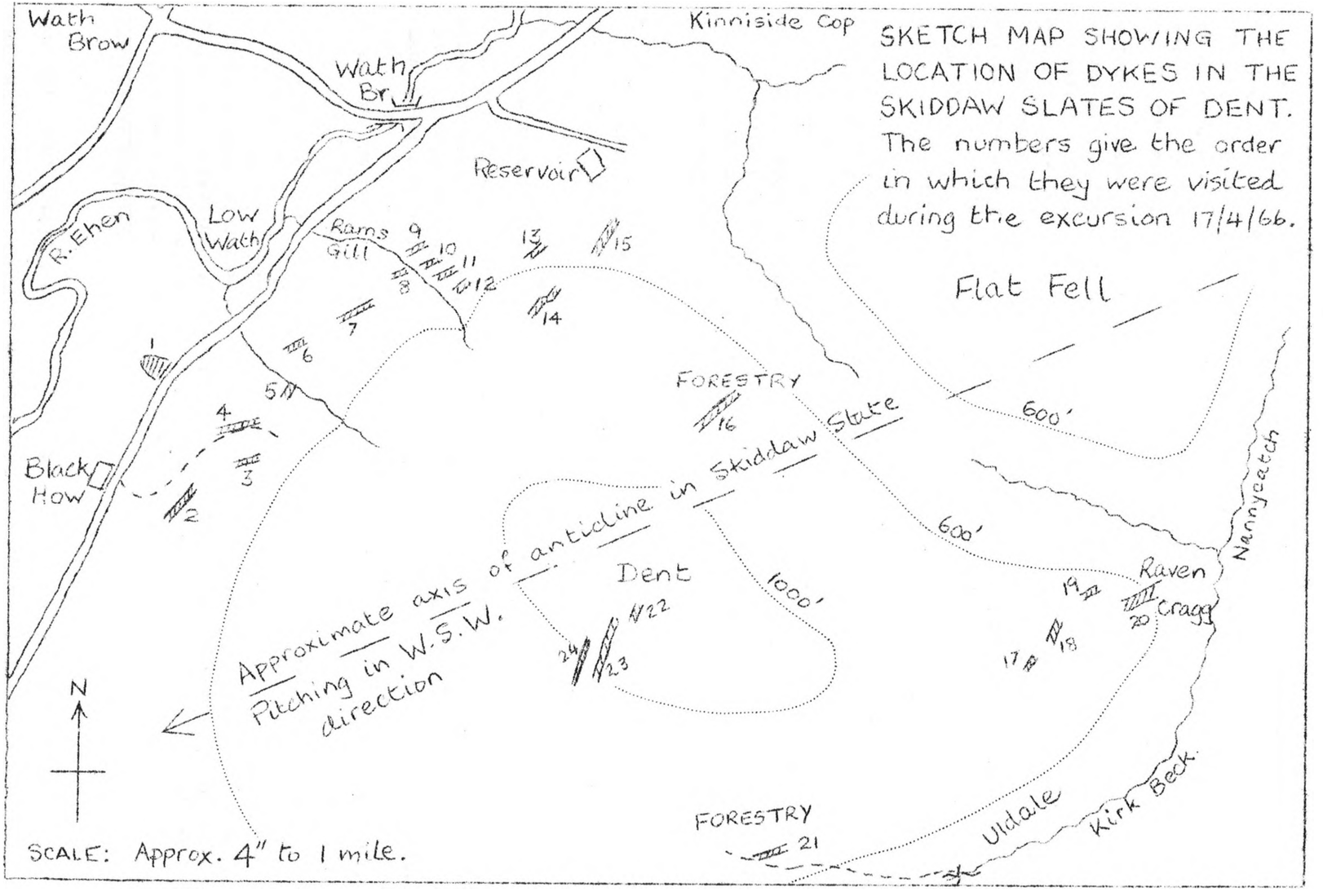
Dyke swarms, probably intimately connected with the minor folds, occur on both flanks and on the axis of the main anticline. The chief purpose of the excursion was to investigate the location and character of these dykes. More than twenty dykes, mostly of felsitic or andesitic rock, were traced, and as forestry roads are exposing rock along most of their length, some hitherto undiscovered dykes have been revealed.

Details of the Excursion

After assembly at Wath Bridge, the party of thirty members proceeded along the fell road towards Black How, stopping at a point beyond Wath Farm (Low Wath) where a stream from Dent passes under the road. The country rock is well exposed in the banks of the stream and is similar in character to the Mosser Slates. Typical graptolites (Diplograptus dentatus) had been found there on another occasion. Just past this point the road crosses the first dyke, quite a substantial one which stands out as a small crag in the field on the right before Black How Farm. The contrast between the blocky nature of the igneous material and the more easily weathered Skiddaw Slate surrounding it was obvious. At the farm the party turned uphill through a small wood, moving up along the line of the second dyke, a distinct ridge set in steeply-dipping slates. The route then traversed the 500ft. contour passing several small felsite dykes until Rems Gill was entered just above a small wood. Here the party inspected five closely-set dykes of vesicular andesite, felsite and altered basalt. After striking obliquely upwards across the fellside in a S.E. direction, the Director led the party down to a large single felsite dyke by the side of a forestry road.

At the eastern end of the Dent "massif", four dykes were seen terminating in the rocky outcrop of Raven Cragg which affords a number of small problems for the rock climber. At this point the Director commented on the unusual features of the valley and its offshoots which had been largely excavated by the meltwaters from retreating glaciers (C.G.S. Proceedings, No. 2, 1963, p. 14 and No. 2, 1964, p. 10). Indeed, Uldale is the site of

Continued opposite:



SKETCH MAP SHOWING THE LOCATION OF DYKES IN THE SKIDDAW SLATES OF DENT. The numbers give the order in which they were visited during the excursion 17/4/66.

EXCURSION TO THE MURTON FELL AREA

Saturday, 21st. May, 1966. Leader: S.E. Gate, B.Sc.,M.Sc.,A.R.I.C.

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Historical Outline of Ore Workings

The oldest working was the Knockmurton Mine, opened about 1853: it is marked on the one-inch Ordnance Survey map. The shaft was only 40ft. deep.

Other workings often started as adits on the southern slopes of Murton Fell into and along the strikes of the veins which were then exploited vertically, in some cases to the surface. Generally, the depth of vein did not exceed 300 ft.

Neighbouring Keltonfell Top Mines were mainly shaft workings which in general were rather deeper, some shafts going down 600 ft., working the veins to the surface.

Below the levels quoted the ore "nipped out", became pyritous, or was not segregated from the slate. The hematite was similar in appearance to that from the limestone mineralisation, and had a rather high silica and low phosphorus content.

The maximum output from the two mines was in 1883 (61,377 tons). By 1913 it was 15,257 tons, but a few years later 12,000 tons a month was won. Activity seems to have ended about 1920.

Faults

The hematite has been emplaced along fault planes, the trends of which can be seen by looking up the south slopes of Murton Fell from the valley. The prevalent trend is N.W.-S.E. These are tear faults crossing a minor anticline with its axis running N.E. through this area towards Loweswater.

The only fault plane which can be seen outcropping is on the small western saddle on Murton Fell. Brecciation is apparent in the walls. The N.E. wall has heaved to the S.E. Here, and on other waste heaps, specimens showing slickensiding, ore with riders of slate, and ore shot through with quartz may be obtained. Kidney ore and mineralised lough fragments may be seen occasionally. The faces of Herdus and Banna Fell repeat the N.W.-S.E. direstion and may also be due to faulting.

The Northern Anticline and its Rock-types

The trend of the anticline in this area may be inferred from the rock sequence. (The movement of the rocks has made it difficult in many cases to follow the dips.)

In the Murton Fell - Fell Dyke - Smaithwaite area there are three types of Skiddaw Slate apparent: (a) brown, fine-grained; (b) fine striped greyish or brownish; (c) grey or greenish sandy, flaggy or mica laminated (may be rhythmic and may pass into grey mudstone weathering white - but this is more noticeable in the Middle Fell - Blake Fell area.) More simply, the fine brown species is above the grey sandy species and there is an apparent transition of the striped species in between. The Survey regard (a) and (b) as the upper division and equivalent to Mosser Slates and Watch Hill Grit. The lower division is Loweswater Flags and Blake Fell Mudstones. Thus, in an eroded anticline the brown rock will be on the outside and the

grey rock on the inside of the outcropping flanks. The brown rock is seen near the western, Fell Dyke end of the reservoir and the grey rock outcrops to the S.E. on the slope of Knock Murton above the western part of the reservoir, whilst above it, just above the fence, the striped rock is observed and then the brown rock. At Smaithwaite the relationship is the same, i.e., the strike being approximately N.E. On the top of Murton Fell the striped variety is seen, in the centre part of which is a highly brecciated outcrop of mainly fine grey rock; sandy rock outcropping is not always the typical grey, and weathered surfaces may appear striped. There are probably minor infolds in places.

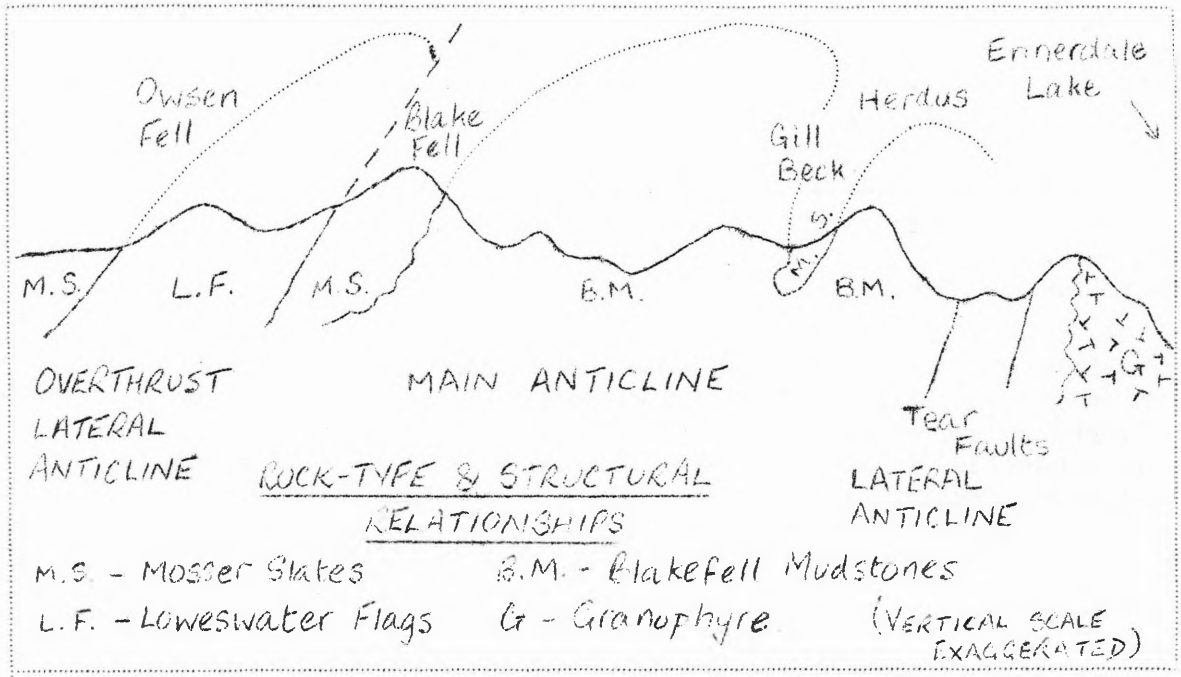
The new forestry road gives easy access to and good sections of the Loweswater Flags and Blake Fell Mudstones on the lower flanks of Middle Fell, Blake Fell and Sharp Knott, and scree specimens of Mosser Slates and spotted slate occur. On Sharp Knott chiastolite slate has been reported. In this and the Murton area there are plentiful examples of quartz veining, and in places the rock has been toughened by quartz. Hematisation is also evident.

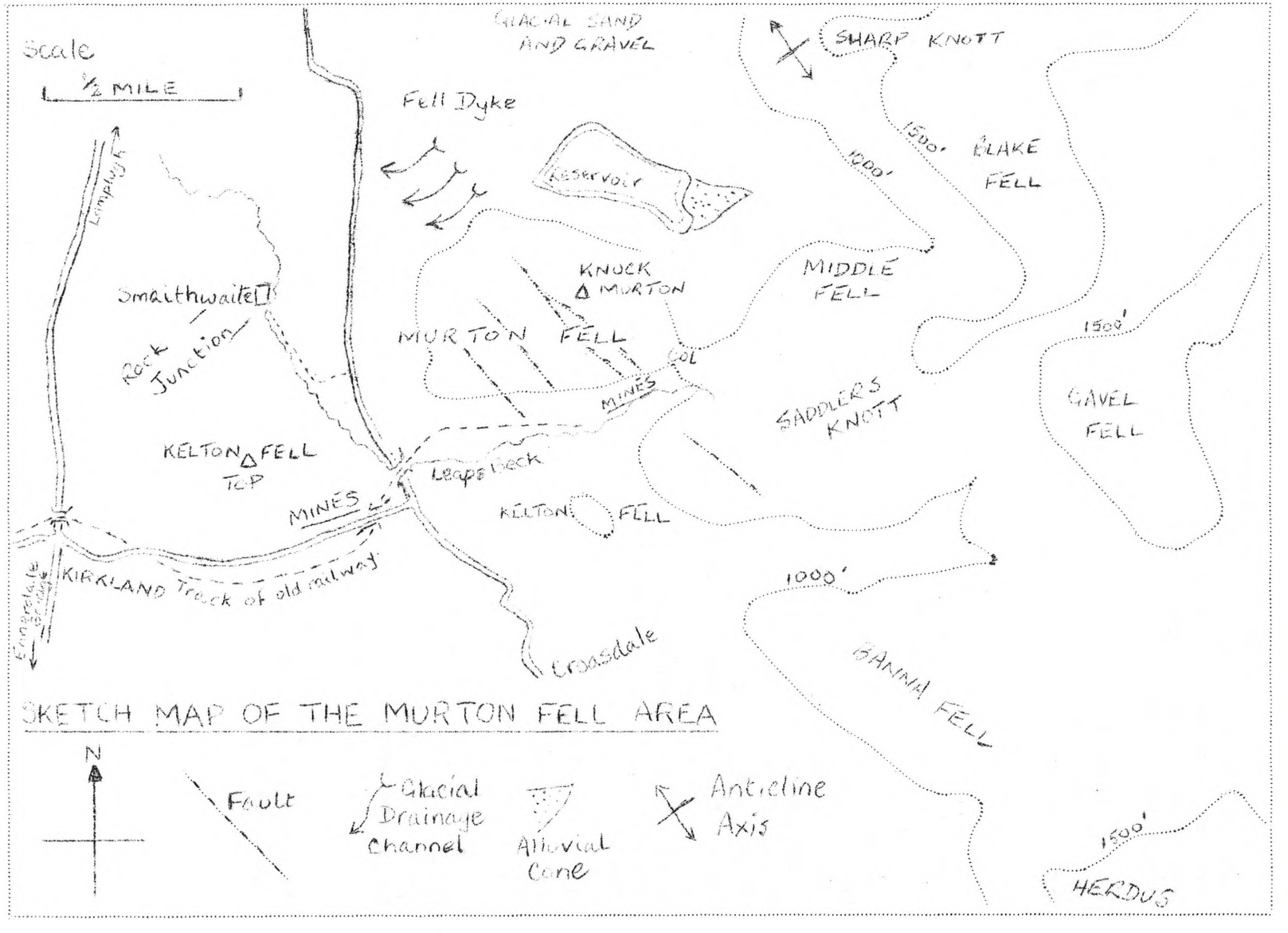
Fossils

Graptolites were reported in the Mosser Slates near the junction, and Caryocaris in the Loweswater Flags. The writer obtained one of the latter at Smaithwaite.

Glaciation

The top of Murton Fell is an excellent vantage point from which to appreciate that ice from the fells could flow out of the Knock Murton-Owsen Fell gap until Irish Sea ice blocked it, and left a moraine ridge across. Thereafter, it spilled over at a higher level into the valley now occupied by Leaps Beck and into Ennerdale. Glaciation features of the lower valley are also well seen from this point.





SKETCH MAP OF THE MURTON FELL AREA

Details of the excursion

The party of about 20 assembled at Kirkland and drove to park their cars near Harris Side. After looking at a model showing the disposition of the various rocks of the area, the party proceeded along the valley of Leaps Beck to see the lines of the faults as indicated by the spoil heaps. Good specimens were obtained from the latter.

The state of the weather was somewhat uncertain: the mist might lift, or it might not! It was decided to climb the fell to inspect rock outcrops and if the fates were willing, to see something of the wider scenery of the area. Nearing the fell top the mist thickened and made location of outcrops a less direct matter. A discussion over the reason for the highly brecciated outcrop arose. Some lines were observed which suggested sharp folding. Towards the south, sandy varieties of rock were examined, some of them being deeply weathered. Slips and folds were noted, and the effects of weathering and water channelling. Weather conditions were so bad that a walk over to the slopes above the reservoir (where the rock sequence can be traced) was abandoned. The party moved westwards on a compass bearing - just to be sure - along the top to the saddle where the fault walls could be examined. En route there were two distinct glimpses of the lowlands in sunshine! Some members found a deposit of kidney ore on one face, and some hefty pieces of more massive hematite. Here the discussion of cold, downwards versus hot, upwards mineralisation was renewed. The leader made the point of the probable significance of spotted slate etc., showing thermal metamorphism at nearby Middle Fell, indicating a connection between the hematite veins and igneous activity. However, the argument is still far from being settled.

At this point the rain began again, and the party came down over the west flank of the fell and looked briefly at a typical outcrop of the Loweswater Flags, grey-coloured, sandy rock with thin quartz veins.

After taking the quickest route back to the cars and driving to Smaithwaite, members examined some outcrops of rock near the farm, by kind permission of the farmer, Mr. Sharpe. Near the farm, grey, sandy, flaggy rocks were seen, whilst further S.W. they were of a finer grain and brown in colour, though not as brown as the rocks of the Fell Dyke area.

The excursion drew to a close just as the rain began to increase, and without standing on ceremony except that of thanking the farmer, members went their respective ways.

S.H. Gate.

EXCURSION TO THE SEATHWAITE PLUMBAGO MINE

June 18th., 1966. Leader: Mr. B. Chandler.

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The mine stretches up the hillside to the west of Seathwaite and has several levels between 500 and 1,000 feet above sea level. These levels are connected by vertical shafts. It is believed that the graphite was first discovered by local shepherds who used it to mark their sheep. This led to a commercial undertaking with the opening of the mine which was first recorded in the seventeenth century. The mine was finally abandoned late in the nineteenth century.

Because the graphite used to be considered extremely valuable, to enter the mine unlawfully was made a felony and miners were stripped and searched after work in buildings erected specially over the mine entrances.

When the mine was explored by potholers many years after its closure, they discovered picks, stools, and the rails on which the tubs of graphite ran. They also saw the clog marks of the miners still impressed in the clay.

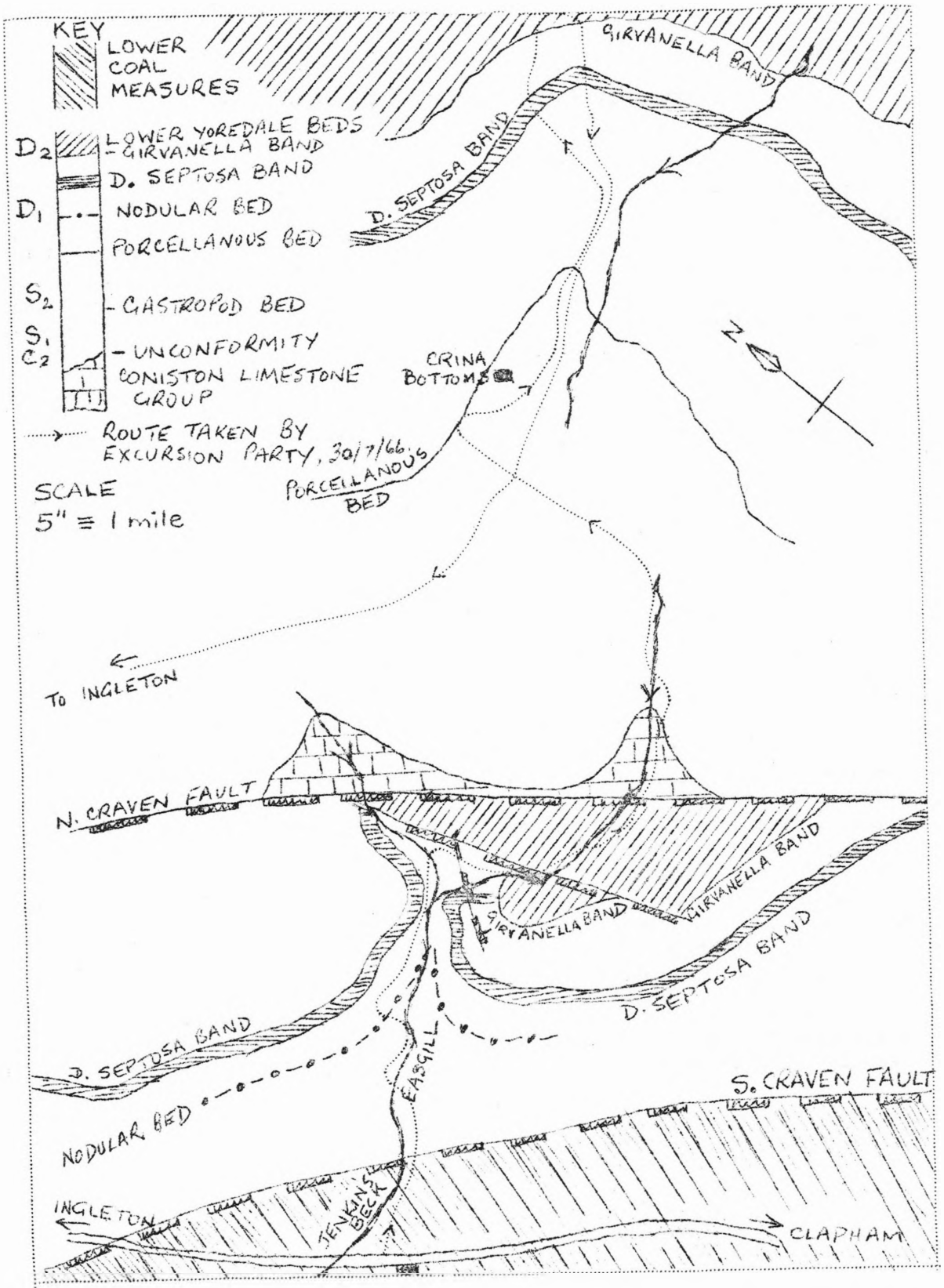
The rocks in the area comprise a central dyke of diorite surrounded by blue diabase intruded into ashy rocks. The graphite is found mainly in the diabase, but it does occur in the other rocks, taking the form of pipes of mineral with 'strings' leading outwards. The miners found the graphite by following these strings until a pipe was reached.

On the afternoon of the excursion, members of the Society met at Seathwaite and ascended the 600 feet of steep fellside to the lip of the shaft leading to the "Old Man's Level". Here aluminium and wire-rope ladders were fixed, together with a safety rope to allow seven members to climb about 75 feet down the shaft to the "Old Man's Level" where some excellent specimens of graphite were obtained from a small vein, probably one of the 'strings' mentioned above. The group then returned to the shaft and one by one ascended the ladder to the surface. Although the party spent four hours at the mine, only a very short time was spent obtaining specimens. Most of the time was spent in the descent and ascent of the shaft, which was steep and wet, sloping down at about 70°.

After thanking Mr. B. Chandler, the Outdoor Activities Organiser at Workington College of Further Education, and his associates whose guidance made it possible to venture underground, the party dispersed homewards.

H.L. Walmsley.

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SKETCH MAP OF S. OF INGLEBOROUGH

THE SUMMER CAMP AT INGLETON

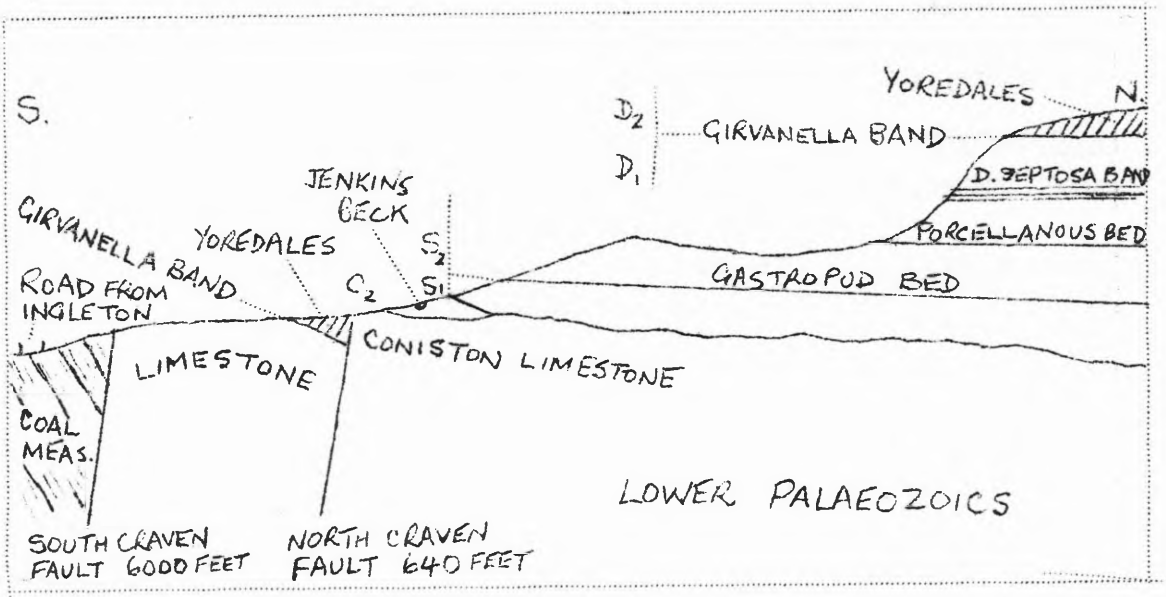
July 29th. to 31st., 1966. Directors: D.H. Learoyd, B.Sc., F.G.S.
J. Slater, B.Sc.

---oOo---

This was a joint meet with members of The Cumberland Geological Society and the North East Lancashire Group of the Geologists' Association attending. Some 20 members camped at Beazley Farm, Ingleton, and about half as many again came as day visitors on the excursions.

On Friday evening, after the tents had been pitched, Mr. D.H. Learoyd outlined the geology of the area, emphasizing the features to be seen on the excursions planned for the following two days, and mentioning some of the geological features within easy walking distance of the camp site which might be visited in "spare" time. These latter included the Carboniferous unconformity at Thornton Force and in Chapel-le-Dale, the isoclinal folding of the Ingletonians, the fossiliferous Carboniferous succession in Neal Bank Quarry, the effects of the North and South Craven Faults on the drainage of the rivers Doe and Greta and the kersantite dyke in the River Greta.

The following morning started pleasantly, the weather improving until late afternoon. The excursion party was met by the director, Mr. Slater, at Jenkins Beck at 10 a.m. He first explained the age of the Craven Faults and the effect of faulting on the various beds in the area. The route followed is shown on the accompanying sketch map, the various horizons being found and identified by their type fossils. The nodular band was of interest; some of the nodules have since been sectioned, and they appear to be of algal origin. Due to the Craven Fault, the Girvanella Band, the D. septosa Band and the Yoredales were crossed twice, as shown on sketch map



DIAGRAMMATIC SECTION OF THE SOUTHERN PART OF INGLEBOROUGH

and section. After thanking Mr. Slater for leading the excursion and demonstrating the features of interest, the party made its way back past Crina Bottoms along the track to Ingleton. At this point a heavy rainstorm prompted many to visit some of the caves in the area.

On Sunday, July 31st., the party met at Horton in Ribblesdale railway station. The Lower Palaeozoic inlier of Upper Ribblesdale, the North Craven Fault and its effects at Cow Side and near Stainforth, and the effects of the South Craven Fault at Scaleber and Giggleswick Scar were examined under the direction of Mr. Learoyd. The weather in the morning curtailed the programme to some extent and the party kept to the more sheltered locations whilst an improvement in conditions after lunch allowed the latter part of the schedule to be adhered to.

Although an adequate detailed explanation with maps and sections will be found in the bibliography, some account is given of the geology seen.

The South Craven Fault marks the northern boundary of the Craven Lowlands. During Carboniferous times limy muds and impure limestones such as the Worston Shale and Chatburn Limestone were deposited. Bioherm reefs accumulated on the margin of the area. North of the Fault deposition of limestone only commenced in C_2 times. The limestone is purer and hence whiter on consolidation. In post-D_1 times an alternation of shale with limestone was the characteristic deposition, the Yoredale sequence of strata. Above the Orionastrea Bed the full Yoredalean cyclothems of shale, sandstone and limestone make their appearance. The C_2 beds may be seen and examined in Chapel-le-Dale, Thornton Force and in the limestone about Arcow The lowest beds of the Michelinia grandis Zone outcrop in Jenkins Beck. The Great Scar Limestone, D_1-S_1 can be seen in Meal Bank Quarry or in the basal exposures around Chapel-le-Dale; in the former place it lies between the faults, whilst at the latter it lies on the Craven Block.

D.H.L., R.H.H.

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EXCURSION TO RACHEL WOOD MINE, THORNTHWAITE, NEAR KESWICK

September 10th. 1966 — Leader; J. Moon, F.G.S.

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A dozen members met outside The Swan Hotel, and after donning helmets, lamps and overalls, made their way along the forestry road to a point above some old mine buildings by the main road now used as a service station.

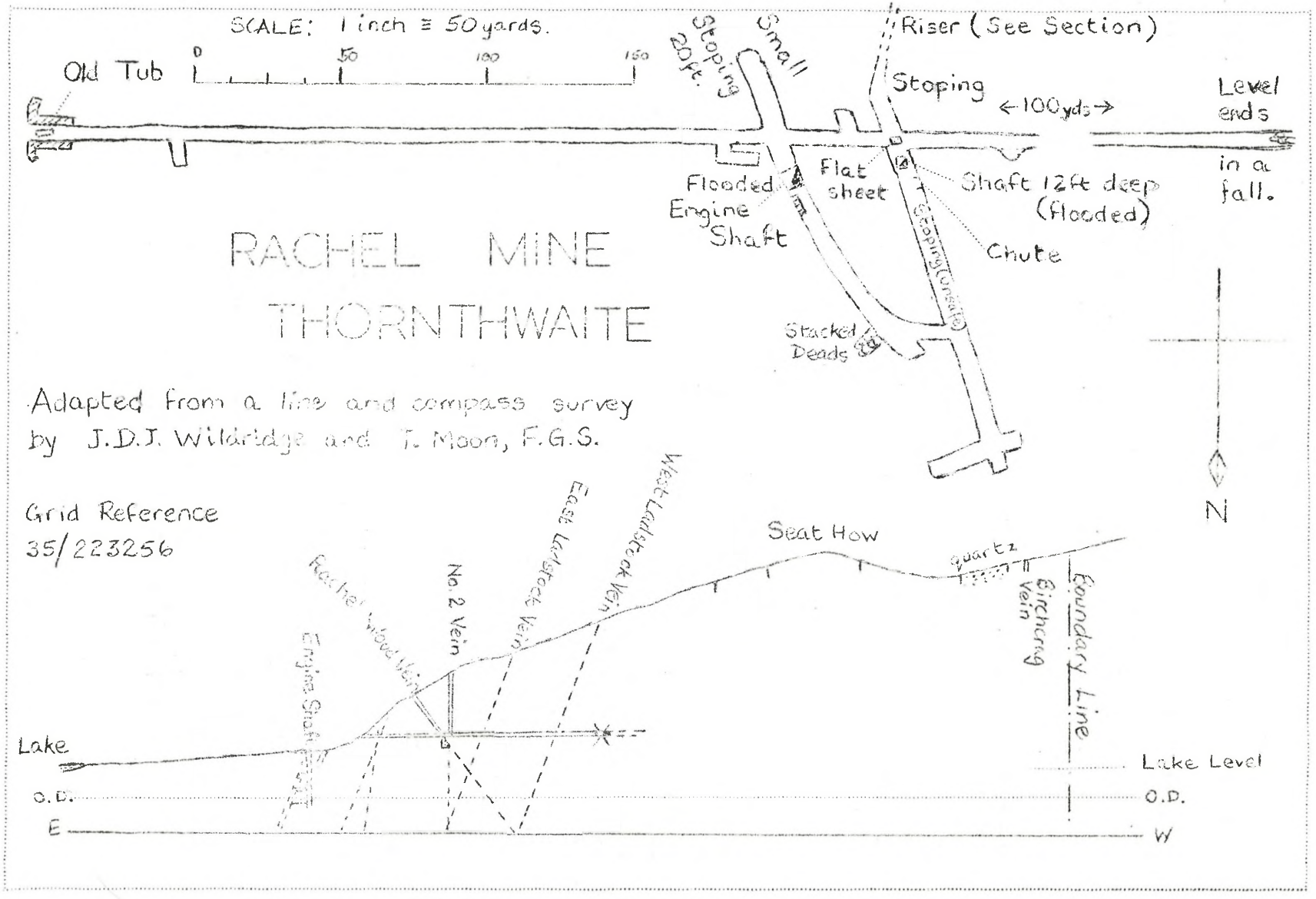
At the concrete-faced entrance to the mine, which is a self-draining adit, Mr. Moon gave details of the geology of the area, the history of the mine and features which it contained. He pointed out that although the rock-cut tunnels were safe, the crosscuts into the veins were to be treated with caution since the old timbering, where it was still in position, was usually in a rotten and highly precarious state. A further danger in these old mines was, he stated, the existence of flooded shafts, which might be mistaken by the unwary for shallow puddles. The party saw two of these in the mine, one full of perfectly clear turquoise water in which the old ladders and stagings could still be made out.

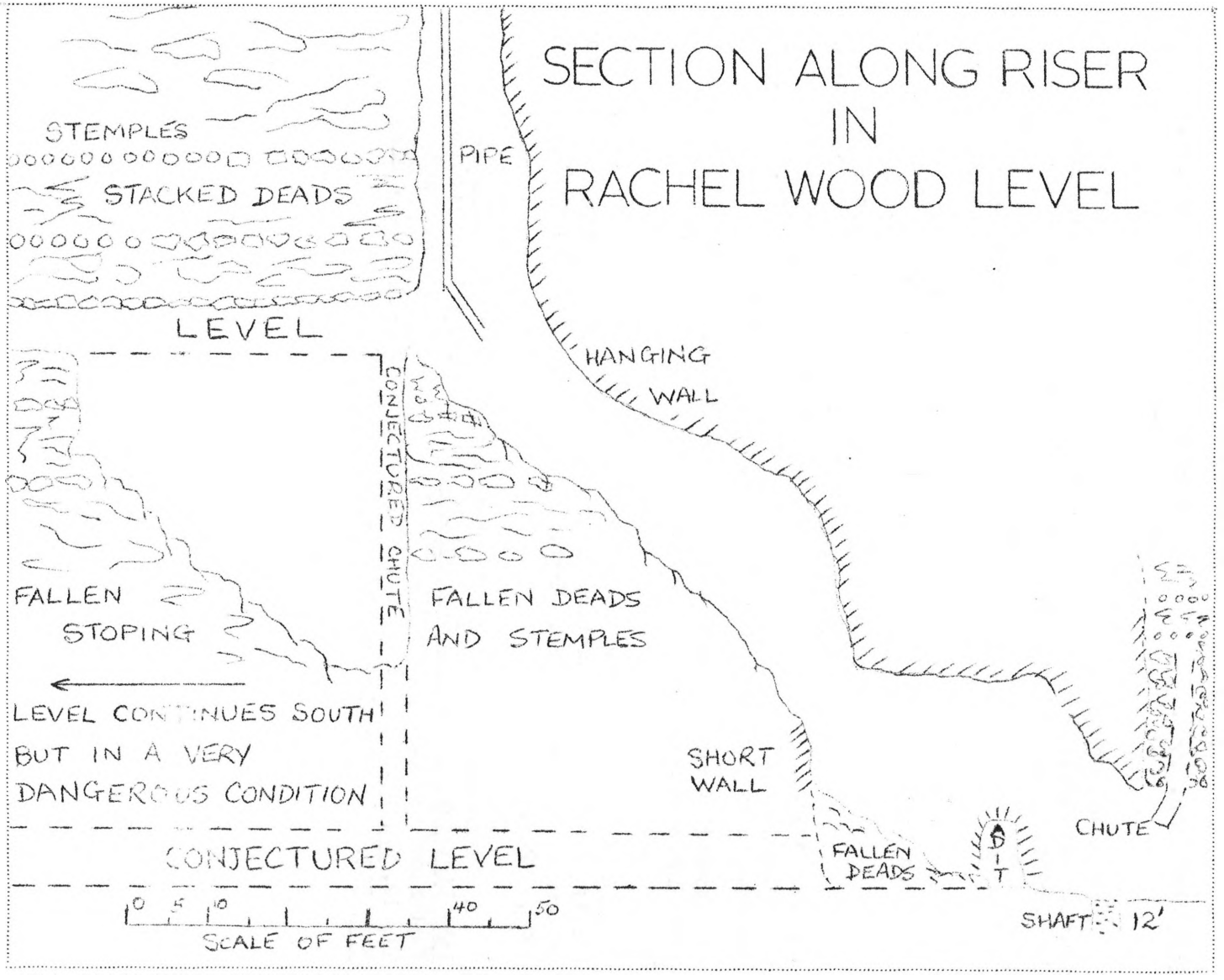
The mine was commenced in 1875 by Captain Francais at a point 500 feet south west and 86 feet above the level of Thornthwaite shaft top. The level cuts both the Francais and Rachel lodes 10 to 20 yards apart (after cutting a barren vein near the entrance) about 180 yards in. Ore was got from both veins over a length of 45 fathoms, the Rachel vein being the better of the two. Continuations of both ends of the levels proved fruitless. On the north, although feeble slips occur, the barrenness seems to be due to the vein dying out. Southwards, heavy broken ground was encountered which suggests faulting. Some thin quartz strings and a feeder of ferruginous water at 247 yards may be the East Ladstock vein. At the far end, about 474 yards from the entrance, broken ground 40 feet wide and requiring heavy timbering was cut through. Some of the "rushed stuff" of clay and slatey material shows a small quantity of blende and galena, and may represent the West Ladstock vein in a very shattered condition. Rachel Wood intersection is stoped out to a height of 25 fathoms and a depth of 10 fathoms. A shaft has been sunk to this depth.

The ore was transported along the fellside and tipped down chutes to the mill at Thornthwaite Mine. It was tipped on to a "rough" picking incline before passing to two Marsden stone breakers and a set of crushing rolls. The material was then sized by trommel and elevated to the jigs, of which eight sets were used, two being reserved for cleaning up fine blende. The rejects from the jigs passed to a ball-mill. The fines were treated on tables, 3 Diesters and 5 Wilfleys, and the slimes on a Luhrig Vanner.

The output for the Thornthwaite area from about 1870 up to the end of 1918 was:

Blende: 15,682 tons, fetching £90,673 (average £5 15 5 per ton).
Galena: 10,987 tons, fetching £111,515 (average £10 3 0 per ton).


SCALE: 1 inch = 50 yards.
0
50
100
150
Old Tub
Stoping 20ft.
Small
Riser (See Section)
Stoping
←100yds→
Level ends in a fall.
Flooded Engine Shaft
Flat sheet
Shaft 12ft deep (Flooded)
Stoping (Open)
Chute
Stacked Deads
RACHEL MINE
THORNTHWAITE
Adapted from a line and compass survey by J.D.J. Wildridge and T. Moon, F.G.S.
Grid Reference
35/223256
N
Seat How
quartz
Eirthcrag Vein
Boundary Line
East Limestone Vein
West Limestone Vein
Rachel Wood Vein
No. 2 Vein
Engine Shaft
Lake
O.D.
E
W
Lake Level
O.D.


SECTION ALONG RISER
IN
RACHEL WOOD LEVEL
STEMPLES
STACKED DEADS
PIPE
LEVEL
HANGING
WALL
CONJECTURED CHUTE
FALLEN
STOPING
FALLEN DEADS
AND STEMPLES
LEVEL CONTINUES SOUTH
BUT IN A VERY
DANGEROUS CONDITION
SHORT
WALL
CHUTE
CONJECTURED LEVEL
FALLEN
DEADS
PIT
0 5 10 40 50
SCALE OF FEET
SHAFT 12'

FIELD MEETING AT KENTMERE, WESTMORLAND

September 18th. 1966. Director: D.H. Learoyd, B.Sc., F.G.S.

---oooOooo---

Members assembled at Kentmere Church in the morning and proceeded to examine the Middle Coldwell Beds of Parkbrow Quarry. Monograptids of the Cyrtograptus lundgreni zone (Blackie 1933) were found, and also an isolated block with external moulds of Orthids on a weathered surface. Slaty cleavage, jointing and minor thrusting between beds was to be seen. In the stream south of Hall Gill, climbing from the rear of Kentmere Hall, the upper part of the Coniston Limestone Series (Mitchell, 1925) and the Browgill Beds (Blackie, 1933) are visible. On ascending, the first tributary to the south cuts back into the Middle Coldwell Beds. Following the northerly stream many glacial erratics of the Borrowdale Volcanic Series are to be found, a good specimen of jasper being picked up. At about 900 feet the stream forks. In the southern stream are Skelgill Beds as a lenticle between Coniston Limestone Series and Browgill Beds (Blackie, 1933), the suppression of beds apparently due to "Schuppen structure".

Descending via the Garbourn Road to Kentmere, rotted volcanics of the Stile End Beds were examined near Greenhead, and Borrowdale Volcanics below Raven Crag.

Ascent of Hollow Moor on the east side of the valley was made, visibility permitting explanation of the erosion surfaces and river drainage patterns (Gresswell, 1952; Marr, 1916; McConnell, 1939, 1940; Mitchell, 1928, 1929).

A comprehensive list of references may be found in the "Bibliography of Lake District Geology and Geomorphology", by R.A. Smith, published by The Cumberland Geological Society. The relevant references are numbered: 11, 12, 22, 141, 151, 291, 302, 309, 315, 321, 322, 331, 332, 333, 334, 335 336, 352. The more important references are underlined.

D.H.L.

EXCURSION TO GREAT HALL GILL, WHIN RIGG, AND THE FALL OF ANDESITE ON THE WASDALE SCREES.

Sunday, October 2nd., 1966. Director: M.F. Burton.

---oooOooo---

The excursion party met at Netherwasdale Church and proceeded by car along the track that leads from the "Flass" via Easthwaite Farm to the Wastwater pumphouse. Beneath the alluvium that covers this route lies the Ennerdale-Buttermere Granophyre. This intrusion apparently makes contact with the Eskdale Granite roughly along a line between the pumping station and the neighbourhood of Easthwaite Farm. The actual contact between the Granite and Granophyre, as with the Granite and Trias further west, cannot be seen owing to the overlying turf. The boundary between the Granite and the Borrowdale Volcanic Series in the shape of the massive lavas of the lower andesites, although complicated by faulting, is located on the side of Whin Rigg at about 1200 feet O.D. It then follows an easterly and north-easterly course and reappears in Robin Gill at about 600 feet where the junction is shown as a small waterfall. From there the boundary swings across Tongue Moor and into Miterdale.

The excursion party was primarily concerned with investigating the extensive denudation of the granite in Great Hall Gill, and then proceeding over Whin Rigg to view the heavy fall of andesite. This fall from the top of The Screes has resulted in sheer vertical faces of contact rock being exposed.

The first feature of interest which the party observed when reaching the Gill from the vicinity of the pumphouse, was the large quantity of granite sand of various textures in the bed of the stream. This served to indicate to the members the great extent of the weathering and transportation by water of the granite in the higher reaches of the Gill. The party then entered the Gill from the hillside slope after avoiding a small but impassable gorge in the stream bed. Pieces of pinkish, coarse, crystalline granite lay in profusion on the floor of the Gill in various degrees of decay; some specimens disintegrating by pressure of the hand. Some massive pink rocks in the side wall of the lower part of the Gill, having little or no crystalline structure, were thought to be a marginal variety of granite. It was obvious from their appearance that they contained a high proportion of free silica. Ascending further, a large cliff of pinkish, kaolinised granite containing much hematite iron was reached. Here small specimens of kidney hematite were found and one member discovered a large piece of iron ore containing "xenoliths" of granite. It was obvious that a hematite vein had run into this ravine as there were also other pieces of evidence including blocks of "raddle", the natural red stain that was used for marking sheep in the old days. The iron ore and the soft, crystalline nature of the granite in this locality no doubt were incidental in producing such a heavily denuded gill. It should be noted, however, that the pattern here is not representative of the Eskdale Granite as a whole, for beneath the turf the granite mass is reputed to be in a very good condition. It (the granite) has been subjected to alteration by "end-stage" factors, namely sericitisation, chloritisation, and epidotisation during its emplacement to

a much greater degree than it has to subsequent conditions resulting in weathering.

Proceeding higher up the Gill the party encountered a rock finger of weathered granite approximately twelve feet high, weighing maybe two tons, and standing on a denuded base only eighteen inches in diameter. Photographs were taken of this pinnacle, which cannot have many more years' existence. Still higher, further denuded cliffs of granite were observed, some having a yellowish tinge, being fairly free of iron. The Gill gave way to moorland at the top and the party halted for lunch before going on to Whin Rigg.

The moorland track to Whin Rigg, which is the highest point on the Screes apart from Ilgill Head, revealed little of geological interest. Loose boulders were examined here and there and were found to be mainly grey volcanic rocks, some showing a porphyritic structure. The summit boulders of Whin Rigg were entirely B.V.S. material. A further walk of about a mile along the top of The Screes, passing over the head of Great Gully with its magnificent view of Wasdale Hall and the lake far below, brought the party to a point directly above the rock fall. A frontal view of the face left by the fall of rock was obtained from a very narrow arete which ran out at a right angle to The Screes. A second, but closer view was obtained from the top of The Screes in the vicinity of a well-known lookout point. Behind the dust and debris that covered the smooth rock faces could be seen patches of the blue-grey lavas of the lower andesites. One edge of the rock face was seen to show heavy hematite staining. The thickness of the individual lava flows comprising these rocks varies from 50 to 140 feet, and in the upper part of the succession they are mainly pyroxene-andesites. After remaining in this delightful spot for a considerable amount of time the party retraced its steps towards Whin Rigg. It was hoped that by traversing the grassy southern slopes of this fell the contact between the Granite and Borrowdale Volcanic rocks could be located. However, the party did not meet with any success on this occasion, but the leader considers that there is more scope in this field on the lakeward side of Whin Rigg.

The party returned to Wasdale via the shoulder of Great Hall Gill, reaching the pumphouse and dispersing about 5 p.m.

Below are tabled three analyses of Eskdale Granite and also that of a typical pyroxene-andesite.

	Normal Granite	Marginal Granite
SiO_2	76·43%	96.16%
Al_2O_3	13·56	1·31
Fe_2O_3	0·08	0·02
FeO	0·55	0·09
MgO	0·54	0·03
CaO	0·03	trace
Na_2O	4·19	0·56
K_2O	4·72	0·30
H_2O (combined)	0·76	0·51
H_2O (free)	0·06	0·08
totals	100·92	99·06

Micrometrical analyses of rock slides - 100 traverses (average)

Pink Granite

Quartz	32.5%
Perthite	58.5
Plagioclase	7.5
Orthoclase	2.3
Sericite	4.1
Muscovite	1.2

Pyroxene-andesite

SiO_2	60.16%
Al_2O_3	15.34
Fe_2O_3	3.07
FeO	2.18
MgO	3.41
CaO	5.79
Na_2O	3.88
K_2O	2.59
H_2O	2.04
TiO_2	0.84
P_2O_5	0.46
ZrO_2	0.01
Cr_2O_3	trace
NiO, CoO	trace
MnO	0.08
SrO	0.08
BaO	0.14
Li_2O	trace
SO_3	0.08
S	trace
	100.15

References

The Petrology of the Eskdale (Cumberland) Granite, by B. Simpson. Proc. Geol. Assoc., Vol XLV, 1934, part 1.

The Borrowdale Volcanic Series between Wastwater and Duddon Valley, Cumberland, by R.J. Firman. Proc. Yorks. Geol. Soc., Vol. 31, part 1, No. 2, 15th. July, 1957.

M.F.B.

Some little-studied British landforms

L. Tufnell

---oooOooo---

INTRODUCTION

During recent years the author has been investigating the morphological effects of Pleistocene and contemporary frost action in northern England. Although research has of necessity been concentrated in a few, selected areas (e.g., the Moor House National Nature Reserve, Westmorland, and the central Lake District), enough information has been collected to show that a wide variety of so-called periglacial features occurs within the region[1]. Investigations have also led to the discovery that north-western England possesses at least four types of landform which seem to have escaped the notice of research workers in all parts of the British Isles. Three of these are genetically related, since each owes its existence to the differential rates at which material creeps downslope. The other landform in the group is the periglacial hummock feature often known as a "thúrfur".

In the remarks which follow attention is drawn to the fact that examples of these landform types occur in areas close to the Cumberland-Westmorland border. Undoubtedly, such features are more common in the British landscape than has hitherto been realised. Moreover, they deserve closer study as they represent processes which are actively modifying the relict glacial forms in north-western England and elsewhere.

SOME ASPECTS OF CREEP IN NORTH-WESTERN ENGLAND

At the present time the downslope movement of blocks and boulders[2] is taking place at many localities in north-western England. The strength of such movements, as well as the morphological features created by them,

[1] A list of such features would probably be about twenty strong and is known to include the following: frost-shattered bedrock, block fields, nivation benches, solifluction deposits, solifluction terraces, screes, block streams, ploughing blocks, circles, polygons, stripes, stone flats, erected stones, thúrfurs, ice wedges, involutions, lake-bottom deposits, and loess. Frozen-out stones and needle ice have also been studied, though these are not necessarily indicative of a true periglacial environment.

[2] In this paper the term "boulder" refers to a predominantly rounded and fairly large rock fragment usually occurring below 1,500-2,000 ft. in north-western England. At higher altitudes fragments tend to be angular and are therefore called "blocks". However, scree material is often angular, even when found at altitudes of less than 1,500 ft. Hence the reason for using "brake block" in preference to "brake boulder" later in the text.

depend on such variables as altitude, slope angle and nature of ground. As a generalisation, it appears true to say that above the 2,000 ft. contour in our region such movements are largely frost-controlled and comparitively rapid. Moreover, since an individual block generally moves faster under these conditions than does a grass-covered area surrounding it, a "roll" of vegetation and soil is pushed up at its downslope end, while a "groove" is left in its rear. Block movements of this type are indicative of contemporary periglacial conditions. It is suggested that the landforms to which they give rise are best referred to as "ploughing blocks". Such features have been examined on the Moor House Reserve[3] and at several places in the central Lake District[4].

Related to ploughing blocks are three landforms which in north-western England frequently occur at altitudes of less than 2,000 ft. The first of these is aptly described by the term "creeping boulder". Particularly good examples of this feature have been studied on Flagdaw, a hill which forms part of the Cross Fell Inlier. As a result of Pleistocene glacial activity slopes in this locality are now dotted with a few sandstone erratics, most of which show evidence of present-day movement. This evidence generally takes the form of a "roll" which has been pushed up immediately downslope from a boulder and a vague "groove" occurring directly behind it (fig. 1). The nature and position of these micromorphological features indicates that this type of boulder, despite its slow rate of movement, is nevertheless creeping downslope faster than is the ground surrounding it. Clearly, there is a striking parallel between creeping boulders and ploughing blocks; yet there are also at least two significant differences. In the first place, the microfeatures associated with a ploughing block are generally much better developed than those formed by a creeping boulder[5]. This results from the difference in strength of the two sets of movements and illustrates the comparitive rapidity with which erosion is proceeding in our upland areas. The second of these important differences rests in the fact that the movement of ploughing blocks is largely frost-controlled, whereas that of creeping boulders may be due to several processes working in conjunction. These include not only frost action but also the expansion and contraction of a boulder, rainwash and vegetational activity (C.F.S. Sharpe 1938). Therefore, while ploughing blocks are formed by differential slope movements operating under periglacial conditions, creeping boulders are an expression of the differential rates at which creep may act in a temperate, humid environment.

Situated adjacent to Flagdaw is Knock Pike, a conical-shaped hill of Ordovician rhyolite. As a result of weathering and erosion under periglacial conditions, this hill is now mantled with a thin layer of solifluction debris. In addition, screes composed of angular rhyolite fragments

[3] They are particularly well developed on Little Dun Fell.

[4] E.g., on Seat Sandal and Greatrigg Man.

[5] A few examples have been studied of where ploughing blocks have two "rolls" associated with them. The length of the "groove" created by ploughing block movement naturally varies a great deal and may in some cases exceed 20 ft. (e.g., on Little Dun Fell).

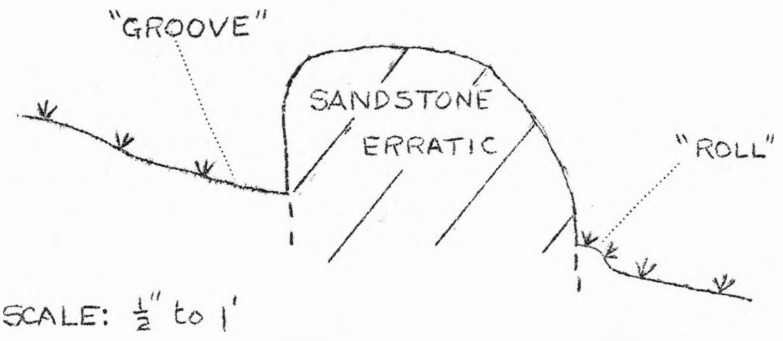


Figure 1. CREEPING BOULDER, SOUTH-FACING SLOPE OF FLAGDAW.

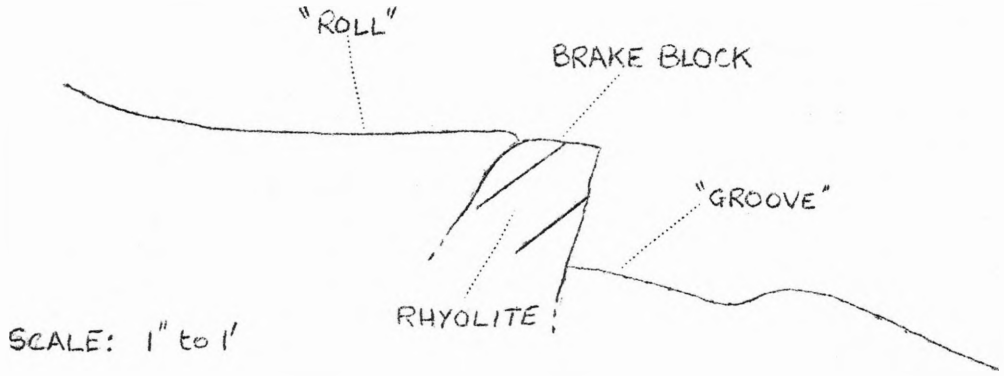


Figure 2. BRAKE BLOCK IN SCREE, EAST-FACING SLOPE OF KNOCK PIKE.

have developed on its eastern slopes. Although these are essentially "fossil" features, whose origin is probably the result of frost weathering in late Pleistocene / early Holocene times, their slow, downward movement still continues. On the whole the smaller material in these screes appears to be travelling faster than does that of larger dimensions. The micro-morphological features to which this kind of differential movement gives rise are shown in figure 2. Thus, it is usual to discover that a "heap" of small fragments has piled up behind a larger, more slowly moving block in a scree. One may also find that a "groove" occurs in the area immediately downslope from such a block. In view of the retarding effect which a large scree fragment can have on the progress of smaller sized material, it seems appropriate to call this type of landform a "brake block" (or boulder).

P.W. Höllermann (1964) has already used the German equivalent of this term in a paper on the geomorphology of the central Alps.

The occurrence of brake blocks on a scree provides evidence of its continued movement. Clearly, "rolls" and "grooves" of the type described are ephemeral features and could not be maintained for any length of time in a "fossil" condition. Moreover, some brake blocks have a third micro-feature associated with them. This takes the form of a second "roll" which is contiguous with the downslope end of the block and which consists not of angular fragments, but of very fine material. Where this occurs there is unequivocal proof of contemporary scree movement. It is inconceivable that such a "roll", devoid of any vegetation cover, would survive for long in the climate of north-western England were it not being continuously renewed through the downward movement of a block directly upslope from it. However such a block is not the most rapidly-moving element in a scree: as already suggested, the ability of smaller fragments to pile up behind it indicates that their rate of movement is even faster. Screes overlooking Grisedale Tarn in central Lake District are among those where differential movements are leading to a block being associated with <u>two</u> "rolls" and a "groove".

Observations to date suggest that brake blocks are a typical component of many screes in north-western England where fragments are of at least two contrasting sizes. However, in an extensive search of the published literature the author has failed to discover any reference to the occurrence of such features in the British Isles. Furthermore, all foreign-language papers so far consulted describe brake blocks as indicative of a very severe type of periglacial conditions and not as forming in a temperate, humid climate. For example, M. Boyé (1950) has noted that in certain parts of Greenland brake blocks occur frequently, though ploughing blocks are rare. Similarly, Höllermann (1964) claims that brake blocks form at higher levels in the central Alps than do ploughing blocks. In attempting to explain this kind of situation B. Högbom (1914) pointed out that in certain areas (e.g. Spitzbergen) the summer thaw layer is usually very thin. Hence the bases of the larger blocks often remain embedded in frozen ground throughout the year, thereby preventing them from moving. On the other hand, smaller fragments are far more likely to be incorporated in the movement of the active layer during summer. This explains why larger blocks move more slowly than does smaller material. It also accounts for the development of a landform remarkably similar in appearance to the brake block which is found on screes in north-western England[6].

On the west-facing slope of Knock Pike there occurs yet another type of landform indicative of differential slope movement. This landform has developed through the sinking and forward movement of a boulder in a patch of unusually damp ground. It may therefore be called a "sinking boulder". As such a feature tends to move a little more rapidly than does the ground surrounding it, a "roll" is pushed up at its downslope end and a vague "groove" is occasionally left in its rear. Of several boulders found near the bottom of the west-facing slope of Knock Pike, that shown in figure 3

[6] Hence, present evidence suggests that there may be two optimum climato-morphological environments for the development of brake blocks - the very severe periglacial region, and the humid temperate area.

is the only one to have associated with it micromorphological features signifying downslope movement. Strangely enough, this is also the boulder which occurs on the gentlest part of the slope. Hence the significance to boulder movement of an easily-yielding medium through which to flow.

It is now almost thirty years since C.F.S. Sharpe (1938) drew attention to the great variety of processes covered by the term "mass movement". In classifying these he recognised inter alia, two main types of slow flowage, one characteristic of temperate and tropical climates, the other typical of cold environments. Further subdivision led him to distinguish "soil creep", "talus creep" and "rock creep" as processes operative under temperate and tropical conditions. When considering these processes in detail he noted that creeping boulders are among the features which result from soil creep. Had he also discussed sinking boulders, he would no doubt have considered them as yet another manifestation of the same process. Likewise, although brake blocks were not mentioned in Sharpe's classification of mass movement

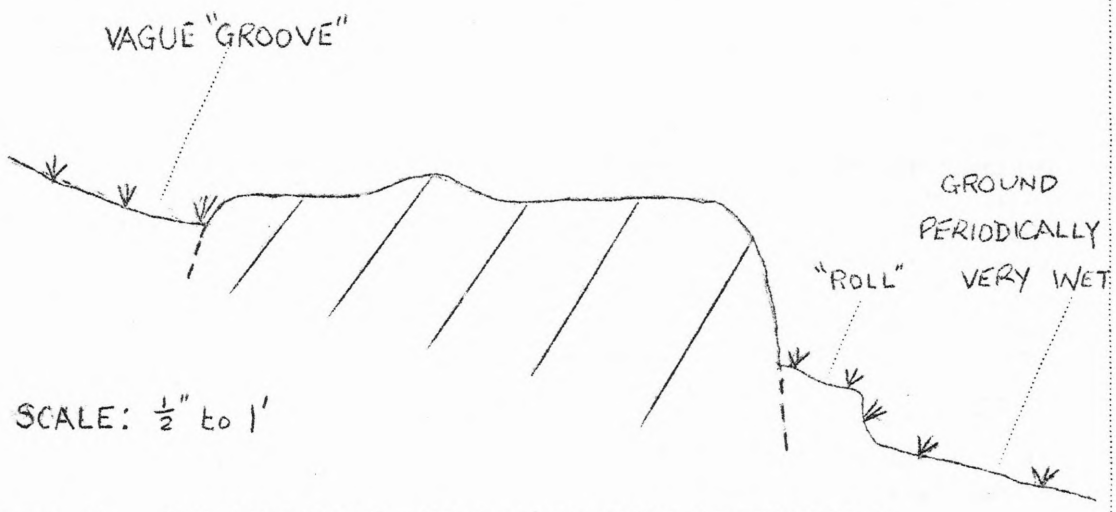


Figure 3. SINKING BOULDER, WEST-FACING SLOPE OF KNOCK PIKE.

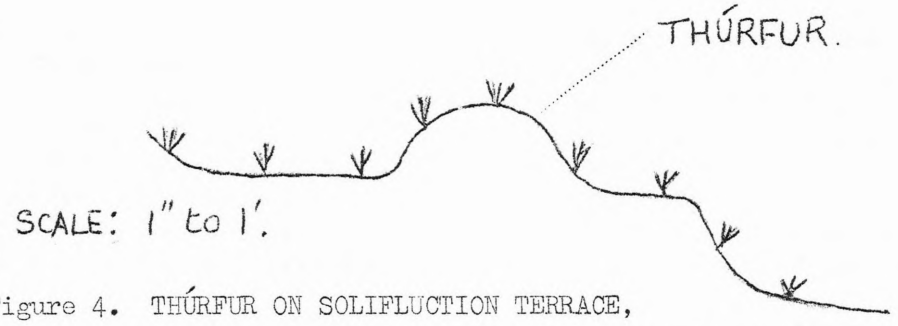


Figure 4. THÚRFUR ON SOLIFLUCTION TERRACE,
WEST-FACING SLOPE OF GREAT DUN FELL.

phenomena, those found in north-western England can generally be placed in his category of landforms due to talus creep. In subdividing the slow flowage processes typical of cold environments Sharpe distinguished between "solifluction"[7] and "rock-glacier creep". Ploughing blocks are one of the many landforms created by the first of these two periglacial processes. Like creeping boulders, sinking boulders and brake blocks, such features provide evidence that mass movement is actively modifying the landscapes of north-western England. The extent of such modifications has yet to be evaluated, though, in the author's opinion it is without doubt much greater than has hitherto been acknowledged.

THÚRFURS

Several types of hummock occur in periglacial regions. Of these the largest is a conical, ice-cored hill often referred to as a "pingo". Examples of this feature may have basal diameters of up to 600 m. and heights of over 50 m. A second type of periglacial hummocked ground is that usually known as "string bog". This landform occurs only on gentle slopes and consists essentially of up-arched, largely water-free areas set within patches of boggy ground. On aerial photographs it can be seen to have a pattern which is often best described by adjectives such as "ropy" and "stringy". Much smaller than either the pingo or string bog is the vegetation-covered hillock frequently known as a "thúrfur". The diameter of this feature is on average between 50 cm. and 1 m., while its height generally lies within the range 20 to 50 cm. (Cailleux and Taylor, 1954). So far as can be determined, the published literature contains no reference to the existence of thúrfurs in the British Isles. However, examples of the landform have been found by the author on Great Dun Fell, the highest peak on the Moor House Reserve. Although these occur at several places on the mountain, they are most fully developed on its exposed, west-facing slope at an altitude of around 2,700 ft. Here the individual hummocks have an average height of eight inches and are usually juxtaposed, thus forming thúrfur "fields". At certain places within these "fields" hummocks and small solifluction terraces have developed in close proximity. Figure 4 shows an example of where a terrace tread has been partly heaved up into a thurfur form. Despite the fact that present-day solifluction is active on this west-facing slope of Great Dun Fell, well-formed hummocks can be found where the slope angle is as much as 17°.

Research to date suggests that thurfurs rarely form at the present time in north-western England. Their occurrence on Great Dun Fell would seem to be attributable to the mountain's severe climatic régime. After all, it is surely no coincidence that this climatic régime is very similar to that experienced in parts of Iceland - precisely the country where thúrfurs are so well developed.

[7] Some authors use the word "solifluction" to denote soil flow under any type of climate, while reserving the term "congelifluction" for soil flow in a periglacial environment.

CONCLUSIONS

The aim of the present paper is to focus attention on the existence in north-western England of certain little-studied British landforms. At first it may seem that creeping boulders, brake blocks and sinking boulders are of little significance to the geomorphological evolution of an area. Yet they represent significant facets of that large and complicated group of processes known as "mass movement". Similarly, the occurrence of thúrfurs on Great Dun Fell may seem of little consequence to the geomorphologist concerned with landscape evolution on a regional scale. Yet frost action and its morphological effects (of which thúrfurs are but one manifestation) have been and still are of considerable significance in many parts of north western England. Moreover, considered with reference to this area, mass movement and periglacial activity have several things in common. First, their study has been very much neglected. Secondly, they have both been of great morphological significance during the late Pleistocene and Holocene periods. This raises an important question, namely, to what extent have non-glacial processes succeeded in modifying and altering the legacy which the Pleistocene glaciers bequeathed to north-western England? Could it, in fact, be that many landforms which we think of as being typically glacial have undergone significant modifications within the last 15,000 years? It is a question to which we have no answer and one well worth investigating.

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L.T.

MAKING AND EQUIPPING A FIELD CASE

K. R. Baker

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Whether in the field, or at home, the time comes when one may wish to carry out some tests on specimens. The equipment required for this may be conveniently housed in a suitable case, and the following suggestions for constructing and equipping such a case will, I hope, prove helpful.

The accompanying drawing shows a general view, with sizes given, and may be sufficient to allow construction to be carried out. However, full working drawings and cutting list may be obtained if required from the writer at 6d. per set.

The top drawer houses the following items:

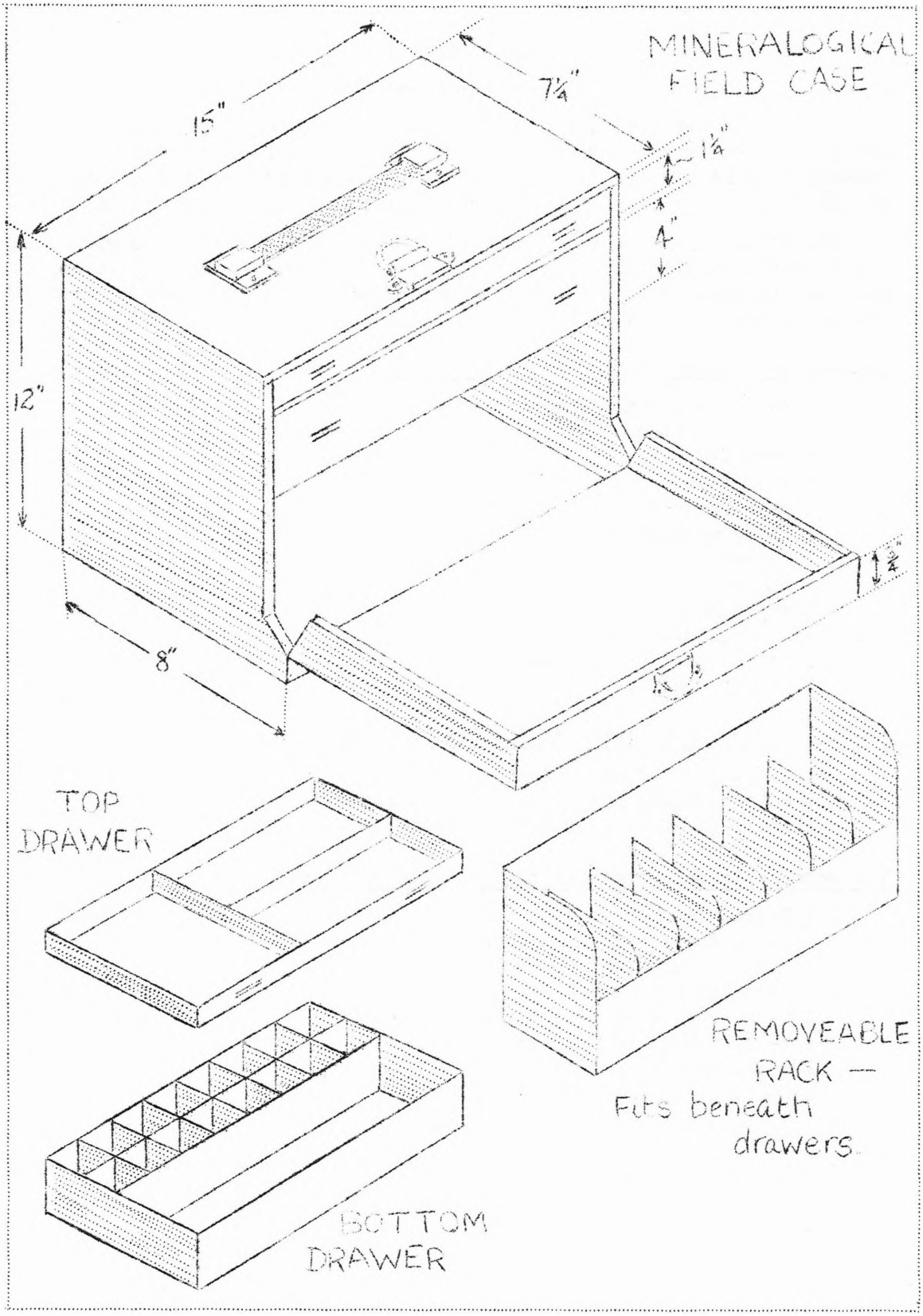
1 Hardness set and streak plates
1 Charcoal block
1 Blowpipe
1 Cobalt blue glass
1 pair Tweezers
1 6" Triangular file
1 Slip-stone
1 Magnet
1 Watch glass
1 dozen small test tubes
1 dozen small open tubes
1 platinum wire.

The bottom drawer contains the following items:

14 2-oz. jars of reagents
1 Retort stand, bosses, clamps and rings
1 small (4-oz.) Geological hammer.

The removeable rack contains the following items:

1 Spirit lamp
2 4-oz. bottles Methylated spirit
1 tin of spare lamp wicks
1 plastic graduated beaker
1 6-oz. bottle of Hydrochloric acid
1 6-oz. bottle of Sulphuric acid
1 6-oz. bottle of Limewater
1 6-oz. bottle of Distilled water.


MINERALOGICAL
FIELD CASE
15"
7¼"
1¼"
4"
12"
8"
TOP
DRAWER
REMOVEABLE
RACK —
Fits beneath
drawers.
BOTTOM
DRAWER