

ABSTRACTS OF THE PROCEEDINGS OF THE CONFERENCE OF GEOLOGISTS AND GEOMORPHOLOGISTS IN THE SOUTH-WEST OF ENGLAND, EXETER 1958

Introduction

Since the war there has been a great revival of interest in the geology of the south-west of England and a large number of post-graduate research workers from the universities have been engaged in field-work in the region. In order to co-ordinate this work and to facilitate contact between all those interested in it, whether amateur or professional, a conference was held in Exeter in January 1956 attended by 52 people. A second conference was held from 7th-10th January of this year, also in Exeter, Dr. D. L. Dineley of the Department of Geology at the University of Exeter acting as Honorary Secretary, as he had for the first conference. Again about 50 people took part and Dr. C. J. Stubblefield of the Geological Survey of Great Britain attended and addressed the conference as its guest.

The papers read at the conference were almost entirely concerned with reports on work in progress or recently completed. They were arranged in three groups - Stratigraphy and Palaeontology, Petrology, Geomorphology ; and were taken on January 8th, 9th and 10th respectively. Below, in the order in which they were given, are abstracts of each of the papers read at the sessions on January 8th and 9th. Unfortunately the abstracts for the papers of January 10th have not come to hand in time for inclusion in this booklet, but it is hoped to print them later.

The abstracts are published by the Royal Geological Society of Cornwall, and it is hoped to print some of the papers in full, in future issues of the Transactions.

1. STRATIGRAPHY AND PALAEOLOGY,

Proceedings of the 8th January, 1958.

1. Trilobites of South-West England : by C. J. Stubblefield, D.Sc., D.I.C., A.R.C.S., F.R.S.

(Submitted for publication with permission of the Director of the Geological Survey of Great Britain.)

The earliest trilobite faunas are found in the north of the region and are of Tremadoc age. The south Cornish Ordovician quartzites carry trilobites akin to those of Normandy and to those found derived in quartzite pebbles of the Triassic Budleigh Salterton Pebble-Beds. Upper Llandovery and Wenlock trilobite faunas occur in the north, in the Tortworth district. No trilobites are recorded from the Lower and Middle Devonian of North Devon. From South Devon, Phacopids are rarely collected in the Lower Devonian but Homalonotids are more abundant. *Homalonotus barratti* described from Cornwall is deemed to be of Upper Devonian age; it is certainly not a Homalonotid, possibly Phacopid. The limestone-preserved Middle Devonian trilobites from South Devon usually have their skeletons preserved. The world-wide diminution of families at the close of the Middle Devonian is noted, and again at the close of the Frasnian. Attention is drawn to R. and E. Richter's revised determinations of several species of Phacopidae, including two without eyes, also of three species of Proetide described from the upper Devonian shales of South Devon and Cornwall. The trilobite fauna of the Pilton Beds is discussed on the lines of Goldring's 1955 revision. Revised determinations of the trilobites from the Culm are discussed and recorded.

2. The Coastal Outcrop of the Culm Measures of South-West England : by D. P. Ashwin, Ph.D., D.I.C., F.G.S.

The coast between Boscastle and the Taw-Torridge estuary is composed entirely of Carboniferous strata, which may be broadly divided into three groups :

(1) The Boscastle Measures. These are black slates, probably of Lower Carboniferous age. They form the 22 miles of coastline between Boscastle and the Rusey fault, which lies two miles south-west of Crackington Haven. They are of unknown thickness for the

foliation, which dips gently northwards and which was previously regarded as bedding, can be shown to be a cleavage-bedding foliation associated with a system of isoclinal folds trending north-south. These folds are thought to have been formed by flow caused by the great weight of superincumbent strata piled upon them during the Variscan movements. The cleavage-bedding foliation produced was then folded into monoclines and zig-zags trending E.N.E.W.S.W. by movements associated with the thrusts seen in the vicinity of Tintagel and elsewhere. (Wilson 1951.)

(2) The Crackington Measures. These are an argillaceous greywacke group of M. and U. Namurian age about 15,000 ft. thick which crop out between the Rusey fault and Widemouth, a distance of six miles. They are folded into large zig-zag folds with horizontal axial planes and the whole group forms the inverted limb of a large fold trending east-west and overturned towards the south. A horizontal, slaty cleavage is developed in the argillaceous beds.

(3) The Bude and Welcombe Measures. These are a dominantly arenaceous greywacke succession of L. Westphalian age, more than 10,000 ft. thick, which form the coastline for 161 miles between Widemouth and Hartland Point. The folding in this group is concentric. The fold axial planes dip southwards in the north and northwards in the south and form an anticlinorium whose axis passes through Welcombe Mouth.

Small sandstone dykes are commonly developed in these beds.

A study of the sedimentary structures developed on and in the greywacke beds indicates that they were derived from a land mass which lay, not as previously believed, to the south, but to the north.

3. The geological interpretation of gravity and magnetic surveys in Devon and Cornwall : by M. H. P. Bott, A. A. Day and D. Masson-Smith. Read by M. H. P. Bott, B.A., Ph.D.

The results of gravity and magnetic surveys in Devon and Cornwall were presented and their interpretations discussed. The main gravimetric feature is a belt of negative Bouguer anomalies following the line of exposed granites and providing information about their shape in depth -- particularly demonstrating their interconnexion. The bearing of these anomalies on isostatic compensation was briefly discussed. In marked contrast to this belt the gravity anomalies only drop slightly over the Lundy granite.

Local negative gravity anomalies correlated with the outcrops of post-Carboniferous sediments. A regional westward increase of gravity is observed over the Culm synclinorium of Central Devon. The remaining gravity changes are attributed to American structures including disturbances within the Culm synclinorium and major thrusts beneath the Start and Lizard districts and Exmoor. In this respect it is thought that the outcropping Devonian of North Devon may be underlain by Carboniferous rocks.

4. The structure and stratigraphy on the northern and western margins of the Dartmoor granite : by W. R. Dearman, Ph.D., B.Sc., A.R.C.S., and N. E. Butcher, B.Sc.

The southern boundary of the great Culm-measures syncline of Devon is characterized by the appearance to the south of a monotonous series of purple and green Upper Devonian slates. The junction can be traced from the Cornish coast at Boscastle east-south-east to Launceston and thence to the western margin of the Dartmoor granite just south of Tavistock. But there is, as de la Beche realised in 1839, a line of Lower Culm-measures limestone quarries extending from Launceston to beyond Okehampton on the northern verge of Dartmoor. Within this triangular area the geological structures is complex ; three distinct lithological groups are repeated in different structural settings.

Along the northern margin of the granite presumed Devonian slates with lenticular grits lie in the core of the Meldon Anticline. This fold, in Lower Culm-measures shales, quartzites and calcareous beds, is overturned to the south ; but as the structure is followed away from the granite to Bridestowe and beyond, the axial planes of the zig-zag folds become horizontal. Lying between the Meldon Anticline and the granite margin is the Southerly Down Syncline in Upper Culm-measures sandstones and shales ; this fold is also overturned to the south, and dies out to the south-west as the structural attitude in the Meldon Anticline changes.

The normal low-dipping limb of this syncline is succeeded southwards by the River Lyd inlier, composed of rocks of probable Devonian age. Here bedding dip is northerly at a low angle but there are many small superimposed isoclinal folds distorted by axial plane shear cleavage. The disposition of two bands of calc flintas on both flanks of this inlier suggests that the major structure itself may be isoclinal. Both junctions of the inlier must be faulted as Upper Culm sandstones

appear to pass at a low angle northwards beneath the River Lyd slates.

On Black Down the structure is probably anticlinal, once again overturned to the south. There seems to be a flat movement plane between the Black Down sandstones and the Lower Culm-measures of the Tavistock area, with small definite Devonian inliers, as for example at Marytavy, suggesting a southward extension of this thrust plane.

The Tavistock Lower Culm-measures are similar to those of Okehampton with hard black shales passing upwards into a dominantly calcareous group. There is, however a general westerly dip of up to thirty degrees off the granite, with only one occurrence of steep beds which are thought to occur in the core of a major recumbent fold overturned to the south, the Tavistock Anticline, since to the south and eastwards to the granite margin the succession is inverted. Before the main outcrop of the Devonian is reached there is a narrow strip of inverted Upper Culm-measures, the Whitchurch Down Greywacke Group, which dips north under the Tavistock Lower Culm-measures.

5. Notes on the Upper Devonian and Lower Carboniferous Rocks of the Launceston District : by E. B. Selwood, B.Sc.

For many years the Petherwin Beds were considered to be the youngest Upper Devonian rocks occurring in Cornwall. The absence of the topmost Upper Devonian and Lower Carboniferous strata led to a certain amount of speculation regarding the nature of the Devonian-Carboniferous boundary ; but the recent discovery of *Gattendorfia* and *Wocklumeria* Zone faunas shows that the boundary is quite conformable.

The Petherwin Beds are a highly fossiliferous series and yield two distinct faunal groups, each being restricted to a different lithology within the beds. By far the more extensive is a brachiopodlamellibranch lithology which comprises a series of slates with thin limestones yielding a typically Famennian fauna. The second lithology is very much more restricted in its outcrop and is composed of cephalopod limestones, sandstones and slates bearing a fauna which can be correlated directly with the *Platyclymenia* and *Clymenia* Zones of the Continent.

It is proposed to call the recently discovered topmost Upper Devonian rocks of the area the Stourscombe Beds, since they possess a characteristic lithology and fauna quite distinct from the underlying Petherwin Beds. The most spectacular development of the Stourscombe Beds comprises a dark slate bearing abundant siliceous nodules. These nodules contain a rich fauna of goniatites and clymenids which can be correlated directly with the upper part of the *Wocklumeria* Zone. The highly fossiliferous nodules are of isolated occurrence, and appear to represent somewhat atypical accumulations since an extensive series of black slates bearing numerous thin cherty seams have yielded rare fossils which prove them to be of comparable age to the nodules. It seems that local concentrations of organic remains acted as nuclei for silica deposition which at the same time elsewhere formed thin seams.

The succeeding Yeolmbridge Beds are composed of a calcareous sandy slate overlain by a thin limestone ; these beds have yielded fossils of *Gattendorfia* Zone age. There is some evidence that the Devonian-Carboniferous boundary lies within the sandy slate.

6. The age of the orogeny in South-West England : by J. E. Prentice, Ph.D.

Three distinct tectonic styles can be recognised in South-West England, occurring in regions which may be designated from south to north, as (a) the Lizard Unit ; metamorphosed rocks of the Lizard, Dodman and Start Point, south of the Lizard Thrust-zone ; (b) the Killas Unit, where fold axes and cleavage planes are near to horizontal ; and (c) the Autochthonous Unit, in which fold axes are nearly vertical and cleavage poorly developed. The main folding in the autochthonous unit is late or post-Westphalian, and it is suggested that the Killas and Lizard Unit may have suffered from an earlier phase of orogeny. This suggestion is supported by the appearance of unconformity below the Upper Culm on the south side of the Culm synclinorium, in the Boscastle region and in the St. Mellion outlier ; by the occurrence of conglomerates in the Upper Culm in the Newton Abbot area ; and by the vastly greater thickness of elastic material in the Namurian of North Cornwall and South Devon than is found in North Devon. It is therefore suggested that the orogeny began in late Namurian times in the south of the region, and that the Culm deposits were laid down in the foredeep of this mountain chain.

II. PETROLOGY.

Proceedings of the 9th January, 1958.

1. Nuclear Emulsion Techniques : by **I. H. Ford**, B.Sc. (Dept. of Geology, University of Bristol).

A-particle sensitive " nuclear " photographic emulsions are being used to study the distribution of radioelements in thin sections of rocks and to obtain quantitative information about the radioactivity of accessory minerals extracted from granites and their country rocks. Two techniques are being used (1, 2), both of which make use of nuclear emulsions obtained from Messrs. Ilford Ltd., in gel form.

To investigate the distribution of radioelements in a thin section of rock, the latter is prepared in the normal way but without a cover slip. Suitable precautions are taken to minimise radioactive contamination of the rock section by carrying out controlled experiments on the abrasives used. The emulsion, in gel form, is liquified by heating it in a glass tube which is immersed in a water bath at 45°-50° C., and then poured over the rock slice which has previously been placed on a level surface. All these operations are carried out in a safely illuminated dark-room. Then the emulsion is cooled and dried in a current of clean air and left for a few weeks in a lighttight box in a refrigerator at 50° C. Afterwards it is processed and systematically examined under a microscope. Metallurgical microscope objectives are used, since they are corrected optically for use without a cover slip, and an achromatic condenser improves contrast. Necessary magnifications range from about $\times 200$ to $\times 1500$.

High-resolution microscopy is essential if the maximum amount of information is to be obtained. The method permits the origin of an a-particle in a rock-slice to be located within a micron or so.

Normally transmitted light is used and the thin section and its associated a-particle tracks are examined at the same time. In the case of an opaque or nearly opaque mineral, " Ultropak " dark field optics can be used, or a polarising normal incidence illuminator such as is often fitted on a good ore microscope. If processed nuclear emulsions are examined by this method with polariser and analyser crossed, the silver grains in the emulsion will show against a dark background since they depolarise and scatter light. An immersion achromatic objective is

recommended for this work.

Small accessory minerals, extracted from rocks by crushing and followed by heavy liquid and/or magnetic separation, are completely embedded in nuclear emulsion, in order to record the complete α -particle emission over a given period. A photographic emulsion can be regarded as an ionisation chamber with a built-in integrating device.

Nuclear photographic plates, 3" x 1" carrying a 50 micron α -particle sensitive emulsion are obtainable from the manufacturer together with some of the same emulsion in gel form. The small accessory minerals are sprinkled or otherwise distributed on the emulsion on the plate, and a layer of emulsion poured over them, to give a " sandwich ".

A Burch reflecting microscope (3) fitted with a standard Cooke Troughton & Simms Federov universal stage, has been constructed to examine the total α -particle emission from individual small crystals. With this microscope it is possible to tilt nuclear plates to 40° from the horizontal using a numerical aperture of 1.0 and a magnification of x 1000.

References :

1. FORD, I. H. (1951), Radioactivity of Rocks : An Improvement in the Photographic Technique.
Nature **167**, p.273.
2. FORD, L H. & OLLIER, C. D. (1955), Radioactivity of Zircons.
Nature 176, p.834.
3. KEOHANE, K. (1954), Reflecting microscopes, J. Quekett Micr. Cl. Ser. 4, Vol. 4, p.89.

2. Radioactivity and Radioactive Accessory Zircon of the Land's End Granite: by Z. M. Zaghloul, B.Sc., M.Sc., (Department of Geology, University of Bristol).

A nuclear photographic emulsion technique (Ford, 1951) has been used to study the distribution of alpha-radioactivity in a thinsection of Lamorna granite.

The distribution found to be heterogeneous, is as follows : 7.5% of the total alpha-activity of the thin-section is due to quartz, 10.1% to perthitic

orthoclase, 17.6% to plagioclase, 41.2% to biotite, 2.0% to muscovite, 12.4% to apatite and topaz, 1.5% to cordierite and andalusite, and 7.6% to the mineral boundaries. About 75% of the total radioactivity of the thin-section is concentrated in the accessory minerals and their inclusions in quartz, feldspars and micas.

Samples of granite were collected from quarries at Lamorna Cove, Sheffield, Castle-an-Dinas, and from St. Michael's Mount. Each granite sample was separately crushed and sieved, the 62-125 micron fraction being taken and the heavy accessory minerals separated from it by using in succession bromoform (S.G. 2.87), methylene iodide (S.G. 3.3) and an electromagnet. A few milligrams of each heavy mineral assemblage was mounted in Ilford G special photographic emulsion (Ford & Ollier, 1955).

The following minerals, identified by means of a petrological microscope, were found to be alpha-particle emitters :-uraninite, monazite, xenotime, sphene, allanite-epidote, zircon and opaque iron-oxides. These minerals are in order of decreasing autoradiographic intensities.

Zircons were singled out for special examination and their characteristics ; crystal form, habit, elongation (length/width ratio), colour, zoning, outgrowths, inclusions and micro-cracks, as well as alpha-radioactivity, were studied in detail.

The zircons in samples of the coarse granite from Lamorna, Sheffield and St. Michael's Mount are euhedral, prismatic, usually terminated by two bipyramids which are equally developed, and have a common elongation between 2 and 3. They are generally dusky, zoned and show pale uneven buff to purple colours. The water-clear zircons and the deep brown ones are subordinate. The inclusions are common, appear to vary in composition and have a random distribution. The specific alpha-radioactivity of the zircons, defined as the number of alpha-particles emitted per cubic centimetre per second, varies between 56 and 97 a/cc/sec. (geometric mean).

Zircons in the sample of fine-grained granite from Castle-an-Dinas resemble the others in crystal form, habit, elongation, zoning and inclusions. They differ in that deeply-coloured crystals are dominant, with colour varying from purple to orange and buff brown, and the geometric mean of their specific alpha-activities is higher by a factor of about 3 (302 a/cc/sec.).

3. The specific alpha-particle activity of zircons from the Carnmenellis composite intrusion : by E. Cameron, B.Sc., (Department of Geology, University of Bristol).

The Carnmenellis composite intrusion (Ghosh 1934), consists of four distinct granite types - three coarse-grained and one finegrained - here designated I, II, III, FG, and represented by samples from the Holman Mine, the Carnsew and Tolcarne Quarries, and Crowan Beacon respectively.

The current research attempts a quantitative comparison of the specific radioactivity of zircon crystals from the four granite types and, ultimately, of variation, if any, within the same type : the present contribution, however, merely illustrates the methods of presentation of the results and some of the difficulties associated with their interpretation.

All crystals so far examined are prismatic euhedra ; for simplicity they are regarded as being of square cross section and in the calculations their volume is considered as approximating closely to the product of maximum length and cross sectional area, as indicated by the measured breadth. The total number of visible alpha-particles originating from each grain is counted, giving the minimum emission from maximum volume.

The method of presentation in which the activity is represented as emission from unit volume time ($a/cc/sec.$) is the simplest and most reliable, though it is also possible to express this value in terms of equivalent radio-element content, generally uranium, in parts-per-million. The disadvantage of this representation lies in the necessity for making a fundamental assumption as to the uraniumthorium ratio in the mineral - an assumption which may be totally unjustified.

The comparative relationships are, however, the same irrespective of the units chosen ; activity/frequency histograms show positively skewed distributions for the four granite types with a reduction in the modal emission in the sequence I, II, FG, III.

From a geometrical study of alpha-particle emission from grains the dimensions of which are of the same order of magnitude as the average alpha-particle range in the mineral, it is apparent that the measurable activity is dependent on crystal size. The problem is a three-dimensional one of some considerable complexity, but may be examined in a simplified form, viz. in the direction of thickness only

When the size, in this direction, exceeds twice the alphaparticle range, the only effective emitting sources are two outer zones, each of depth R (R being the particle-range) from which the alpha-particle can reach only the adjacent crystal surface, and separated by a central region the particles from which are never recorded. In such cases, increasing crystal thickness results in the enlargement of this central ineffective zone, with a corresponding very gradual decrease in the apparent activity ; such are the characters of " Thick Source " emission.

In order to determine the effect of crystal dimensions on the results obtained, specific activity was plotted against thickness for each crystal and a curve constructed on the basis of the resulting scatter diagram for each granite type. In all cases the curves are of identical basic form, showing only a very gradual reduction in activity with increasing dimensions in excess of 60 microns i.e. twice the average alpha-particle range in zircon : those obtained for types I and II are identical both in form and position, whilst III and FG show a displacement towards higher emission values, accompanied by a slight reduction in the degree of curvature, indicating an alteration in the relationship with higher activity. Variations in crystal length are assumed to have no profound effect on the apparent activity since in virtually all cases the crystals may be considered as thick sources parallel to the crystallographic c-axis.

On the basis of the activity/thickness relationships obtained, a series of iso-activity curves were constructed with the aid of which comparison of the minimum alpha-particle emission is possible irrespective of size-variation of crystals. Such a comparative study reveals that the zircons of granites I and II have identical modal specific activities, whilst those of III and FG are greater by factors of one third and two thirds respectively.

The results thus obtained, supplemented by a study of the varietal features of the zircons, suggests that the similarity between I and II is sufficiently close to warrant their consideration as almost identical types, whilst III and FG can only be regarded as quite distinct. Such a view tends to support the conclusions, reached by normal petrographic methods, on which Ghosh constructed his map, and the opinion of Chayes (1955) regarding types I and II, that though "..... the two fades may not be absolutely identical the differences between them must be trifling ".

References :

GHOSH, P. K. : The Cammenellis granite. *Quart. J. Geol. Soc.*, (1934) 90. 240-76.

CHAYES, F. : Modal composition of two facies of the Cammenellis granite. *Geological Magazine*, (1955) 92, 364-6.

4. Petrological features of the greenstones and sediments in the Carn Moyle-St. Ives section of the Land's End metamorphic aureole : by J. Hawkes, B.Sc., (Department of Geology, University of Birmingham).

The mineralogy of the greenstones.

Non-thermally metamorphosed West Cornwall greenstones consist chiefly of titan-augite, sodic plagioclase and ilmenite.

Within the Land's End aureole between Carn Moyle and St Ives, contact metamorphism has led to a series of essentially internal changes in the greenstones. Mineralogical observations give a guide to the nature of these adjustments, but chemical techniques must be applied in order to gain a full understanding of all the factors involved.

The most widespread changes seen in the basic rocks are the replacement of augite by hornblende, recrystallisation of oligoclase crystals as granular andesine and the partial alteration of ilmenite to granular sphene. Hornblende veining is common. Igneous textural features are generally preserved in greenstones bearing this mineralogical assemblage.

It is clear that lime necessarily expelled in the replacement of augite by hornblende has been incorporated into sphene and the granular andesine. The occasional presence of the calcium rich minerals epidote and axinite in hornblende veins is a further indication of the movement of lime.

More advanced mineralogical changes of restricted occurrence are seen in the greenstones. Four distinct trends can be recognised :

(i) Replacement of hornblende by diaspore and clinocllore, accompanied by the development of the magnesian spinel, pleonaste in the matrix. The original igneous texture is still apparent. These mineralogical changes indicate a relative desilicification of the rock and an enrichment in magnesia relative to iron.

(ii) Replacement of hornblende by sheaves and stellate groups of cummingtonite and anthophyllite crystals, and the conversion of localised areas of granular plagioclase into single diffuse patches of cordierite. Ilmenite is abundant, but shows no sign of alteration to sphene. Complete recrystallisation has changed the original texture of the rock to that of a hornfels. The development of cummingtonite, anthophyllite and cordierite can be explained by postulating a continued expulsion of lime from the restricted areas in which the minerals occur. These rocks have a banded appearance, but there is no field evidence suggestive of extensive shearing.

(iii) Replacement of hornblende in the hornblende-plagioclase-ilmenite-sphene rocks by granular biotite. In extreme cases, igneous texture is reduced to that of a fine granular hornfels. Biotite is often developed after cummingtonite and anthophyllite in rocks characteristic of the second subsidiary metamorphic trend. The appearance of biotite is considered to be due to the introduction of potassium from an external source, namely the Land's End granite.

(iv) Conversion of hornblende to diopside as a result of the introduction of lime displaced elsewhere in the aureole greenstones. The replacement occurs chiefly in hornblende veins and in the rock matrix in the immediate vicinity of the veins, without the destruction of the original igneous texture. Ilmenite is completely replaced by granular sphene. Diopside is occasionally seen in biotitised rock and as the mineral contains inclusions of mica, this trend is thought to be the last in the sequence of changes outlined above.

Changes indicative of low temperature conditions are seen to modify various varieties of the greenstones. They correspond to the well marked late stage retrogressive phase in the sedimentary hornfelses, but are represented on an extremely localised scale. Aggregates of sericite flakes appear after plagioclase, and chlorite may replace hornblende, cummingtonite, anthophyllite and biotite.

The killas.

The origin of the quartz laminations.

In his paper, Mr. Lacy refers to the thin quartzose laminations found in killas rocks of the aureole, suggesting that they may represent an original bedding structure. The only evidence in the present area to support the idea, is that where uncontorted, the lamination planes approximate in dip and direction to that recorded in the pillow

lavas.

Excellent sections in Mylor beds of a low metamorphic grade may be seen near Porthleven, a few miles away. They consist of thinly banded argillaceous and silty rocks. In localised areas, cataclastic shearing has disrupted the silty bands into augen varying from a few millimetres to several centimetres in length.

Within the Land's End aureole, there are killas sections in which the quartz laminations give way to quartzose augen remarkably similar to the Porthleven silty structures. It appears likely therefore that the quartz laminations represent the site of original silty bands, a process of metamorphic segregation having produced their present aspect.

The mineralogy of the killas.

The argillaceous material prior to thermal metamorphism probably consisted of quartz, chlorite, sericite, ore and rare feldspar.

Thermal metamorphism, with the presence of circulating fluids, produced internal changes in the sediments, resulting in the formation of cordierite-biotite-quartz hornfels. Such rocks are a dark purple grey colour, the cordierites standing out as black shining patches on fresh surfaces. The rare appearance of corundum (sapphire) with increase in grade suggests a trend towards relative desilicification of the hornfels.

Accepting the presence of original silty bands, this relative desilicification might have been brought about by migration of chloritic and sericitic material from the silty to the argillaceous bands and the reverse movement of silica.

With the eventual fall in temperature and the continued presence of hydrous fluids, retrogression occurred in the hornfels. Biotite and cordierite were reduced to chlorite, sericite and ore. The new assemblage constitutes a return to an earlier mineralogy, but the hornfels texture is generally preserved.

5. Some features of the contact-aureole of the Land's End granite : by E.

D. Lacy, B.Sc., A.R.C.Sc., (Department of Geology, University of Birmingham).

A suite of distinctive and unusual rocks featuring cordierite, ferromagnesian amphiboles, spinel and diaspore was described from Kenidjack and Botallack in 1930 by Flett and Tilley. In 1935 Tilley

ascribed its origin to the metasomatism of rocks of basaltic composition. These papers described only briefly the field relationships of these rocks and the associated sediments and hornblendic types. The present work arose from the belief that by careful search rock types similar to those of Kenidjack and Botallack would be found in a more easily interpreted structural setting and that further study of the type area would be fruitful. The general work in the field has been carried out by the present author and various students. The detailed mapping of the seven mile tract of aureole from Carn Moyle to St. Ives was undertaken by J. Hawkes.

Carn Moyle to St. Ives.

This area comprises altered basic igneous rocks of megascopically fine - grained and coarse - grained types bearing abundant hornblende ('greenstones') and silty sediments ('killas'), the latter bearing the imprint of cleavage as well as the superimposed contact metamorphism. The granite contact is seldom seen, but locally it plunges steeply and veins and apophyses penetrate the country rocks, which typically dip 20° north off the granite.

Where it is near to the granite, the killas is a very fine-grained purple-brown hornfels, and at many localities carries cordierite spots, which occasionally reach 5 mm. in diameter. These spots tend to be discoidal, lying in what seem to be the bedding planes. Sparse corundum is occasionally seen in thin sections. Further from the granite the killas is slaty and is sometimes spotted, the micaceous flakes being apparently parallel to the bedding. The killas usually has a laminated appearance, the coarser laminae often being conspicuously quartzose. This lamination is normally the most important structural surface in the killas, is interpreted as representing the original bedding, and is the feature that leads to the correlation of these rocks with the Mylor series outside the aureole.

The killas often shows minor folding, the structures being marked by the quartzose laminations. The axial planes of the folds strike at about 45° east of north and dip to the north-west at angles between 20° and 55° . Parallel to them a cleavage is frequently developed.

The killas is typically from 100 ft. to 300 ft. in thickness and is sometimes sandwiched between fine-grained greenstone below and coarse-grained greenstone above, the latter often forming the tips of the

headlands. Occasionally, as at Carn Moyle, the killas rests on coarse greenstones. At other times little killas is seen, then occurring only as thin bands in greenstone, or, as at St. Ives Head, consisting of disoriented rafts enveloped in igneous material.

The fine-grained greenstone includes developments of pillow structure, as at the extremity of Gurnards Head near high water mark, at Clodgy Point, Zennor Cliff and Carrick Du. The pillow lavas dip to the north at angles in conformity with those measured in the killas. Individual pillows show gravity sag and proof is afforded that the rocks are not inverted. Immediately to the west of St. Ives, coastal exposures of pillows are numerous and the aureole is wide, though poorly exposed inland, and it would appear that there is a development of about 2,000 ft. of lavas hereabouts.

In the field ophitic texture is easily recognised in the coarse-grained greenstones, where the latter are suitably weathered. Transitions to fine-grained greenstone, with or without pillow structure, can be found. The fine-grained material locally shows a small scale lobate penetration of the killas. The dolerites are therefore, at least in part, contemporaneous with the pillow lavas, which were intruded into incompletely consolidated sea floor muds. Contacts of dolerite with sediment are frequently highly transgressive, however, and narrow angular apophyses can be found. Such relationships suggest the break through of relatively larger masses of magma with injection into comparatively consolidated sediment some little distance below the sea floor. This activity was probably pene-contemporaneous with pillow lava eruption.

Usually no original pyroxene is left in the igneous rocks, but at St. Ives Head, a mile from the granite outcrop, this mineral remains. Only locally are the greenstones appreciably sheared. In the greenstones development of much biotite of metasomatic origin is a common phenomenon and can be studied conveniently at Gurnards Head. In places, as on Trowan Cliff, on Gurnards Head and at Porthmeor, types are developed, of demonstrable igneous parentage, containing cordierite and ferromagnesian amphibole, but such rocks are very limited in the extent of their occurrence.

Faults which can be mapped are not numerous. Those which do occur commonly strike either 060° or 160° east of north, with westerly downthrows of up to 250 ft. The principal joint pattern has N.E.- S.W. and N.W.- S.E. trends in the western part of the area, with a tendency to

assume directions nearer north-south and east-west in the eastern half. A floor jointing is seen in the granite, dipping seawards.

The western part of the aureole.

Traverses in the Pendeen to Kenidjack area, to which mapping is now being extended, have revealed the presence of pillow lavas, dipping off the granite, at numerous localities. Pillows can be found quite near to the Botallack mine, but there they are distorted by shearing. Near Kenidjack completely unsheared pillows, several feet in maximum dimension, were found completely transformed to a hornfels containing cordierite, anthophyllite and biotite. Between the pillows there were wedges of fine-grained cherty material representing original sediment. Nearby, complex intrusive penetration and adinolisation of soft mud by basic material can be demonstrated, sometimes associated with the development of very small pillow forms.

Near the Crowns a large mass of garnetised rock has been located. A thin section of a specimen was found to contain garnet, epidote, a sodic hornblende, diopsidic pyroxene, pennine, and tourmaline. The mass lies further from the granite than the associated hornfels containing cordierite and ferromagnesian amphibole. It would thus appear that the repository of some of the substances leached from the silica-poor hornfels has been found. This occurrence is probably paralleled by a zone of metasomatism seen in the reef seawards from the Geevor tin mine. At this locality there is also, further from the granite, an area of intense silicification. This may be complementary to desilicified hornfels close to the granite contact.

On the promontory between Zawn a Bal and De Narrow Zawn killas is found intercalated amongst the highly metasomatised basic rocks. This killas contains dark-weathering nodules, up to at least 3 cms, in size, flattened along the bedding. Examined microscopically the nodules are seen to be highly enriched locally in iron ore, to contain cordierite and sometimes ferromagnesian amphibole. These observations are highly suggestive of a tendency toward metamorphic convergence of the most highly transformed 'greenstones' and sediments.

Other localities.

A small area of aureole rocks is preserved at Tater Du, consisting largely of altered basic igneous material. At the eastern end of the outcrop the junction with the granite is faulted, but at the western end is normal. The rocks are apparently considerably sheared and include types with ferromagnesian amphibole, garnet and diopside.

In a thin section of a specimen collected at Penlee Point, near Mousehole, cummingtonite was found.

Discussion.

It is evident that many of the hornfels types described by Flett and Tilley are not confined to the Kenidjack and Botallack localities, but are present in many parts of the aureole, albeit on a restricted scale. There is little doubt that further occurrences will come to light as investigation proceeds.

A complete account of the petrogenesis of the rocks of the Land's End aureole cannot be given until further chemical studies of the rocks and minerals have been made. The present work supports Tilley's deduction that the exotic hornfels are metasomatically derived from basic igneous rocks. Both field relationships and textural studies entirely rule out the possibility of their origin by the transformation of limestones and calcareous shales according to the suggestion of Reynolds, made in 1947. The present studies do not permit the complete rebuttal of her hypothesis of a regional Fe-Mg metasomatism. This point cannot be cleared up without detailed chemical investigation of the rocks inside the aureole and of related types outside. It is considered probable, however, that the hornfels rich in Mg and Fe have resulted from local redistribution of these elements. The fact that they are developed only in relatively close proximity to the granite seems significant in this connection.

It is an interesting coincidence that the only extensive development of minerals such as anthophyllite, cummingtonite, spinel and cordierite is in an area traversed by a plexus of mineral veins that was, in the past, a leading producer of tin. If it be held that fluorine is an important agent in carrying tin, then it may be postulated that this element greatly facilitated the metasomatic processes or was the active agent involved. It would be of great interest to analyse amphibole and

biotite species with especial reference to their fluorine content and Mg/Fe ratio. Potassium has been added to the basic rocks and this element may be the only metallic one that was furnished by the granite in major quantities. The recognition of highly metasomatised but unshered rocks shows that shearing is not a pre-requisite condition for metasomatism.

The period during which the aureole was at an elevated temperature must have been a long one and the present author cannot accept Miss Reynolds' thesis that tourmalinisation of anthophyllite-cordierite rocks demonstrates that the" metasomatism was accomplished before the arrival of the granite.

Pillow lavas have been found outcropping along a twelve-mile tract of coast and there can be little doubt that all of them are substantially the same in age. They are intimately associated with Mylor-type sediments. The Mylor series is currently assigned to the Lower Devonian, but so far no pillow lavas of proven Lower Devonian age have been described from Cornwall and Devon. However, there is a number of records of such rocks assigned to post mid-Devonian times and later, e.g. at Pentire Head (House 1956). This suggests that the possibility should be considered of at least some of the sediments mapped as of Mylor-type being of Upper Devonian age. Further evidence of their age should be sought.

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6. The Petrology of the St. Austell Granite: by C. S. Exley, M.A., D.Phil., F.G.S., (Department of Geology, University College, Keele, Staffs.)

The St. Austell mass includes four main varieties of granite, namely biotite-muscovite granite, early lithionite granite, late lithionite granite and fluorite granites.

Changes in mineralogical composition, from the biotite-muscovite variety to the fluorite variety, include decreases in biotite and

potash feldspar, and increases in " lithionite ", muscovite, plagioclase, the albite-content of the plagioclase, and minerals such as fluorite and topaz. These, and chemical, changes, suggest that the varieties are due to magmatic differentiation.

Sharp compositional changes across the junction between the biotite-muscovite and other granites, the shape of the metamorphic aureole and the disposition of mineral lodes, indicate that the biotite-muscovite granite was the earlier of two intrusions.

All the granites are altered in four ways. Two of these, unrelated to structure, are late-magmatic, consisting of tourmalinization at the expense of feldspar and mica, and greisenizing as a consequence of which perthite has been altered to mica and quartz.

Following consolidation, during which series of essentially N.-S. and E.-W. joints were established, the other alteration processes became effective, including the tourmalinizing of joint walls and the conversion of plagioclase into kaolinite and mica.

Both stages of tourmalinization required B and -OH. Greisenizing required acid environments, suitable concentrations of K, Si and Al, and temperatures of 350°- 400° C. Kaolinization also required acid conditions, suitable Al : Si ratios and temperatures below 350° C. Its intensity depended on the ionic potentials of the elements involved and the ion exchange capacity of the clay.

The full data on which this paper was based are to be published by the Geological Society of London ; an abstract has already appeared.

7. The distribution of alkalis and fluorine across some granitekillas and granite-greenstone contacts : by C. M. L. Bowler (Department of Geology, University of Bristol).

A number of granites, hornfelses and unaltered country rocks from the south-west of England are being analysed for Na, K, Li, Rb, Cs, and F. Li, Rb and Cs are determined by an optical spectrograph in the Department of Geology and Mineralogy, University of Oxford, using K as a variable internal standard. Na and K are obtained by a flame photometer and the spectrographic method is used for F.

The average of four main granites which have been analysed quantitatively is : Na 2.26%, K 4.29%, Li 635 ppm., Rb 420 ppm., Cs 47

ppm., K/Rb 102, and further data show that the granites of S.W. England are characteristically enriched in rare alkalis when compared with values for granites in other parts of the world. The Lundy Island granites show a similar enrichment.

Killas and greenstone hornfels from Tater Du and Pendeen, Megiligar, North Hill, and Petertavy (lying off the granite masses of Land's End, Godolphin, Bodmin Moor, and Dartmoor respectively) show that, while the distribution of the alkalis and fluorine varies considerably in detail, generally on passing from unaltered country rock towards the granite contact the K/Rb ratio decreases and the concentration of Cs, Rb, and F increases. This increase is most marked for Cs, for unaltered killas and greenstones invariably contain 10 ppm. Cs which rises by a large factor to values between 70 ppm. and 260 ppm. Cs in some hornfels near to the contacts. Peak values for K, Rb, Cs, and Li occur in a biotite-rich xenolith contained in a granite vein. In hornfels close to the contact, fluorine rises to values commonly between 2,000 ppm. and 6,000 ppm., although occasionally, values considerably in excess of these, (up to 26,000 ppm.) are found.

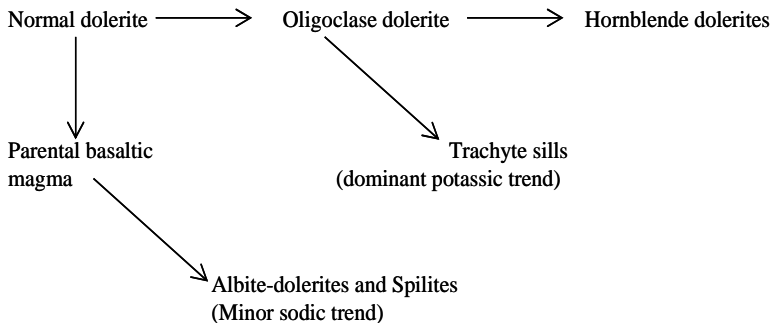
The distribution of Rb and Cs is known to be governed largely by that of K. In the granites both Rb and Cs favour K-sites in biotite in preference to K-sites in feldspar, but this preference is most pronounced for Cs. In the hornfels the most important mineral harbouring Rb and Cs is biotite. At this stage it can be said there is evidence that F, Rb, Cs (and possibly K and Li) were available to metasomatise the country rock.

8. The Culm igneous suite near Tavistock, West Devonshire : by N. E. Butcher, B.Sc., F.G.S., (Department of Geology, University of Reading).

Igneous rocks of pre-granite age occur in two main areas in the Culm Measures on the north-east side of the Dartmoor granite and to the west of that mass. The eastern part of the latter area is described, an attempt being made to distinguish features which are thought to be the result of original magmatic differentiation and metasomatism from effects of later contact metamorphism and metasomatism by the granite.

The igneous suite is largely confined to the Lower Culm and occurs mainly as sills, most of which lie within the metamorphic aureole of the granite. The sills appear to be fully involved in the folding which produced the pre-granite structure and it is suggested that the main injection of magma took place prior to the deposition of the Upper Culm sediments.

The rocks are believed to fall into two groups. The bulk of them - probably 90% or more of the sills - are included in a differentiation sequence considered to show a potassic trend. The rest of the rocks form a small spilitic group, presumably showing a sodic trend. The following differentiation scheme is suggested :



A feature associated with only the larger group of rocks is the widespread development of tremolite, the mineralogical expression of an essentially magnesian metasomatism which is thought to be connected with the magma giving rise to this series of rocks.

It is clear from Memoirs of H.M. Geological Survey that most of the above rock-types are present in other parts of Devon and Cornwall. Since South-West England may be considered to be the type-area of the Spilitic Suite, recognised by Dewey and Flett (1911 *Geol. Mag.* ,8, 202-9 and 241-48), it appears that these authors included rock-types within the Spilitic Suite which in fact appear to show a potassic trend.

9. The Distribution Pattern of the Hypothermal Lodes of the South-West of England : by K. F. G. Hosking, M.Sc., Ph.D., A.M.I.M.M., (Camborne School of Metalliferous Mining).

Examination of appropriate maps reveals the following facts concerning the distribution of the hypothermal lodes of the South-West of England

(a) In any given area hypothermal lodes strike approximately parallel to the porphyry dykes and both are usually intersected by a later set of mesothermal lodes and barren cross-courses.

(b) To the north of the St. Austell granite mass there are several hypothermal lodes with an anomalous, roughly N.-S. strike.

(c) Many of the hypothermal lodes and dykes are near the granite/killas junctions : comparatively few occur near the centres of the larger granite outcrops.

(d) Some marginal parts of the granite are devoid of lodes.

(e) Certain dykes and associated *hypothermal* lodes are several miles from outcropping granite.

(f) Usually the distribution pattern of dykes and hydrothermal lodes bears little, or no, obvious relationship to the shape, in plan, of the nearest outcropping granite. However, the lodes and dykes of the Carn Brea area are exceptional in that they strike approximately parallel to the long axis of the granite ridge.

(g) Throughout Cornwall and Devon marked " streams" of lodes and dykes occur. Thus, a stream " flows " across the southern margin of Bodmin Moor and thence, via the granite cusps of Kit Hill and Hingston Downs, to Dartmoor.

(h) Finally, there is an approximate parallelism between the lode/dyke streams and those portions of the arcuate Lizard/Dodman/Start Point thrust to which they are closest.

The writer believes that the fundamental characteristics of the hypothermal lode -(and dyke) pattern can be explained by assuming that both lodes and dykes are orientated approximately parallel to the long axes of granite ridges with undulating crest-lines. It is thought that these ridges were determined largely by the moulding action of pre-granite anticlines which were developed in the sedimentary envelopes by the same forces which caused the Lizard/Start thrust. Certain other " moulding " anticlines were formed by rucking of the country rock during the emplacement of closely-spaced granite " knots ". Forces operating from the south caused granite " fingers " to be forcibly intruded into the sediments to the north of the major granite domes and a few hypothermal lodes are aligned parallel to these northern extensions and thus exhibit regionally anomalous strikes.

Centres of mineralisation occur near the cusps on the granite ridges, and it is believed that whilst the greisen-bordered lodes were formed from the residuum which accumulated during the crystallisation of the cusps, the " normal ", economically important hypothermal lodes were formed from that which was left when the body of the batholith consolidated.

10. Geochemical Prospecting in Cornwall : by K. F. G. Hosking, M.Sc., Ph.D., A.M.I.M.M., (Camborne School of Metalliferous Mining).

Geochemical methods of prospecting aim at locating hidden ore-deposits by establishing and interpreting variations in the concentration of substances which were either deposited in the country-rock at the time of lode formation or which have been liberated subsequently by oxidative processes into the adjacent soil, ground-water or surface-water. As variations in the concentrations of certain heavy metals in the soil may be reflected in the composition of some plant species, it follows that plant analysis may play an important role in geochemical investigations.

In Cornwall certain areas are unsuitable for geochemical prospecting because they have been contaminated by the waste products of mines, whilst others of economic interest are inaccessible because they have been built over. On the other hand much of Cornwall is ideal for this method of mineral exploration because it is covered with a thin residual soil which possesses very distinct "lode-element" anomalies over sub-outcropping

ore-bodies. Furthermore, as the soil-sampling techniques used do not mutilate the surface, geochemical prospecting can be employed on actively farmed land.

Although much is known about the distribution, etc., of the Cornish lodes there are many problems which await solution. Some of these are capable of partial or entire solution by the employment of geochemical techniques. Thus, lodes occurring in areas which have been but little mined can be rapidly located and the heavy metals that they contain can be determined to some extent.

"New" lodes near known lodes can be located. Lode-extensions can be traced.

The identities of metals occurring in ore-bodies which have been detected by geophysical methods can be established.

The possibility of finding certain minerals in a lode in depth when there are no *obvious* indications of them at the outcrop can, on occasion, be ascertained.

The analysis of underground wall-rock may indicate the presence of lodes beyond a point of development whilst the chemical examination of diamond-drill cores serves to indicate the proximity of ore-bodies and often facilitates an appreciation of the economic potential of lodes which have been intersected during drilling.

Investigations carried out in Cornwall during the past five years amply support the above statements.

11. A Radioactivity Reconnaissance in Scilly : by A. T. J. Dollar, Ph.D., F.R.S.E., M.I.M.M., F.G.S., (Birkbeck College, University of London).

The main aim of this survey was to establish the general distribution and intensity of radioactivity in the earlier peripheral coarse granite (G1) and the later central finer-grained granite (G2) --both apparently of Permo--Carboniferous age --which, together, build the boss of elliptical plan from which the isles of Scilly have been eroded. A secondary aim was to determine the relation, if any, between this radioactivity and the pneumatolysis in these granite. On the one hand, in both granites pleochroic haloes in biotites, muscovites and tourmalines afforded visible evidence for the presence of radioactive elements. On the other hand, representative modes indicated relative abundance of F, Cl,

B, Li, Ti, with - OH and - PO,.

The radioactivity was assessed in terms of γ -radiation at 165 stations, distributed throughout the islands, using a new design of scintillation counter. For part of the study a transistorised Geiger counter, with electro-mechanical counter, was employed for comparative purposes.

After preliminary studies, errors due to cover, to topographic and mass effects, and to weathered and leached granite, were made as small as possible by suitable choice of stations. At each station the mean milliroentgen value (mR) per minute was recorded for" each of ten consecutive minutes, particularly in order to detect and correct for cosmic showers. In each case, corrections were applied for background and diurnal variation of random radiation and the values expressed in mR/hr. The final results were plotted geographically, when " isorads " (lines of equal γ radiation intensity per unit time) were drawn.

The form and spacing of these isorads suggests that the radioactivity in G1 exceeds that in G2. Further, it suggests that in G1 the highest values are (a) peripheral (i.e. near to the junction of G1 with its former roof and wall of country rocks) and (b) situated over detectable zones of structural weakness (e.g. likely sites of magma inlets, major shear belts). Also, it suggests a localised uprise of radioactive elements in a zone parallel and near to the south-east margin of the boss, and a spread of these elements towards the north-west, under the former roof. The relationship between this pattern and that of pneumatolysis suggests that at least some of the radioactive elements were transported with the agents responsible for the pneumatolysis.