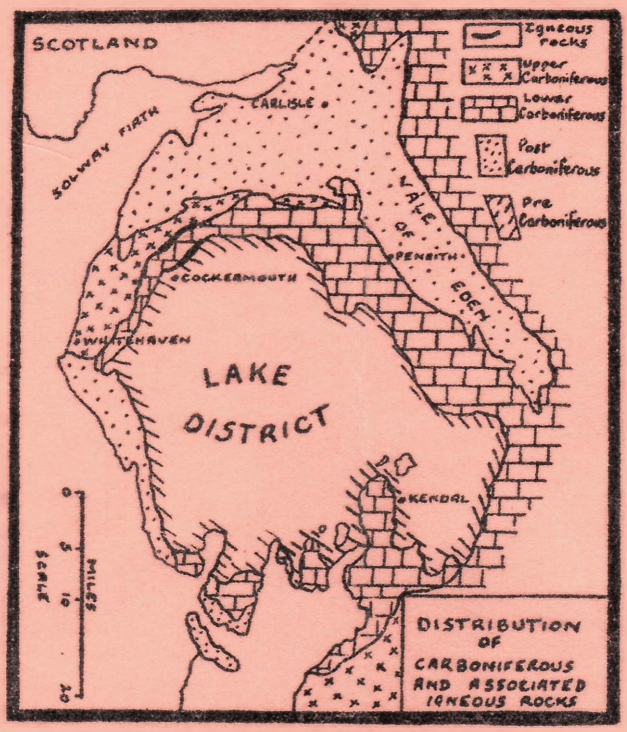
CUMBERLAND GEOLOGICAL SOCIETY



PROCEEDINGS

No. 1 1965

Two Shillings and Sixpence

THE CUMBERLAND GEOLOGICAL SOCIETY

President:

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

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PROCEEDINGS 1965, Number 1.

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Published by The Cumberland Geological Society

June, 1965.

GENERAL SECRETARY:

R.E.O. Pearson,

[redacted]

EDITOR:

T. Shipp, B.Sc.,

[redacted]

THE CHARLES EDMONDS MEMORIAL FUND

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Since the death of our Honorary Life President, Charles Edmonds, more than a year ago, a sum of money has been donated by his friends and associates in order to further geological knowledge in the North of England. This has been done in memory of a man who did a great deal of geological work in West Cumberland, and who firmly believed in and strove for the best educational opportunities possible for young people of this county. The Memorial Fund was instigated, you may remember, by our President in his Presidential Address of last year (Proceedings No. 1, 1964, pp. 3 and 16), and since that time, the Council has given much thought to the matter, and has produced the following scheme:-

1. A fund is to be raised by public subscription and vested in three Trustees who shall be appointed by the Council of the Cumberland Geological Society.

2. The fund will be suitably invested by the Trustees and the interest used to provide a Prize to be awarded every three years, or more frequently if the Trustees so decide.

3. The Prize shall consist of a book, or books, suitably inscribed, and shall be presented to the successful candidate at the Society's Annual Dinner.

4. The Prize shall be awarded by a Panel consisting of the President, Vice-President and Secretary of the Cumberland Geological Society, together with one other person who shall be appointed by the Council of the Cumberland Geological Society.

5. Candidates for the Prize shall be limited to:-
   (a) Students at a school, university, training college or other institution of full-time education, including post-graduate students, but excluding full-time members of teaching staffs of such institutions.
   (b) Amateur geologist Members of the Cumberland Geological Society.

6. Candidates shall produce evidence of having done work which was calculated to furtherance of geological knowledge of some part of the six Northern Counties of Cumberland, Westmorland, Lancashire, Yorkshire, Northumberland and Durham.

The President has asked for further donations to this fund to provide sufficient capital for a prize under the conditions stated above. Donations should be forwarded to the General Secretary, or to the Hon. Treasurer, H.A. White, Esq., B.A., at 3, Stainburn Road, Workington, Cumberland.

- E D I T O R I A L -

Having completed the collection of material for these Proceedings, and prepared the stencils in readiness for duplicating, it falls to my lot as Editor to write a few words by way of introduction.

A great deal of thought has been given lately to the dissemination of geology both within our Schools and in Institutes of Further Education. The Geologists' Association anticipated this trend as early as 1947 with an article on "The Teaching of Geology in Schools" by Dr. Wilson and associates, followed in 1963 by a Presidential Address by Professor Kirkaldy on "Education in Geology". "Syllabus and Method in the Teaching of Geology" is another paper, very well worth reading, by Professor Neville George in The Advancement of Science of March 1964. Other bodies interested in the teaching of geology include the Association for Science Education with papers on the subject by Dr. J.T. Greensmith in the School Science Review, the Geological Society which has a committee working on the subject, and the B.B.C. whose series "The Changing World" on television appears at an inconvenient hour on Saturday mornings, and is repeated abominably late on Tuesday evenings. Nevertheless, the programmes are excellent.

The widespread ignorance of the general public of matters scientific is in my opinion scandalous, and the blame for this state of affairs can be laid largely on our Educators. By an insistence on rigid syllabuses in "compartmentalised" sciences, on the "classical" physics of a century and more ago, on the chemistry of Lavoisier and Boyle and Berthollet, on mere description and classification of living things and life processes, all to the end of passing an examination, possibly to enter a University, Science will continue to be thought of by most people as a mere jumble of unrelated facts remote from everyday experience. Even "General Science" is usually an aggregation of topics from physics, chemistry and biology and is almost invariably taught by a specialist in one of these subjects who is naturally biased towards his own subject.

It is time less emphasis was placed on so-called "Specialist Sciences", and even on "General Science" with its readily apparent limitations, and a new approach developed in our schools to a truly "Basic" Science, based on the earth on which we live, its relations in space, the chemistry of formation and use of rocks and minerals, the physics of forces of erosion, sedimentation and isostatic adjustment, and the biology of fossils framed in the broad picture of evolution. A science is required that is soundly based on matters of everyday experience, on readily made observations and deductions, not mere repetition of experiments first performed by the alchemists or several different ways of determining specific heat, or the detailed cell structure of Hydra. If the recognition of simple types of rocks and their contents, of the building-up and wearing-away of the land is taught early in a child's school career, then the chemistry of minerals and man's use of them, the physics of forces moulding the earth, the biology of present-day living creatures compared with the remains of what went before, all these fall into a natural, logical order of Science from which the more abstract developments can be taken on. It would be far better to have this sort of development of Science than to be forced to learn the chemistry of sulphur and its smelly compounds, simply for the privilege of being able to

retail in an examination the laboratory preparation of sulphur dioxide and its conversion into sulphuric acid. This blights the interest of all but the mentally toughest fifteen year old. Far better to start from the basic principles, sulphide and sulphate minerals, how they were formed and how they are exploited and utilised by man. This is the rational approach, but it is largely precluded on the grounds of insufficient time owing to the demands of the examination syllabus.

Our own Society, although a relatively small, local body, has given active thought and furtherance to the subject of education in geology as the basic scientific discipline. It needs no publicity by me to emphasise how fortunately we are placed in the Lake District and its environs for the evidence of a vast number of geological phenomena. Yet, in spite of this, only two or three of our local secondary schools include geology as an examination subject in their curricula. The number of candidates for G.C.E. (O) Level Geology has increased more than tenfold over the last fifteen years. Is such an increase shown in Cumberland Schools? I doubt it! How many of our local schools, both junior and secondary, make use of geology as a "cultural" subject, unfettered by the formalities of an examination syllabus, enabling pupils to see for themselves some of the processes that have built up our complex earth, and given us the raw materials upon which we all depend? On the other side of the coin, teachers may argue that they have been trained to teach Chemistry, Physics, Botany or Zoology, and that they have little knowledge of Geology, or means of "putting it across". As a chemistry specialist myself, I can understand this view, and realise the need for a certain amount of re-training and enthusiasm in order to achieve a new approach to Science.

In this publication you will read a report of a Weekend School in Geology, organised with the co-operation of the Cumberland Education Committee, aimed to acquaint teachers with some of the geological features to be found in the county, and to stimulate interest in teaching at least some of the elements of the subject. This delightful weekend was the first of what we hope will be a regular feature of the Society's activities in promoting interest in Geology and in Science as a whole.

T. Shipp.

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We wish to acknowledge the receipt of the following publications:

Proceedings of the Liverpool and Manchester Geological Society for 1964. *

The Mercian Geologist. Journal of the East Midlands Geological Society. *

Transactions of the Leeds Geological Association. Vol.VII, Pt.1. 1955-7. **
Vol.VII, Pt.2. 1958-9.
Vol.VII, Pt.3. 1960-3.

* Donated by Mr. W.H. White, A.I.R.I.
** Exchange agreement with Leeds Geological Association.

THE ANNUAL GENERAL MEETING

Held on 12th. January 1965 at the Whitehaven College of Further Education.

The evening commenced with an Extraordinary Meeting at which a number of alterations to Rules were approved. The President moved the adoption of the following recommendations:

(a) That the word "Librarian" be inserted after "Editor" in Rule 20. This Rule will therefore read:-

"The Society shall be governed by a Council consisting of President, Vice-President, General Secretary, Excursion Secretary, Treasurer, Editor, Librarian, and four Ordinary Members."

(b) An additional Rule, numbered 33a, will be inserted after Rule 33. This new Rule will read:-

"Librarian

33a. The Librarian shall receive, on behalf of the Society, donations to the Library and shall record their receipt. He shall keep a register of all books borrowed from the Society's Library. He shall keep the Library of the Society in such place and under such conditions as the Council shall, from time to time, direct."

Then ensued the Annual General Meeting proper.

The General Secretary, Mr. Pearson, in his Report stated that membership had increased from 135 in 1964 to 152, made up of 1 Honorary Member, 91 Ordinary Members, 55 Associate Members and 5 Institutional Members. He then went on to stress that the right kind of publicity for the Society was essential to keep membership numbers trending upwards, whilst continued efforts by Members to obtain copies of Society publications and postcards for themselves and their friends were essential if the Society was to keep a healthy financial state without increasing subscriptions. Mr. Pearson then thanked the other Officers of the Society and Members for their continued support and co-operation.

Mr. Hewitt, the Excursion Secretary, presented in his Report a statistical view of attendances at visits and excursions in 1964. There were 5 mine visits with an average attendance of 10, and 13 Field Excursions with 30 Members and friends attending each on average. The most popular excursion was to the Shap Granite, with 63 people in attendance. Other excursions to study particular features of the petrology of the area were made to the Sale Fell Minette, to Skiddaw Dodds, to the Threlkeld Microgranite and to the Dash Beck Picrite. The Carboniferous was well studied with visits to the Carboniferous Limestones of Cartmel and West Cumberland, the Yoredale Beds of the Hartside area and the Coal Measures at Rowgill Head Quarry, Whitehaven. An excursion to Pull Wyke, near Ambleside, was made to study Silurian Graptolites, whilst finally the effect of glaciation in West Cumberland was studied, both along the coast and inland. In conclusion, Mr. Hewitt thanked Directors of excursions for easing the burden of arranging all these varied activities.

The Treasurer, Mr. Shipp, in presenting his final Balance Sheet, expressed his regrets at feeling obliged to resign. Increasingly onerous duties as Editor, coupled with outside commitments, made him intimate to Council his decision to resign one or other post, so they promptly asked Mr. White to stand as Treasurer. The Treasurer stated that during the year the Associate Members' subscription had been raised from 2/6 to 5/-. This

was felt to be fair, as Associates received five shillings' worth of Proceedings, as well as all other official communications from the Society. Sales of publications had fallen off, particularly postcards, though there was a slow but steady demand for Limestone Memoirs and back numbers of Proceedings. Although the Society had never boasted since its inception a large sum of money in the Bank, its assets had risen steadily, the fullest possible use of the moneys available being maintained.

The Reports having been received and accepted, the President called for the election of Officers and Members of Council for the 4th. Session of the Society. The following were elected:

President:	E.H. Shackleton, F.G.S.
Vice-President:	G.S. Gowing, M.A., F.G.S.
General Secretary:	R.E.O. Pearson.
Excursion Secretary:	R.H. Hewitt, A.M.I.N.Eng.
Treasurer:	H.A. White, B.A.
Editor:	T. Shipp, B.Sc.
Librarian:	M.F. Burton.

Members of Council:

Miss V.G. Beer, M.S.R. S.H. Gate, B.Sc.,M.Sc.,A.R.I.C.
D.C. James, B.Sc.,A.M.I.Chem.E. Miss E. Pimblett, B.A.

This concluded the formal business of the meeting.

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THE ANNUAL DINNER

Held at the Eclair Restaurant, Whitehaven on January 15th., 1965.

About 45 Members and friends arrived for this, the most eagerly awaited of the Social Events held by the Society. As this was a new venue, we felt somewhat inquisitive about it, but Mr. Stainton the Manager and his staff quickly made us welcome in a delightful room, with a pleasant meal and excellent wines.

After the meal the Guests of Honour, Professor and Mrs. Gordon Manley, were formally but pleasantly welcomed by the President. Professor Manley, who holds the Chair of Environmental Studies at the University of Lancaster, after thanking the Society for the invitation and welcome, spoke of his interests, claiming that because of his preoccupation with climatic and weather studies he was not really a geologist and was therefore present under false pretences. This assertion caused considerable amusement, but when he referred to the notion of a "fossil climate" he identified himself with the geological world.

During the evening the President, on behalf of the Council, presented a stainless steel dish to Mr. D.C. James and Miss E.A. Gate who were to be married the following morning. He wished Clive and Elizabeth a very happy marriage, a sentiment echoed by all present.

The evening ended informally and convivially at about 11 p.m.

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THE PRESIDENTIAL ADDRESS

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Delivered by E.H. Shackleton, F.G.S. on Tuesday, 9th. February, 1965 at Workington College of Further Education.

---oooOooo---

As many of you know I work at the Workington Branch of the United Steel Company which some ten years ago was actively engaged in the smelting of manganese ores. These ores were imported from many parts of the world, and during their transit from the docks to furnaces, they all came to rest for varying periods on the ore stocking ground. By kind permission of the management I was allowed access to these piles of ore which, from the point of view of a mineralogist, proved to be very interesting. Sources of supply varied considerably but at this time manganese from Sinai, Griqualand West, Takoradi and the Central Provinces of India was continually in stock. I had already extracted many fine specimens from these dusty piles, when, one day after a sharp shower of rain, the sun came out and strongly illumined a great pile of ore newly arrived from India.

As I stood before this great pile of freshly-washed braunite my eye was taken by innumerable points of twinkling light and I felt a thrill of anticipation, for I knew from past experience that each point of fire emanated from a crystal of some sort. But what were these crystals? Never before had I seen such riches and although I did not know this at the time, never again was I to see its like. By one of those fortunate coincidences that sometimes sustain our endeavours the flow of ore to the furnaces was halted, and throughout that summer I collected unhindered. Crystals of spessartite were so common that rather foolishly I came almost to ignore them whilst I collected some of the most magnificent specimens I had ever seen. Since they were puzzling I passed them on to the Minerals Department of the British Museum, which classified them as quite rare manganese amphiboles and pyroxenes that had first been found and reported upon by the late Sir Lewis Leigh Fermor while he was attached to the Indian Geological Survey.

About this time Mr. S. A. Bilgrami of the Department of Geology at Manchester University gave a paper on these same minerals to the Mineralogical Society in London, and this brought us in touch.

If fortunate coincidences had conspired to give me a lively and very interesting time, yet another happy coincidence introduced me to the real subject matter of this address. About this time I regularly received lists of books and papers available from a secondhand bookseller in London who specialises in geological works. Imagine my surprised interest when one day he advertised a number of papers by Sir Lewis L. Fermor. Although I applied at once I was not successful in obtaining all those advertised, but I did manage to buy a few, and it is with one of them that I would like to deal in my Address.

Among the many institutions the British introduced into India was the Indian Association for the Cultivation of Science, the Indian equivalent of the British Association, I presume. To this body Sir Lewis L. Fermor, as Ripon Professor, delivered in 1937 a series of lectures which had as a general title "Garnets and their role in Nature", and which were published

in Calcutta in 1938 by the I.A.C. of S. as a special memoir. It was this copy of the lectures that I had the good fortune to buy. At the time, my principal interest lay in the descriptions of the Indian deposits of manganese; not until later did I turn to the section on garnets. To encounter unexpectedly a paper such as this was to experience the happy thrill of a new discovery for it dealt not only with the subject of garnet in a masterly way, but also with several great topics of earth lore. To my knowledge, this paper has never been published in England and the only reference to it that I have seen is in Du Toit's "Our Wandering Continents". I hope that the following impressions of it, however inadequate they may be, will help to draw attention to ideas well worthy of more notice than they seem to have enjoyed so far.

After a brief introduction, from which it appears that Fermor had enjoyed a long collaboration with the I.A.C. of S. and had also first drawn attention to the magnetic properties of Indian braunites, he went on in his first lecture to deal with garnet as a mineral. The name itself, he says, is very old and was applied as long ago as 1270 by Albertus Magnus to small red crystals which reminded him of the tiny seeds in a pomegranate, indeed, "garnet apple" is an old name for that fruit. Garnet is now a comprehensive name given to a closely allied group of isomorphous crystalline minerals, all of which crystallize in the cubic or isometric system. Chemically, all garnets conform to a general formula, written either as:

$$3R''O.R'''_2O_3.3SiO_2 \quad \text{or as} \quad R''_3R'''_2Si_3O_{12}$$

where R'' may be either magnesium, ferrous iron, manganous manganese, or calcium, and R''' either aluminium, ferric iron, or more rarely manganic manganese or chromium. Although, because of the isomorphous nature of their "molecules" all garnets are mixtures, it is customary in textbooks to give the following six sub-species and formulae:-

Pyrope	$3MgO.Al_2O_3.3SiO_2$	or	$Mg_3Al_2(SiO_4)_3$
Almandite	$3FeO.Al_2O_3.3SiO_2$	or	$Fe_3Al_2(SiO_4)_3$
Spessartite	$3MnO.Al_2O_3.3SiO_2$	or	$Mn_3Al_2(SiO_4)_3$
Grossularite	$3CaO.Al_2O_3.3SiO_2$	or	$Ca_3Al_2(SiO_4)_3$
Andradite	$3CaO.Fe_2O_3.3SiO_2$	or	$Ca_3Fe_2(SiO_4)_3$
Uvarovite	$3CaO.Cr_2O_3.3SiO_2$	or	$Ca_3Cr_2(SiO_4)_3$

In nature, all garnets are mixtures of the above minerals. Pyrope garnet never contains more than 70% of the pyrope "molecule" though exceptionally other garnets may contain up to 98% of the principal "molecule". For example, a pyrope from Meronitz in Bohemia contains 69·9% pyrope, 17·53% almandite, 0·90% spessartite, 6·68% uvarovite and 3·69% andradite, whilst at the other extreme there is an andradite from the Ala Valley in Italy with 98·48% andradite and 0·65% khoharite.

Mention of khoharite brings us to another aspect of Fermor's research into garnets. From detailed study of the molecular structure of garnet he came to the conclusion that the idea of "molecules" in this application, whilst a convenience, was rather misleading, and that the idea of ionic "unit cells" in the crystal space lattice was more relevant. Detailed studies of these ionic unit cells suggested that besides the six varieties of garnet already recognised, there was no theoretical reason why a further

three ferric garnets should not exist. Fermor goes on to tell how these were eventually discovered and named:-

Khoharite	$3MgO.Fe_2O_3.3SiO_2$	or	$Mg_3Fe_2(SiO_4)_3$
Skiagite	$3FeO.Fe_2O_3.3SiO_2$	or	$Fe_3Fe_2(SiO_4)_3$
Calderite	$3MnO.Fe_2O_3.3SiO_2$	or	$Mn_3Fe_2(SiO_4)_3$

Khoharite was discovered in a meteorite that fell at Khohar in the Banda district of the United Provinces. Although it is rare at the earth's surface, Fermor advanced interesting reasons for supposing it to be present in considerable amount deep within the earth. Skiagite, whilst found to the extent of 25% in some Indian spessartites, was named after Glen Skiag, the locality where it occurs in Scotland. The third of these ferric garnets calderite was discovered in the Hazaribagh district of India.

If theory be pressed to the limit, no less than sixteen garnets are possible, but so far only one other has been found, again due to Fermor's inspiration, in the Nagpur district of India and named blythite after its discoverer. Blythite is a manganic garnet, $3MnO.Mn_2O_3.3SiO_2$, the type specimen shewed 35% blythite, 18% spessartite, 13% calderite, 19% pyrope and 15% andradite.

All garnets, because of their closely packed space lattice, have a fairly high specific gravity, but this is unreliable as a means of classification. Laboratory work has shewn that garnets, in common with such minerals as jadeite, are almost incompressible. Despite this they are readily fusible, melting in most instances at or below 1000°C. They melt incongruently, and the fused product solidifies not as garnet but as a mixture of pyroxenes, spinels and other minerals. One especially noteworthy feature; all garnets expand on melting by about 25-30%, and it seems highly probable that the reaction is exothermic.

Attempts to synthesize garnets have met with only a limited success due to the difficulty of producing and maintaining in the laboratory the very high pressures required.

From his consideration of the chemical and physical properties of the garnet minerals, Fermor went on to investigate their occurrence in Nature, and noted that garnets are often present as derived minerals in the sedimentary rocks, whilst in the igneous rocks they are often present as original constituents. They occur in many lavas; locally almandite is by no means uncommon in the Borrowdale Volcanic Series. Garnets are common in hypabyssal rocks, and Fermor instances the frequent occurrence of spessartite in such rocks from locations in India, a fact which I have observed and already commented upon. Although garnets occur in plutonic rocks they do so with no great frequency.

Garnets occur most commonly in schists, gneisses and granulites which have been formed by metamorphism of sedimentary or igneous rocks. In an earlier paper entitled "Garnets as a geological barometer, and on an infra-plutonic zone in the earth's crust" Fermor put forward the argument that garnets would of necessity be formed in rocks of suitable chemical composition if the pressure became sufficiently great. Fermor went on in meticulous detail to state the kind of garnet likely to be found in given rocks under various degrees of metamorphism. In all instances of formation of garnet he stressed that there would be a decrease in volume and, he

believed, an absorption of heat.

Garnet, then, is a mineral with two marked characteristics. It is formed under great pressure with absorption of heat, but upon release of pressure it can re-form into the original minerals with a consequent emission of heat and increase in volume. This is a completely reversible process to which the principle of Le Chatelier applies.

In this connection are mentioned the so-called "kelyphite rings" often found round both almandite and pyrope garnets. The term, which means a nut-shell, very well describes the rim of mineral, often of a radially fibrous structure, found round garnets in such rocks as eclogites and peridotites. They were, I believe, first noticed in the Kimberlites from the diamond pipes of South Africa, a most interesting source of rocks of the deep. The minerals of which these rims are composed belong as a rule to either the pyroxene or amphibole groups and chemically are the same as the garnet around which they have been formed. Many varied explanations have been given for these rings which are frequently found in meteorites, especially, according to Sir Lewis, in what are known as chondritic meteorites. These he relates to that portion of the earth's crust which he calls the infra-plutonic zone, speculating on the possibility that meteorites are bits of a disrupted planet not unlike our own. However this may be, it is possible that these kelyphite rings could be silent witnesses to that completely reversible process we have just visualised.

When Fermor begins to develop the theme of the role garnet plays in nature, his work becomes really fascinating. I cannot adequately cover all his topics, but I can at least give you their range and indicate the scope and depth of his views.

"The subjects on which I wish to touch briefly," he writes, "and to attempt to explain by these reversible reactions are:-

(1) The emission of great floods of basaltic lava.
(2) Isostasy, or the support of mountains and plains.
(3) Deep-focus earthquakes.
(4) Continental drift.
(5) The formation of chondritic meteorites."

I give this quotation in full knowing that I cannot possibly cover his five points. What I can attempt is to say enough on one or two of them to shew the value of this neglected paper.

In India the Deccan Trap covers some 200,000 square miles. Careful survey has shewn that these mostly, but not exclusively, basaltic flows issued at the surface from fissures and not from volcanoes. In this they are similar to the basaltic flows that cover vast areas in Oregon and Idaho and in the Arcto-Britannic Province that includes Giant's Causeway, the Western Isles of Scotland, and Iceland. All these great floods are roughly of the same age, i.e., Lower Tertiary, but going back through geological time, such floods are far from unique. By and large all this enormous amount of material, and the Deccan Trap is in places 5,000 to 6,000 feet thick, is basaltic in character and this leads to the supposition that there is, at a suitable distance below the earth's surface, a continuous shell of material which, when melted, forms the basaltic lava we find issuing in fissure eruptions. It is believed that in the continents this basaltic shell is overlain by the more acid materials like granite, and the

sedimentary rocks are derived from their breakdown. Under the oceans the acid rocks are assumed to be either entirely missing or present only in small amounts. Basalt is assumed for the most part to form the floor. In passing might I say that it is high time that these assumptions were proved one way or another. The constitution of our planet and the mechanisms that control this earth upon which we live are of far more import to us and to our descendants than the purely academic question of what covers the surface of the moon.

It must be remembered that in applying the term basaltic to this shell of the earth we are using an adjective that well describes this material as it occurs at the surface. It may, however, be totally misleading when applied to material at depths indicated by seismic surveys. Chemically it may be basaltic, but its mineral phase may be altogether different. Basalt as we know it at the surface contains considerable amounts of glass because of comparitively rapid cooling, but at depth crystallization would be much more slow and complete. Gabbro is chemically similar to basalt, mineralogically the glass is missing and the rock is of a higher density. In our postulated basaltic shell there must be a critical depth where the volume law prevails and non-garnetiferous rocks begin to pass into garnetiferous rocks with decrease in volume and absorption of heat. Authorities disagree over the depth at which this will happen; Fermor quotes 37 to 60 Kms. with a preference for the higher figure. In any case this lies below the zone in which rocks can exist in a plutonic phase, and Fermor in 1913 coined the term "infra-plutonic zone" (Du Toit later renamed it the "paramorphic zone"). In this zone it would seem that gabbro must pass into its high pressure equivalent, eclogite. It may be that this is the reason that eclogites are such rare rocks at the surface.

Garnet, it may be remembered, has the general formula $3R"O.R"'_2O_3.3SiO_2$ and since its formation is favoured by pressure its average abundance should increase in depth, as long as the trivalent oxides of iron, chromium and aluminium are present. Any rock in the infra-plutonic zone would probably rearrange as many of its constituent minerals as possible in the form of garnet, any excess crystallising as feldspars, quartz and ferromagnesian minerals. However, whilst Fermor makes garnet the focus of his discussion, he readily agrees that there are other minerals formed under very high temperatures and pressures, depending on the availability of suitable materials. In this connection he mentions diamond, sillimanite, rutile, kyanite, and the diopside-jadeite series.

Fundamentally this deep zone in the earth's crust is inferred from the wide occurrence of huge spreads of basaltic lava, as in the Deccan Trap. Individual lava flows can be traced for surprisingly large distances. Fermor indicates flows of 25-30 miles to be quite common, whilst in the Nagpur district, he traced one for no less than 65 miles. The persistence of flows over such distances makes the assumption of high fluidity inescapable, but to what can this high fluidity be ascribed? After a careful review of all the evidence, Fermor relates high fluidity with a high degree of superheating caused by a change of phase consequent upon release of pressure.

Geologists have long known that the strength of the earth's crust is limited, and this being so, it has been one of the problems of geology to account for such great upstanding masses as the Himalayas. First steps

towards an explanation were taken in India when Archdeacon Pratt discovered that there was a marked deficiency of mass below the Himalayas as indicated by the behaviour of a pendulum. From these observations sprang the theory of isostasy, the dictum that "mountains have roots", and that the crust of the earth tends towards a state of equilibrium. It is interesting to note that Dutton, one of the early theorisers on this subject, recognised that isostatic adjustment could be explained either by a change of mass or a change of density. Fermor quotes him, and I think the quotation worth reproducing: "What the real nature of the uplifting force may be is, to my mind, a complete mystery; but I think we may discern at least one of its attributes, and that is a gradual expansion, or a diminution of the density of the subterranean magmas. If the isostatic force is operative at all, this expansion is a rigorous consequence, for whenever a rise of the land has taken place one of two things has happened; the region affected has either gained an accession of mass or a mere increase of volume without increase of mass. We know of no cause which could either add to the mass or diminish the density, yet one of the two must surely have happened. But the difference of the two alternatives in respect to consequence is immense. If the increase of volume of an elevated area be due to an accession of matter, the plateau must be hoisted against its own rigidity and also against the statical weight of its entire mass lying above the isostatic level. But if the increase of volume be due to a decrease of density there is no resistance to overcome in order to raise the surface. Hence I infer that the cause which elevates the land involves an expansion of the underlying magmas, and the cause which depresses it is a shrinkage of the magmas. The nature of the process is, at present, a complete mystery."

I am hopeful that those of you who have followed thus far may now be in a position to see how Dutton's mystery might be resolved. But at this stage I would like to dwell a little further on the subject of isostasy. Holmes, in his treatise on Physical Geology, deals with the allied subjects of mountains, erosion, deposition, and the maintenance of isostatic balance, for which he suggests as an explanation flowage in the substratum. At a later stage in his great treatise, Holmes deals with the development of a geosyncline and shews how the mere pressure of deposits is not a sufficient cause in itself to account for the depression of the earth's crust. However, if we add to the sedimentary load the paramorphic effect, the change of phase between plutonic and infra-plutonic, from gabbro to eclogite, then we have within the basaltic layer itself a superb mechanism for adjustment and readjustment. Du Toit uses the analogy of a layer of sponge rubber sandwiched between two layers of solid rubber and says: "-its response to loading and unloading would be immediate, perfect and considerable. Since the mass of the crustal column would remain unchanged, the movement of its upper surface will become additive to that due to lateral flow in the zone of compensation following such loading and unloading. To the normal isostatic displacement must be added the paramorphic effect and the actual change in elevation, whether positive or negative, will be greater than that given by the usual calculations.

Knowledge of earthquake phenomena expanded rapidly with the perfection of the seismograph, by means of which it is possible to pinpoint the focus of any sudden shock within the earth's crust. In the majority of earth-

quakes the focus is sufficiently near the surface to be ascribed to such causes as the slipping of faults but there are others whose depth of origin is so great as to preclude any such origin. It was R. D. Oldham of the Geological Survey of India who, as a result of studies of the Great Assam Earthquake of 1897 and others, laid the foundation of modern seismography by his discovery and application of three main types of earthquake waves. In trying to account for the causes of earthquakes, Oldham was puzzled by the shocks of deep-seated origin until, coming across one of Fermor's earlier references to the infra-plutonic zone, he wrote: "I had been searching for some satisfactory explanation of big earthquakes, which seem to require a fairly extensive though still local and fairly rapid expansion in the deeper layers in the earth's crust, and had come across none which had any relation to the actual composition of the earth. The passage from the infra-plutonic mode would give me just such an effect as I want."

Thus to the problems of Dutton on isostasy and Oldham on earthquakes comes help and inspiration from the work of Sir Lewis Leigh Fermor and his deliberations on garnet. Du Toit's theory of "Wandering Continents", the finding of sufficient forces to move the continents, owe something to the work of Fermor on the chemical and physical changes taking place deep in the infra-plutonic zone, ideas which arose initially from his study of garnet.

In closing may I say that the sole object of my Address has been not so much to inform you as to stimulate you to search for yourselves in the geological literature. I have tried to draw your attention to a fascinating piece of research which regrettably seems to be little known, although fundamental to the mechanisms governing the crust of the earth which is our home.

References:

FERMOR, L.L., 1938, Garnets and their role in Nature. Indian Association for the Cultivation of Science. Special Publication No. VI.

DU TOIT, A.L., 1937, "Our Wandering Continents". Oliver & Boyd, Edinburgh

PRATT, J.H., 1855, On the Attraction of the Himalaya Mountains, and of the elevated regions beyond them, upon the Plumb-line in India. Phil. Trans. Roy. Soc., A. Vol. 145, pp. 53-100.

DUTTON, C.E., 1892, On some of the Greater Problems of Physical Geology. Bull. Phil. Soc. Washington, Vol. XI, pp. 51-64.

HOLMES, A., 1944, "Principles of Physical Geology", Nelson.

OLDHAM, R.D., 1900, On the Propagation of Earthquake Motion to Great Distances. Phil. Trans., A. Vol. 194, pp. 135-174.

JOE AND THE GEOLOGIST

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The following tale, published in the sixties of the last century, refers to Adam Sedgwick, who was Woodwardian Professor of Geology at the University of Cambridge from 1818 until 1873.

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Ya het foorneun, when we war oa' gaily thrang at heäm, an oald gentleman mak' of a fellow com' in tul oor foald an' said, whyte nateral, 'at he wantit somebody to gā wid him on't fells. We oa' stopt an' teuk a gud leuk at him afoor anybody spak; at last fadder said, middlin' sharp-like - (he ola's speaks that way when we're owte sae thrang, does fadder) - "We've summat else to deu here nor to gā rakin ower t'fells iv a fine day like this, wid neabody kens whoa." T'gentleman was a queerish-like oald chap, wid a sharp leuk oot, grey hair and a smo' feäce - drist i' black, wid a white neackcloth like a parson an' a par of specks on t'top of a gay lang nwose 'at wasn't set varra fair atween his e'en, sooa 'at when he leuk't ebben at yan through his specks he rayder turn't his feäce t'ya side. He leuk't that way at fadder, gev a cheärful bit of a laught an' said, iv his oan mak' o' toke, 'at he dudn't want to hinder wark but he wad give anybody 'at ken't t'fells weel a matter o' five shillin' to gā wid him, an' carry two lāl bags. "'Howay wid tha, Joe," sez fadder to me, "its a croon mair nor iver thou was wūrth at heäm!" I meäd neä words about it, but gat me-sel' a gud lūmp of a stick, an' away we set, t'oald lang-nwos't man an' me, ebbem up t'deäl.

As we war' climmin' t'fell breist, he geh me two empty bags to carry, meäd o' ledder. Thinks I to me-sel', "I'se gān to eddle me five shillin' middlin' cannily." I nivver thowte he wad find owte on t'fells to full his lāl bags wid, but I was misteän.

He tūrn't oot to be a far lisher oald chap nor a body wad ha' thowte, to leuk at his grey hair and his white hankecker an' his specks. He went lowpin' ower wet spots an' gūrt steäns, an' scrafflin' across craggs an' screes, tul yan wad ha' sworn he was sūmmat a kin tul a Herdwick tip.

Efter a while he begon leukin' hard at oa't steäns an' craggs we come at, an' than he teuk till breckan lumps off them wid a queer lāl hammer he hed wid him, an' stuffin' t'bits intil t'bags 'at he geh me to carry. He fairly cap't me noo. I dudn't ken what to mak' o' sec a customer as this. At last I cudn't help axin him what meäd him cum seä far up on t'fell to lait bits o' steäns when he may'd find seä many doon i't deäls. He laugh't a gay bit, an' than went on knappin' away wid his lāl hammer, an' said he was a jolly jist. Thinks I to me-sel', thou's a jolly jackass, but it maks neä matter to me if thou no'but pays me t'five shillin' thou promish't ma.

Varra weel, he keep't on at this feckless wark tul gaily leät at on i't efter-neun, an' be that time o' day he'd pang't beäth o't ledder pwokes as full as they wad hod wid bits o' steän.

I've nit seä offen hed a harder darrak efter t'sheep, owther at clippin time or soavin time, as I hed followin' that oald grey heidit chap an'

carryin' his ledder bags. But hooiver, we gat back tul oor house afoor neeght. Mūdder gev t'oald jolly jist, as he co't his-sel', some breed an' milk, an' efter he'd teän that an' toak't a lāl bit wid fadder aboot sheep farming an' sec like, he pait me five shillin' like a man, an' then tel't ma he wad gie ma ūdder five shillin' if I wad bring his pwokes full o' steäns doon to Skeäl-hill be nine o'clock i't' mwornin'.

He set off to walk to Skeäl-hill just as it was growin' dark: an' neist mwornin', as soon as I'd gitten me poddish, I teuk t'seäm rwoad wid his ledder bags ower me shoolder, thinkin' tul me-sel' 'at yan may'd mak' a lāl fortune oot o' thūr jolly jists if a lock mair on them wad no'but come oor way.

It was anūdder het mwornin', an' I hedn't wok't far till I begon to think that I was as gurt a feul as t'oald jolly jist to carry broken steäns o't way to Skeäl-hill, when I may'd finnd plenty iv any rwoad side, clwose to t'spot I was tackin' them tul. Sooa I shack't them oot o' t'pwokes, an' then step't on a gay bit leeter widout them.

When I com nār to Skeäl-hill, I fūnd oald Aberram Atkisson sittin' on a steul breckan steäns to mend rwoads wid, an' I ax't him if I med full my ledder pwokes fra his heap. Aberram was verra kaim't an' tell't ma to tak them 'at wasn't brocken if I wantit steäns, sooa I tell't him hoo it was an' oa' aboot it. T'oald maizlin was like to toytle off his steul wid laughin', an' said me mūdder sud tak gud care on ma, for I was ower sharp a chap to leeve varra lang i' this warld; but I'd better fill my pwokes as I liked, an' mak on wid them.

T'jolly jist hed just gitten his breakfast when I gat to Skeäl-hill, an' they teuk ma intil t'parlour tul him. He gūrned oa't feäce ower when I went in wid his bags, an' tel't me to set them doon in a neuk, an' then ax't ma if I wad hev some breakfast. I said I'd gittan me poddish, but I dudn't mind; sooa he tel't them to bring in some mair coffee, an' eggs, an' ham, an' twoastit breed an' stuff, an' I gat sec a breakfast as I nivver seed i' my time, while t'oald gentleman was gittan his-sel' rūddy to gang off in a carriage 'at was waitin' at t'dooar for him.

When he com doon stairs he geh me t'ūdder five shillin' an' paid for my breakfast, an' what he'd gittan his-sel'. Than he tel't ma to put t'ledder bags wid t'steäns in them on beside t'driver's feet, an' in he gat, an' laugh't an' noddit, an' away he went.

I niver owder seed nor heard mair of t'oald jolly jist, but I've offen thowte ther mun be parlish few steäns i' his country, when he was sooa pleas't at gittin' two lāl ledder bags full for ten shillin' an' sec a breakfast as that an. It wad be a faymish job if fadder could sell o' t'steäns iv oor fell at five shillin' a pwokeful - wadn't it?

From "The Life and Letters of the Rev. Adam Sedgwick" by J.W. Clark & T. McKenny Hughes, Cambridge, 1890, pp. 252-254, Volume 1.

EXPERIMENTAL STUDIES AT HIGH TEMPERATURES AND PRESSURES

G. McL. Biggar, Ph.D.

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Pressure and temperature are the major physical variables of the geological environment, affecting the states of matter and transformations between these states. Even within the solid state, pressure and temperature can profoundly alter the arrangement of the atoms of which a substance is composed.

The general effects of temperature and the experimental study of matter at various temperatures are well documented (References 1 & 2).

During the past twenty years pressure has been increasingly studied and techniques are now available for simulation in the laboratory of many of the pressure and temperature combinations that have influenced the nature of the igneous rocks. For obvious reasons field studies of this topic are largely out of the question, but the experimental geologist is now in a position to put to the test some of the theories that have been evolved concerning the structure of the earth and the composition of the crust and mantle.

Below the continents the earth's crust extends downwards for some 35Km. but below the oceans it can be as little as 15 Km. thick (Figure 1).

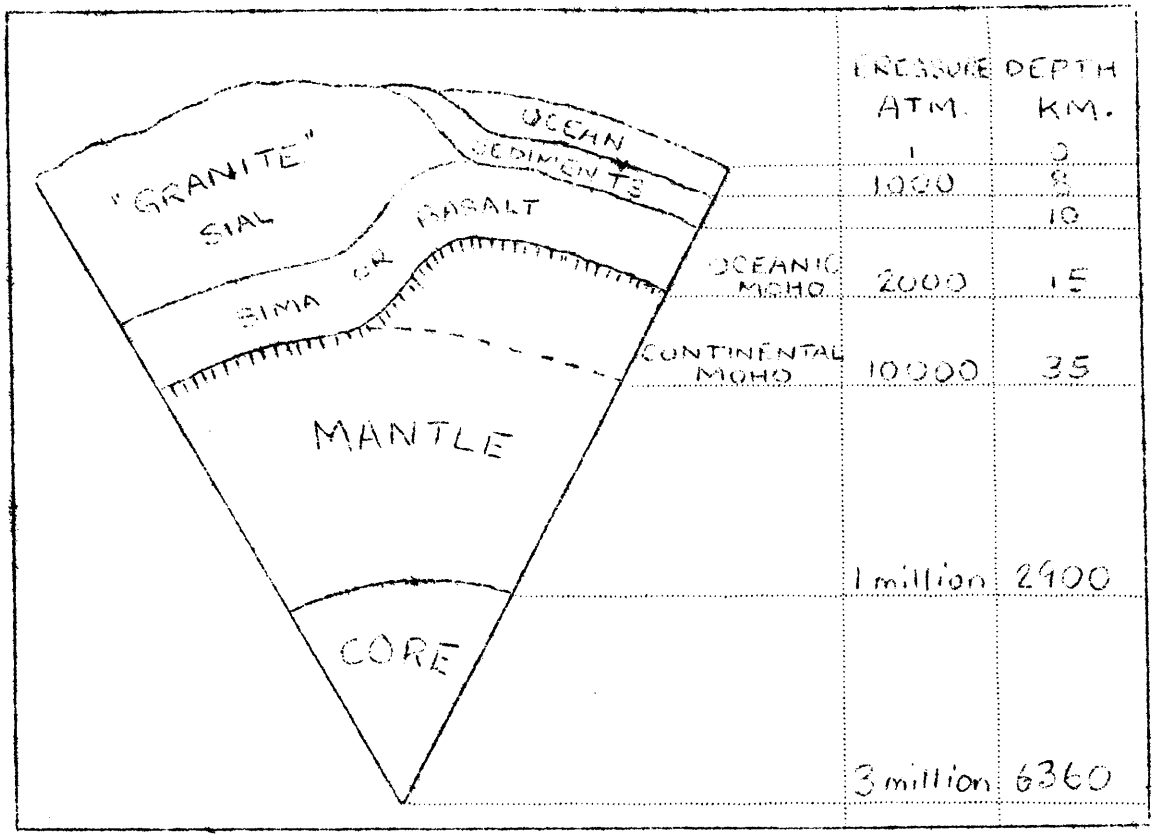


Figure 1. DEPTH AND PRESSURE ESTIMATES IN THE EARTH (Not to scale).

This crust is in effect a very thin skin on the earth and is highly differentiated within itself and with respect to the bulk of the earth. The existence of a discontinuity marking the base of the crust was inferred by Dr. Andrija Mohorovicic in 1909 from his studies of the refraction and reflection of seismic waves. The "Moho" is a major feature of our earth, and below it there apparently exists a more uniform state of matter - the mantle.

Few facts concerning the discontinuity are known. There is a mean density difference across it of 0·5 gm./cm.^{3} from about 2·7 gm./cm.^{3} in the crust to 3·2 gm./cm.^{3} in the outer mantle. It is not known if the boundary is sharp or spread over a few kilometers. Various estimates have been given of the pressure and temperature at the discontinuity, ranging from 120°C. and 2,000 Atm. for the oceanic moho to 600-1300°C. and 10,000 Atm. for the continental moho. Two main theories exist to explain the changes at the moho:

i. that it is a chemical or compositional change from gabbro (pyroxene and plagioclase) to peridotite (pyroxene and olivine), and

ii. that it is a structural or phase change from gabbro to eclogite (pyroxene and garnet).

The mantle contains minor discontinuities and ends in another major discontinuity with a very large density jump from 5·7 to 9·4 gm./cm.^{3} at 2,900 Km. Below this is the core.

The general effects of increasing temperature are well known, including thermal expansion, increased vibration of atoms within a crystal lattice, liquefaction, and eventually vaporisation. It is, however, worth listing the generalised effects of pressure which can mainly be derived from the Principle of Le Chatelier which implies that pressure favours the process that reduces the volume of the system.

a. Pressure inhibits vibrational and translational motions of atoms and molecules and therefore decreases their rate of diffusion (often a mechanism associated with metamorphism and with mineral concentration).

b. Pressure favours a polymorphic form with a greater degree of order in the crystalline lattice (decrease of entropy); thus the number of oxygen atoms surrounding an aluminium atom increases from four to six.

c. Pressure favours the alignment of ions and molecules, for example the arrangement of mica plates normal to the direction of pressure.

d. Eventually only the solid state can exist, even helium freezes at 100,000 Atm. and ice can exist at 200°C. under a pressure of 40,000 Atm.

e. At extreme pressures the valency electrons of atoms become detached and non-metals assume metallic properties. Thereafter more electrons are removed and only elementary particles can exist, as for example in star centres at pressures of 10^{18} Atmospheres.

The laboratory production of high pressures became possible with the advent of materials and techniques developed during the Second World War. Descriptions of a large and elaborate "squeezer" and of Tuttle cold seal pressure vessels (small and inexpensive) will serve to give sufficient insight into types of apparatus in current use. Variations of apparatus are legion, many laboratories designing their own, but the principles used are fairly standard.

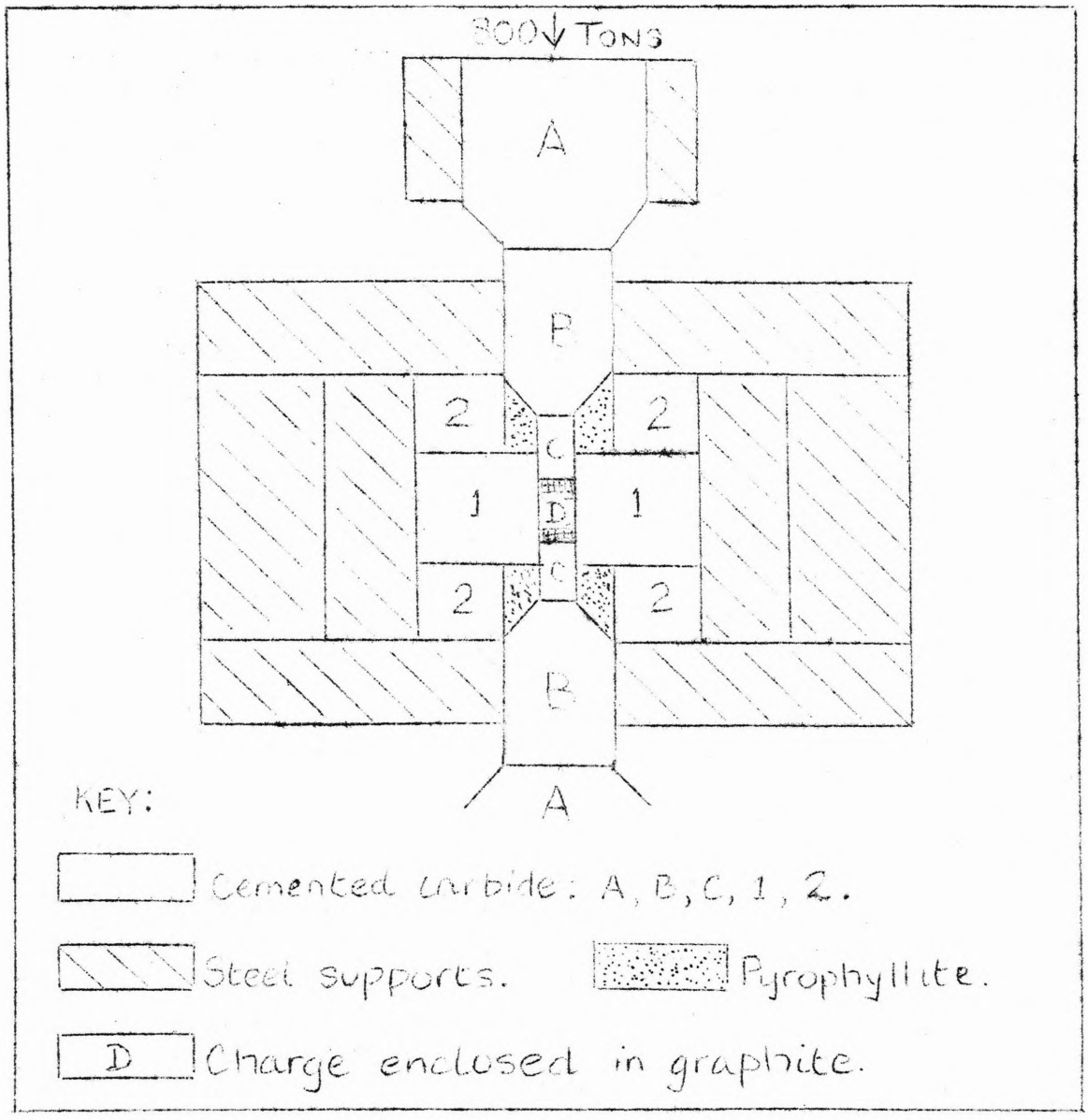


Figure 2. THE SUPPORTED, STEPPED PISTON PRESS (Reference 3).

The supported, stepped piston press is an elaborate and expensive piece of apparatus, although considerable simplification is possible in smaller squeezers for lower temperatures and pressures. Essentially, two pistons or anvils of tungsten carbide cemented with cobalt are opposed and brought together by hydraulic rams of up to 800 tons load. The charge of material under investigation is placed inside a graphite tube between the pistons. The whole system is prevented from extruding sideways by supports of pre-stressed steel or by other rams. Alternatively four rams can be arranged tetrahedrally. A high current at low voltage passed through the pistons heats the graphite. In such presses, maintained pressures of 100,000 Atm. at 3,500°C. are possible, conditions almost undreamed of 20 years ago.

Measurement of such high pressures is not easy, but estimates based on force and area with allowances for frictional losses can be checked to some extent by calibration against known transition points. For example, the electrical conductivity of bismuth increases sharply at 25,000 Atm. For many alloys the electrical resistance varies uniformly with pressure, and electrical resistance gauges can be used.

Refinements to such presses include windows of sodium chloride, transparent to infra red radiation to allow changes in intramolecular distances to be measured. Pyrophyllite packing round the carbon tube is believed to aid the transmission of pressure, to some extent converting the essentially uniaxial pressure of the pistons into a hydrostatic pressure.

Such apparatus has been applied to physical measurements, e.g., electrical conductivity, and the synthesis of polymorphic forms of many solids. The most famous example of the latter was the change of graphite to diamond (Reference 3), and the production of boron nitride (borazon) as a dense diamond-like crystal in which the carbon atoms of diamond are alternately substituted by boron and nitrogen.

Two of the polymorphs of silica are interesting examples of minerals synthesized in the laboratory and subsequently found in the field. The application of 35,000 Atm. pressure at 750°C. causes quartz to change into coesite, a denser polymorph, and recently at 160,000 Atm. and 1300°C., a second very dense polymorph, stishovite has been synthesized (Reference 4). Both forms have since been identified in rocks from meteor craters. Stishovite is unusual in that the silicon atom has a coordination number of six instead of the usual four.

The iron olivine fayalite, Fe_2SiO_4, and the related compound magnesium germanate, Mg_2GeO_4, have both been synthesized as spinels in which the coordination number of half the silicon or germanium atoms has increased to six. So far, the spinel form of the magnesium olivine forsterite has not been made. Nevertheless, the change to spinel is expected and would occur somewhere in the mantle of the earth. It may account for one of the less well-marked discontinuities that exist in the mantle.

Pyroxene structures are known to transform to corundum structures with increasing pressures; this may also account for one of the minor discontinuities. Synthetic garnets have been synthesized by temperature alone, but many natural garnets such as grossularite, $Ca_3Al_2Si_3O_{12}$, have recently been synthesized under pressure. It is of interest to note in passing that new semiconducting materials and also materials for masers and lasers have been or may be synthesized at high pressures and temperatures.

Another means of sustaining high pressure is by the use of a Tuttle Cold Seal Pressure Vessel (Reference 5). Although limited in range to 1,000 Atm. at 950°C. and 5,000 Atm. at 750°C., this equipment is cheap, easily set up and maintained, and reliable in use. It is in fact the test tube of the high pressure chemist and has been used to investigate many chemical and geological problems. The vessel is a stellite (special steel alloy) rod, eight inches long by one inch diameter, with an axial hole drilled seven inches down. A furnace designed to maintain the last three inches at a uniform temperature is placed round the vessel. The upper end, kept outside the furnace, is cool and is sealed to a pressure line by a

cone in cone union. The pressure in the line is adjusted by means of a simple piston and cylinder actuated by a hydraulic lorry jack. The piston, cylinder and pressure lines are normally filled with water, but carbon dioxide and argon have been used.

Materials to be studied can be placed directly in the vessel, but are more usually weighed into gold capsules formed by welding one end of a gold tube. The second end is welded, thus forming a closed system. Up to five capsules are dropped into the pressure vessel and kept in position by a loosely fitting steel rod. Pressure is transmitted to the sample by the collapse of the soft gold walls, and the contents exist under a truly hydrostatic pressure. The pressure vessels last for years, but slowly deform and eventually split with a gentle hiss. There is very little energy stored in the water in a vessel despite pressures in excess of 1,000 Atm.

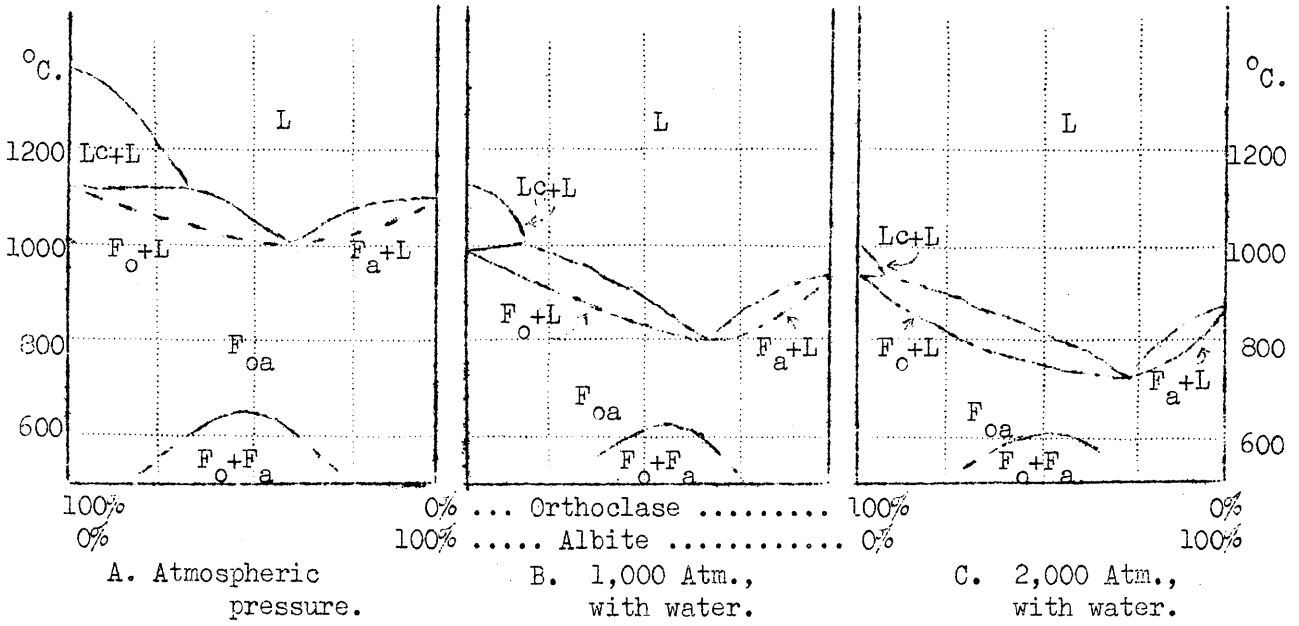
When a batch of capsules in a vessel has been maintained at elevated temperatures and pressures for the time believed to be necessary to reach equilibrium (which may be a few minutes or a few years) the vessel is quenched in cold air or water in an attempt to freeze the equilibrium. The gold is cut away from the charge, which is examined. It is often possible to detect in the charge "fossilised" features such as a bottom layer of coarse crystals, i.e. crystals that existed and sank to the bottom at high temperature and pressure. There may also be a layer of material, glassy or crystalline, terminating in a frozen meniscus. Such a layer represents the former liquid and the meniscus is itself evidence of a vapour phase. Detailed examination, in the polarising microscope, of the crushed charge, or even a thin section of the charge, enables many other deductions to be made.

In this way the complete determination of phase diagrams is possible, which in geological terms can mean the complete determination of the conditions of pressure and temperature required to form a mineral or the determination of the pressure and temperature at which a mineral will start to crystallise from a magma.

Unfortunately natural rocks and magmas are very complex but simple systems related to them have been studied. In the system $CaO - Na_2O - K_2O - Al_2O_3 - SiO_2 - H_2O$ in which the minerals anorthite, orthoclase, albite, leucite, nepheline, carnegieite and quartz are stable many of the compositions are close to the various compositions of granites. Studies of this system may lead to a choice between the various theories of granitisation. A phase diagram for the orthoclase-albite section of this system at atmospheric pressure is shown diagrammatically in Figure 3A (Reference 6). The system demonstrates some interesting points but firstly the limitations of the diagrams must be understood. Since orthoclase dissociates to leucite and quartz the two dimensional diagram shown (Figure 3A) is only a true representation up to the appearance of the leucite field. Thereafter a three dimensional diagram is required to describe properly the stability of leucite. It is an equilibrium diagram and shows what phases are present if equilibrium is attained, which is not always so for natural rocks.

Samples at equilibrium in the region marked F_{oa} consist of a single phase which is a solid solution of orthoclase and albite. Samples at equilibrium in the region $F_o + F_a$ consist of two solid phases. Each phase possesses distinctive optical properties by which it can be identified.

Figure 3. DIAGRAMMATIC REPRESENTATION OF THE SYSTEM ORTHOCLASE-ALBITE



KEY: F_o Orthoclase solid solution
F_a Albite solid solution
Lc Leucite
L Liquid.

Samples at equilibrium in the other two-phase spaces F_o + L, F_a + L and Lc + L consist of felspar crystals (or leucite) and liquid. If all the above samples are cooled quickly enough to prevent readjustment of the equilibrium they would, respectively, consist of one felspar, two felspars, and one felspar (or leucite) plus glass, the latter representing the quickly cooled liquid.

Only one case of cooling while maintaining equilibrium conditions need be discussed. As a liquid cools the first crystals will form when the temperature reaches the upper curve of the figures 3A, B, C. This temperature represents the crystallisation temperature of felspar from the liquid (or magma) under the conditions for which the figures are valid. The high viscosity of silicate melts and the slow rates of diffusion and of attainment of equilibrium caused considerable difficulties in the past and require that considerable care is taken with the interpretation of experimental results.

Under pressure and in the presence of added volatiles such as water (Figures 3B, C) and hydrogen fluoride, which it can be presumed are lost from many magmas on cooling, crystallisation temperatures 200-300°C lower are found. These volatiles split Si-O-Si bonds to form respectively Si-O-H + H-O-Si and Si-F + H-O-Si bonds. This disrupts the continuous silicate network and greatly reduces the viscosity of the liquids. Other volatiles such as carbon dioxide and argon have scarcely any effect.

Other important effects of water under pressure are the gradual disappearance of the leucite field and the change of the eutectic composition towards albite.

Changes in crystallisation temperatures and eutectic compositions are important in differentiation of magmas. With extensive and detailed studies of many similar sections of the system $CaO - Na_2O - K_2O - Al_2O_3 - SiO_2 - H_2O$ an insight into the mechanism of crystallisation and differentiation of granitic magmas is emerging.

Some work on ground samples of natural granites acts as a check on results and gives an indication that the presence of many minor and trace elements in natural rocks does not have large effects on the results.

The system $MgO - SiO_2 - H_2O$ (Reference 7) has also been extensively studied. The minerals quartz, enstatite, forsterite, periclase, brucite, talc and serpentine are stable under various pressure and temperature conditions. Many of these minerals occur in metamorphic rocks and reactions occur between some of them as the metamorphic conditions alter, for example the serpentinisation of olivine at low temperatures. The curves of pressure against temperature at which such reactions occur have been experimentally determined. If the data could be directly transferred to natural rocks then an accurate delineation of metamorphic facies would be possible. Unfortunately the presence of other constituents, particularly volatiles, in rocks affects the position of these pressure-temperature curves.

There is an interesting application to metamorphic rocks of the generalised effects of pressure described on page 1. In thermal and regional metamorphism where temperatures are high and pressures are relatively low, aluminium four co-ordination is favoured, and aluminium substitutes for silicon. In low and medium grade metamorphism six fold co-ordination of aluminium is favoured by the conditions of higher pressure and lower temperature.

Many carbonatites occur as plugs in eroded volcanoes and, with other field evidence, this indicates the former presence of a magma. Calcite has such a high melting point, 1340°C., compared with accepted volcanic temperatures (up to 900°C.) that alternative hydrothermal, gas transfer, or xenolithic theories of origin have been postulated. A recent study of the system $CaO - H_2O - CO_2$ (Reference 8) showed that along and close to the section $Ca(OH)_2 - CaCO_3$(portlandite-calcite), liquids exist at temperatures above 635°C., adequate indeed to support the magmatic emplacement theory. Portlandite is not found in carbonatites but it can reasonably be expected that subsequent hydrothermal or carbonatic alteration converted it to calcite.

Extension of the above system to include $Ca_3(PO_4)_2$ gave apatite as a third solid phase. The solubility of the phosphate in the melt was only 2 to 15%. In these carbonate systems the quenching of a liquid did not produce a glass. The liquid crystallised but the habit of the crystals formed during the quench was often distinctive from the habit of the crystals that existed at equilibrium. Apatite was a notable example of this, the equilibrium crystals were short, stubby, hexagonal prisms with pyramidal terminations, whereas freezing of the liquid produced acicular crystals. Further, these acicular crystals were frequently characterised by skeletal features, for example some had centrally placed holes running down

the length of the needle. Several cases of natural apatites which are elongated and exhibit skeletal features are known from extrusive basic rocks although none have yet been reported from carbonatites.

That the carbonate melts were labile was demonstrated by the frequent occurrence of settled crystals of calcite and apatite at the bottom of the charge, a considerable change from the viscous silicate liquids.

A great deal remains to be done but the coming years should see an increasing volume of work and, one hopes, the solution of many problems put to the experimentalist by the observer in the geological field.

Books and Reviews for further reading

Bridgman, P.W., The physics of high pressure. G. Bell & Sons. 1952.

Hamann, S.D., Physico-chemical Effects of Pressure. Butterworths. 1957.

Ellis, A.J. and W.S. Fyfe, "Hydrothermal Chemistry", Reviews of pure and applied Chemistry, Vol.7, page 261, 1957.

Bradley, R.S. (Editor), High Pressure Physics and Chemistry, 2 Vols. Academic Press. 1963.

Ricci, J.E., The Phase Rule and Heterogeneous Systems. Van Nostrand. 1958.

References

1. Kingery, W.D., Property Measurement at High Temperatures. Wiley, N.Y. 1959.
2. Hehemann, R.F. and G.M. Ault, High Temperature Materials. Chapman & Hall, London. 1959.
3. Giardini, A.A., J.E. Tydings and S.B. Levin, Am. Min., 45, 217, 1960.
4. The Equilibrium Coesite-Stishovite, Dokl. Akad. Nauk. S.S.S.R., 148, 1186, 1963.
5. Harker, R.I. and O.F. Tuttle, Am. Journ. Sci., 253, 209, 1954.
6. Tuttle, O.F. and N.L. Bowen, Geol. Soc. Am., Mem. 74, 1958.
7. Bowen, N.L. and O.F. Tuttle, Bull. Geol. Soc. Am., 60, 439, 1949.
8. Wyllie, P.J. and O.F. Tuttle, Journ. of Petrology, 1, 1, 1960.

WEEK-END SCHOOL IN GEOLOGY AT HAWSE END, NEAR KESWICK.

April 2nd., 3rd. & 4th., 1965.

This course was run by the Society with the full support of the Cumberland Education Committee. The object of the course was to introduce teachers, and other interested persons, to Geology by a combination of theory and field work, particularly so that they might be able to pass on the enthusiasms and practical approach to pupils, students and friends. Thus the fourteen people attending the course consisted of Members of the Society and teachers, some of whom were new to the area.

We were very sorry that our President, Mr. Shackleton, was unable to be present owing to ill health, but were fortunate in having Mr. Hewitt and Mr. Shipp who worked so hard, in preparation and during the week-end, to make the course so resounding a success.

Hawse End is a delightful Hostel, built in 1886, which the Cumberland County Council bought with great foresight a few years ago. It is situated about a mile and a half south of Portinscale, 200 yards from the west side of Lake Derwent Water, 50 feet above the lake, with magnificant views of the lake, the fells beyond, and of Keswick. Mr. W. Morton, the Warden, and Mrs. Morton gave us all a warm welcome and we were very well looked after throughout the course.

On the first evening, after an excellent meal, we were welcomed by Mr. J.L. Bond, Assistant Director of Education for the Cumberland Education Committee. Mr. Shipp welcomed us also and introduced us to a most useful exhibition which he and Mr. Hewitt had set up in the main lounge, to remain there throughout the week-end. This display of items relevant to Geology was invaluable for instance to Geography teachers who had not yet developed Geology fully as a subject or as part of a Geography course or yet as a hobby. Books were laid out suitable for "Junior Use", "Senior Use", and "General Reading"; there were displays of maps of geological structure in the region, and copies of the Society's publications including a proof of the new bibliography of Lake District Geology. Possibly we were most impressed by the large number of rocks, fossils and minerals which were on display, all of which were from the Lake District. This again brought home to us how very fortunate we are to have such a variety of examples on our very doorstep. In addition to these there were examples of certain phenomena such as kaolinisation of felspar, and diagrams and specimens of Skiddaw Granite and its metamorphic aureole. Apart from the remarkable display of rocks, fossils and minerals there were also examples of useful filmstrips on geology and physical geography, together with catalogues. Finally one had only to look out of the window from this room to see examples of scenery associated with the particular geology and climate of the area in view.

Surrounded as we were by these visual aids, we were then given an illustrated talk by Mr. Shipp on the Geological History of the Lake District. We were first shown some projected slides of varying scenery in the Lake District and asked to consider how it was that these varying landscapes existed and how they had been created. The geological history was traced in chronological order from the oldest rocks of the region - the Skiddaw

"slates" - right through to glacial and post-glacial times including what is actually going on before our eyes today. In each case useful maps and diagrams were displayed to illustrate the points made; these maps were large and clear and made by the lecturer by using coloured felt-nib pens. Some were original, while others were enlarged versions from useful books which in a school not every pupil might have himself. It was pointed out that an episcope can be used to "blow up" useful maps and diagrams to the size required. For example, diagrams from the recently revised book called "Principles of Physical Geology" by Arthur Holmes (Nelson, 84/-) could be enlarged in this manner for all to see together. Photographs were projected illustrating the scenery resulting from the underlying rocks of particular areas today, and also showing phenomena such as, for instance the formation of erosional and depositional features in recently glaciated areas.

Thus the course was started in the ideal way. We were in the heart of the Lake District; we had already actually handled a remarkable variety of geological evidence; we had been introduced to the background history of the Lake District right up to present day phenomena; we were well aware of the fascinating geological variety to be found there. It only remained for us, under the guidance of Mr. Hewitt and Mr. Shipp, to get on our feet and really explore and discover for ourselves on the ground. We had certainly been inspired to do this.

G.S.S.

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On Saturday morning, 3rd April, the sun was hot in a clear sky. Packed lunches were hurriedly collected, and we were transported to the first rendezvous on the lake shore at Keswick, on the way to Friar's Crag. Here Mr. Shipp caught our interest immediately by showing and explaining the presence of a dolerite dyke intruded in Skiddaw Slate. Not many yards later he pointed out a fault in the dyke which had moved forward and produced some shattering. At the end of Friar's Crag itself, the last exposure of the dyke was examined adjoining slightly altered Skiddaw Slate, followed by the unaltered rock.

Castle Head was climbed and the sun was still shining! The panoramic grandeur before us was explained by the Society's Vice-President to be the results of Ordovician Volcanoes as well as comparitively recent glaciation. Mr. Gowing's measured eloquence made this half-hour one of the gems of the weekend. He also led us to an old quarry at the back of Castle Head, which incidentally is thought to represent the neck of an Ordovician volcano, in which the jointing of the dolerite rock is very well displayed.

After a picnic lunch on the site of the Brandlehow Stamping Mill, Mr. Hewitt, with his endless patience and detailed knowledge, stimulated the group into finding galena, zinc blende, platey quartz and sugar quartz. Higher up, some adit entrances were seen, following through to the mineral vein running up the fellside.

South-West of Grange, Mr. Shipp led us past a thrust plane at the back of the Hollows Farm Youth Hostel, and on up the fell to see a normal junction of the Skiddaw Slates and Borrowdale Volcanics, clearly marking the

change of scenery from the gentle slopes of the Slatey Fells into fierce, craggy Borrowdales.

We continued along the back side of the River Derwent, the leader constantly pointing out examples of the works of rain, river and glacier, often close ups of what Mr. Gowing had referred to in the distance from the vantage point at Castle Head.

The Bowder Stone and Rainspot Slate Quarry were the last places to be visited on this memorable day. Mr. Hewitt explained the lithology of the slate and demonstrated its cleavage. He mentioned that the slate here had been both quarried and mined although some of the mine tunnels had become unsafe, and were recently blown up.

After dinner back at Hawse End, Mr. Hewitt gave a lecture on minerals, their nature, and mode of formation. This was ably illustrated by wall-charts, whilst to conclude, Mr. Hewitt demonstrated some simple chemical (borax bead and heating), and physical (streak, hardness and specific gravity) tests for the identification of common minerals.

T.M.

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Sunday dawned wet, and the party proceeded, well prepared with waterproofs, to the Sanatorium on the flank of Saddleback, above Threlkeld. The object was to visit the Skiddaw Granite in Sinen Gill, and to find evidence of the metamorphic aureole. A fuller description of a further visit paid by the Society to this locality is given on page 29. The weather steadily improved as the day wore on, and somewhat reluctantly we returned in mid-afternoon to Hawse End for tea, packing and dispersal after an eminently successful and worthwhile weekend's geology.

(It is hoped to hold at least two similar courses next year, one for Teachers, the other for Senior Students. - Ed.)

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A BIBLIOGRAPHY OF LAKE DISTRICT GEOLOGY AND GEOMORPHOLOGY

by Dr. R.A. Smith, Lecturer in Geography at Padgate College of Education.

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The Society wishes to announce the publication of the above work, which contains over 550 references to geological and geomorphological papers and books appertaining to the Lake District, with authors' names listed alphabetically. In addition there is a classified section subdivided into 29 topics each having a list of appropriate reference numbers in chronological order, the major works being shown by asterisks. Two maps locating areas covered by recent geological and geomorphological research are included. An indispensible book for anybody who wishes to delve into the geological literature of the district.

The Bibliography is obtainable from the General Secretary, price five shillings (six shillings by post).

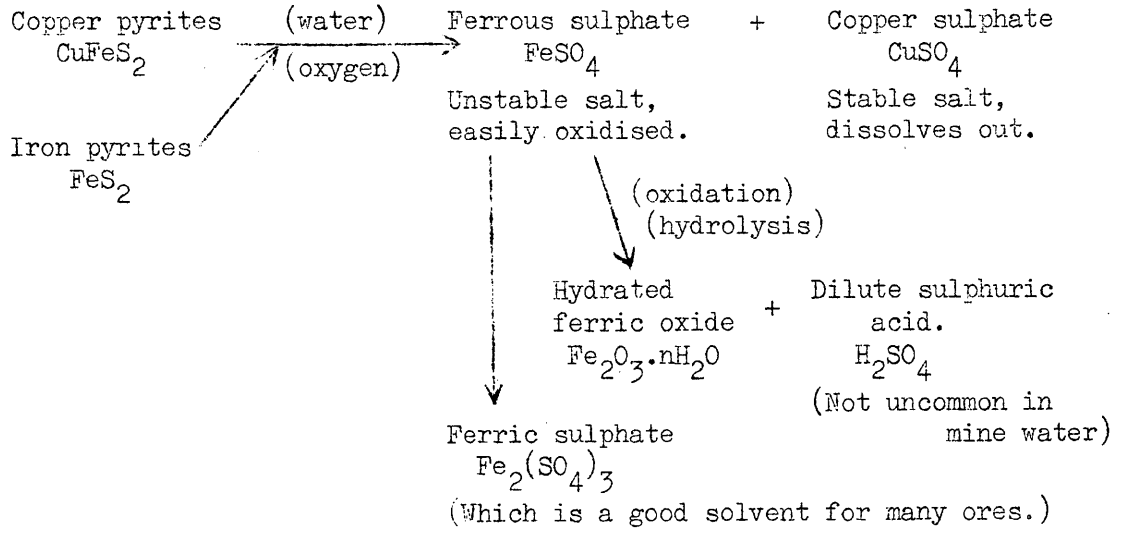
LECTURE - SECONDARY METALLIFEROUS MINERALS.

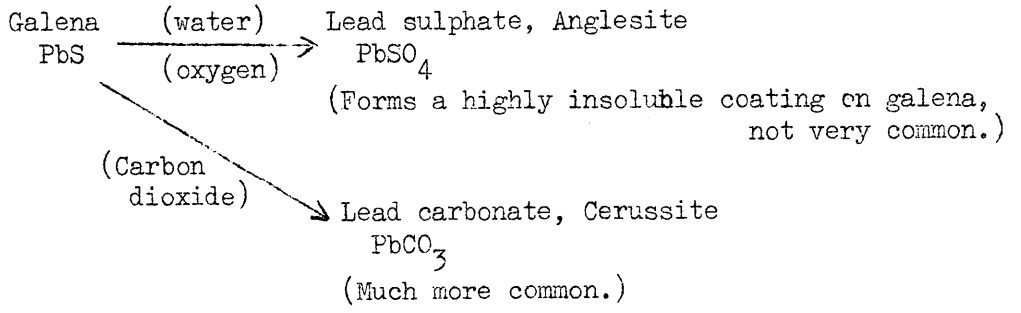
Given by Dr. F.H. Day, Ph.D., M.Sc., F.R.I.C., at Workington College of Further Education on Tuesday April 6th., 1965. 18 Members attended.

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Dr. Day began his lecture with an attempt to define minerals, noting that although it was fairly easy to recognise primary ore bodies, it was by no means as easy to classify the minerals contained in them as of primary or secondary occurrence. Thus most sulphides and arsenides and some oxides are primary minerals, and these are characterised by their metallic or sub-metallic lustre and covalent or metallic bonding. Secondary minerals are formed by chemical action upon primary minerals, and the lecturer went on to explain by means of diagrams how a primary mineral in a vein is attacked by percolating ground water, leaving a mass of hydrated ferric oxide or "gossan" at the surface, and resulting in an enriched zone of secondary mineralisation at or near the water table.

This enrichment is brought about by the solution or disintegration of the primary mineral, transport downwards by water seeping down the vein, which as likely as not occupies the shatter-zone of a fault, and deposition precipitation or crystallisation at the point where the downward movement of the water is checked. Secondary minerals are generally oxidation and hydration products, such as basic carbonates, sulphates, arsenates and phosphates. The following examples of formation of secondary minerals were cited:





Not all soluble salts are leached away, soluble copper sulphate forms by hydrolysis an insoluble basic salt called Brochantite, $Cu_4(SO_4)(OH)_6$, and both zinc sulphate and copper sulphate form insoluble silicates with silica leached from surrounding rocks, these silicates being called Chrysocolla and Hemimorphite respectively.

Having dealt with some of the theories concerning the formation and emplacement of secondary minerals, Dr. Day talked about his own happy hunting ground in the Caldbeck Fells and the Carrock Fell area. He dwelt on the suite of unusual and highly complex minerals formed at the intersections of veins carrying copper, lead, arsenic and phosphorus minerals. The deposit of Scorodite $FeAsO_4.2H_2O$ in Brandy Gill was mentioned, formed in situ by oxidation and hydrolysis of Arsenical pyrites FeAsS. The phosphate, arsenate and tungstate minerals, particularly Pyromorphite, Campylite and Scheelite were described, together with their mode of formation by interaction of phosphoric acid, soluble phosphates, arsenious acid and tungstic acid with ore minerals.

The question of the ages of secondary minerals was raised. Although there is usually no great difficulty in giving approximate ages of primary mineral bodies, it is a different matter when we come to the secondary products derived from them. They are obviously younger than the primary ore body, but we have no accurate means of establishing their ages. Some deposits of secondary minerals can be formed within a man's lifetime, as instanced by the relatively quick formation of Cerussite in old mine workings and dumps after a few years. Pyromorphite is, however, of greater age, instanced by the fragments of it found in the glacial drift of the Carlisle Plain.

Dr. Day brought his lecture to an interesting conclusion by showing some of his excellent colour slides of minerals he had described, and giving some useful hints on localities and collection of minerals. He said that many of the rare minerals recorded in the area occurred as traces in joints in the rock, having arrived there by a process of differential adsorption analogous to chromatography. Two useful papers he recommended for further reading:
"Some notes on the Minerals of the Caldbeck Fells" in the Transactions of the Carlisle Natural History Society of 1928, Volume IV, pages 66-79, and "Some notes on the Minerals of Cumberland and Westmorland" by W.F. Davidson and N. Thomson, in the North-Western Naturalist of 1948, Volume 23, pages 136-154.

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IMPORTANT NOTE

Owing to increased Postal Charges, would all Correspondents with the Excursion Secretary, General Secretary and Editor please enclose a stamped, addressed envelope if they require a reply. As this is not a wealthy Society, and the subscription is kept as modest as possible, this will assist greatly in keeping expenses to a minimum.

FIELD MEETING AT SNEBRO GILL, WHITEHAVEN.

THE HENSINGHAM GROUP OF THE LOWER CARBONIFEROUS.

April 24th., 1965. Director, R.H. Hewitt.

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The parish of Hensingham lies mainly on an inlier of the upper part of the Carboniferous Limestone Series surrounded on all sides by younger rocks. Technically, it is a "horst" - an area left upstanding between faults that throw down in opposite directions. At Overend, the Second and First Limestones are exposed, the First being capped by Hensingham Grit.

Above this grit occurs a series of shales, sandstones and lenticular limestones which were at one time regarded as part of the Millstone Grit. It was the discovery by one of our honoured members, Mr. T. Eastwood, in these beds, of fossils more obviously related to the Limestones than to the Millstone Grit that first caused doubts to be raised as to the stratigraphical position. In this situation the non-committal name "Hensingham Group" was applied, and this has not been altered.

Snebro Gill is a steep-sided ravine that descends from Hensingham village to the floor of the St. Bees - Whitehaven valley, cutting through much of the Hensingham Group and giving many exposures of its various strata.

It was to the exploration of these interesting, if somewhat puzzling beds that the first excursion of the 1965 series was directed, ably led by our Excursion Secretary who had gone to a lot of trouble to provide large scale diagrams, and drawings of some of the commoner fossils to be found.

Ten members met outside the "Crown and Anchor" on the Whinlatter Road, Whitehaven, at 2p.m., and were conducted into the Gill at its lower end, where black shales were examined in a small bank in the bed of the stream (location 1)*. A few fossils were found in these shales, among them some Spirifers and a small but well-preserved Zaphrentis.

One surprise of this visit was the valuable assistance the party had from a young local lad, Master J. Hilliard, who seemed to have an intimate knowledge of the Gill and its fossil locations. It was he who produced the first trilobite from location 1b, an excellent pygidium of Phillipsia. From location 1c Mr. and Mrs. James obtained a very fine Reticularia, whilst later, by much careful work, Mr. James and Mr. Shaw were able to locate a trilobite band from which several good specimens and casts were obtained. A very good Productus longispinus (J. Sowerby) and several Spirifers were also found in this location.

Location 1d, the sponge spicule bed, was next examined. Good specimens of the spicules were obtained, as well as a quite well-preserved Edmondia.

The section in Snebro Gill, from the top downwards, is roughly as follows:

SECTION IN SNEBRO GILL

The Udale Coal	(Now regarded as the base of the Millstone Grit.)
Ganister Sandstone	8 - 15 feet.
Dark Shales with Lenticular Limestones	40 feet.
Dark Limestone with sponge spicules	2 feet.
Shales with interspersed lenticles of sandstone and limestone	30 - 40 feet.
Hensingham Grit	(not seen.)

Even though the weather was not of the kind to induce many of our members out of doors, those who did attend enjoyed the excursion and were well-satisfied with their finds. They readily joined the President in his thanks, both to the Director for his careful preparations, and to Master Hilliard for his unexpected help.

* The Fossil Locations, discovered with the aid of the Whitehaven Memoir of the Geological Survey, were listed as follows, working up from bottom to top of the Gill:

(1) 60 to 75 yards below pipeline. Cephalopods, gastropods, trilobites many brachiopods and crinoid ossicles.

(1a) 20 to 35 yards below pipeline. A few brachiopods.

(1b) 10 yards below pipeline on South bank. Dark limestone with brachiopods, merging into shaly limestone with crinoid ossicles.

(1c) North bank near pipe, dark limestone with brachiopods, a few cephalopods and trilobites.

(1d) Dark limestone with sponge spicules, flooring gill above pipeline.

(1e) North bank above pipeline, 4 feet below Ganister Sandstone. Brachiopods.

E.H.S.

EXCURSION TO GLENDERATERRA VALLEY AND SINEN GILL
THE SKIDDAW GRANITE AND ITS METAMORPHIC AUREOLE

Sunday, 9th. May, 1965. Leader: T. Shipp, B.Sc.

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The party met outside the entrance of Blencathra Sanatorium, in dull, cloudy weather, in time for a start about 10.30 a.m., and walked along the hillside track to an old quarry just above the Sanatorium. Here the leader explained that the purpose of the excursion was to examine the exposure of Skiddaw Granite in Sinen Gill and its Metamorphic Aureole. In the quarry we were on unaltered Skiddaw Slate, at that exposure a dark fissile, rather brittle rock. Between there and the outcrop of the granite itself it would be possible to observe a progression of changes in the slates as the contact with the intrusion became nearer.

The first of these changes was observable in a craggy outcrop a few hundred yards further along the fellside track, where the party found that the slate was noticeably hardened and had become very tough and resistant to the hammer. Succeeding outcrops showed similar features until a more substantial exposure in the side of a gill by a beck gave a most striking display of Chiastolite Slate. Here the rock was plentifully besprinkled with rod-like crystals of this form of Aluminium Silicate, showing clearly its diamond shaped cross section, with a darker core which, the leader explained, distinguishes it from the chemically similar Andalusite. Another feature of the rock was its heavy haematite staining which taken with its shattered condition led the leader to suggest tentatively that the gill might have been eroded out along a fault.

Approaching the intrusion more nearly, we found the next outcrop where Roughten Gill crossed the track, and here the rock was of a more gritty character and had hardened to form flaggy beds which gave a ringing tone when struck by a hammer. On the banks and in the bed of the beck, some specimens of spotted slate were found, as evidence of another stage in the alteration of the country rock.

In increasing dampness we rounded the fellside into Sinen Gill where we soon began to see detached boulders of the granite. The first appearance of the rock in place, however, was in an eroded overhanging bank of the gill where the granite was so weathered as a result of the chemical alteration of the felspars that it was more of the nature of kaolinite and of a very crumbly consistency. The leader explained that this process can be brought about either as a result of hydrothermal action or through the effect of percolating acidulated ground water from the overlying peat and that in the present case, he was inclined to attribute the change to the latter cause. This conclusion was reached by observing the joints in the weathered granite which were full of dark brown organic matter which was obviously washed down from the top soil.

Higher up the gill we were able to examine the granite in a less weathered condition and to see that it is gray in colour, with orthoclase,

and an abundance of mica, mostly biotite apparently. The upper part of the fell is in the slates, and the top exposure of the granite showed a line of contact that was remarkably sharp, although the normal granite was not in actual contact with the hornfels above, but was separated from it by a thin band of quartz, about 1" in width, on the inner side of which was a further intervening layer of pegmatite of undetermined thickness.

At this point the growing inclemency of the weather and the approach of lunch hour led to the abandonment of the intention to go higher up on to the more exposed portion of the fell, and the party broke into groups with a view to taking refreshments with a minimum of discomfort. For most this led to the resort to some ruined buildings down in the main Glenderaterra valley, where the main party was taken later to some of the old abandoned mine workings and tips associated with the zone of mineralisation round the granite. Just above the junction of the Glenderaterra with Roughten Gill a copper vein, characterised at the surface by exposures of rust-stained quartz or Gossan, was seen; an old tip on the east side of the beck yielded malachite and chalcopyrite, with quartz and barytes. The swollen stream presented an obstacle which proved too much for all but a few of the party when old lead workings further downstream, with a flooded shaft and adit (both dangerously accessible) were visited and specimens of galena, pyromorphite and barytes collected. After this the leader and his few remaining followers waded across the beck and scrambled back up to the track and rejoined the rest of the party at the assembly point near the Sanatorium.

The weather had certainly interfered with our activities and finished by bringing them to a premature close, but it had not prevented us from seeing much of interest in respect of the granite and its effects, the main purpose of the trip, and we had in addition an opportunity of glimpsing some superb views from an unaccustomed angle up the vales of St. John and Borrowdale and across the neighbouring fells. Early on, the leader had taken the chance of pointing out how the alternating beds of lavas and tuffs in the Borrowdale Series revealed their presence in the stepped character of the opposing slopes, and it was with regret that we saw so much of the distant prospect blotted out from view as the clouds closed in.

L.J.H. and Senior Boys of
Heversham Grammar School.

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EXCURSION TO THE FIRST LIMESTONE AT BRIGHAM, NEAR COCKERMOUTH

HOTCHBERRY AND TENDLEY HILL QUARRIES

May 29th. 1965. Director: T. Shipp, B.Sc.

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As this excursion was identical in all main respects to one held two years ago, and reported in "Proceedings", No. 1, 1963, pages 22 and 23, no separate report is submitted now, other than that attendance, abundance of fossil specimens, and weather were all good.

- Book Review -

"GEOLOGY FOR SCHOOLS."

J. T. Greensmith.

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Leonard Hill, 1964. 176 pages. 18/=

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The book is written in a concise but vigorous, stimulating manner with graphic accounts and intriguing descriptions. Though designated as school material it will also make for interesting general reading, especially as it is thoroughly up-to-date, and its terms of reference are not slavishly adhered to.

The book is intended for G.C.E.(O) Level studies: therefore it has been appraised with reference to the most widely used syllabus (N. U. J. M. B.) which stipulates a properly balanced coverage of the subject. There are omissions and places where extra detail is desirable; the author states that this was foreseen when he developed this compact style. However it could be important to know just where these occur and an analysis is given below.

Chapter 1 consists of a brief introduction, and Chapter 2 goes on to deal with minerals. Coal and iron ore are described later, in the chapter on rocks. Petroleum is omitted. The usage of physical properties in identification of 22 common minerals in three groups - metallic, non-metallic and silicates - is described. Limonite is in the first category and siderite in the second: another classification would be more logical. An apparent error describes iron pyrites as bronze-yellow and copper pyrites as brass-yellow.

Rocks are the subject of Chapter 3. The features of volcanic rocks are well done except that the author's definition of amygdales as almond-shaped (empty) vesicles is peculiar, and little is said about rhyolite. The subject of volcanoes is not adequately covered. A notable feature in the section on sedimentary rocks is a lucid account of turbidity currents. A sandstone classification table is given. Treatment of the argillaceous group includes remarks on different clay-mineral types and conditions of deposition. In a good description of coral reefs the point is emphasised that algae make up a greater proportion of the material than do corals in present-day reefs. Information on coal is mainly on its rank: there is nothing about its mineral constitution. Examples of ironstones quoted are those of N.E. Yorkshire, Lincolnshire and Northamptonshire, and Cumberland haematite (the origin of the latter by hydrothermal replacement). Rhythmic succession of evaporites is clearly explained.

One of the examples quoted of thermal metamorphism is the Skiddaw Granite with the zones of alteration of country rock. Formation of slates, schists and gneisses and their characteristic minerals conclude the section on metamorphic rocks, with granulites and calc-silicates just mentioned.

Chapter 4 is concerned with earth structure of which a model is shown.

Treatment of earthquakes is somewhat brief: there is no mention of earthquake intensity, no illustration of a seismograph or seismogram, and "focus" and "epicentre" are used as though synonymous. 'S' and 'P' waves are briefly described. A neat distinction is drawn between "fault scarps" and "fault line scarps". Geosynclines are related to subsequent fold mountains. Unconformity ("overlap" and "overstep" are differentiated), folding, faulting and their effects are described.

"Landscapes" is the title given to Chapter 5. Isostasy is referred to without a model of the mechanism. Weathering is dismissed rather too briefly: a summary of weathering effects on common rocks would have been useful here.

Water erosion and deposition has some omissions such as potholing, the cycle of erosion and bends (as distinct from meanders): though drainage patterns are treated comprehensively and well.

Marine erosion, currents, coastline types, estuaries and deltas, the nature of submarine canyons and oceanic deposits are all well explained. The origin of tides and waves is not included.

Effects of glaciation - distinguishing highland and lowland features - are well covered. Not all features of glaciers themselves are considered, though this is not regarded as a defect.

The chief features of limestone (karstic) scenery are explained, whilst desert features and processes are well described. Evaporites are discussed in an earlier chapter.

Fossils are dealt with in Chapter 6. All detail necessary at this level is amply given. The chapter is written in a lucid manner, illustrated by clear, useful drawings. It describes corals, echinoids, crinoids, brachiopods, lamellibranchs, gastropods, ammonites, belemnites, trilobites, graptolites, and the appearance of plants.

A balanced first course in geology must include an account of the chief events during geological time which affected our islands. Chapter 7 does this well and prepares the way for later stratigraphy studies. Diagrams illustrate the palaeo-geography of many Systems and the stratigraphical column showing ages in years (radioactive dating). Correlation principles are mentioned briefly.

There are short appendices giving suggestions on field and indoor work.

In many aspects the author more than just covers the requisite ground, and running through the book are numbers of fresh ideas and modern views. Useful features are questions at the end of each chapter and clear line drawings complete with scale indication where appropriate.

I don't know where else so much good material is available in the same page span and at this price. The compact style of the book is an advantage.

S.H.G.

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The next Proceedings are due at the end of December, 1965, and the Editor requests contributors to submit their articles as soon as possible, and in any case, before October 31st. 1965.