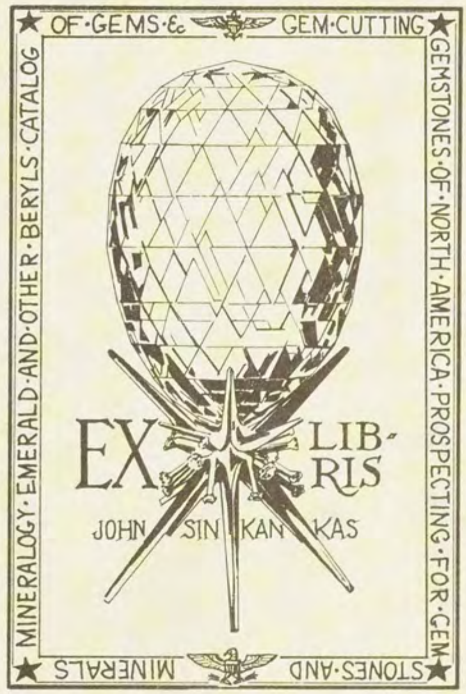
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JOHN SINKANKAS

[illegible]

Kynance Cove, with Old Lizard Head and the Man of War Rocks in the distance.

MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

EXPLANATION OF SHEET 359.

THE GEOLOGY OF THE LIZARD AND MENEAGE.

BY

J. S. FLETT, M.A., AND J. B. HILL, R.N.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

LONDON:
PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE,
BY DARLING & SON, LTD., 34–40, BACON STREET, E.

And to be purchased from
E. STANFORD, 12, 13, and 14, LONG ACRE, LONDON;
W. & A. K. JOHNSTON, LTD., 2, ST. ANDREW SQUARE, EDINBURGH;
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1912.

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PREFACE.

This memoir deals with the geology of the area represented by Sheet 359 of the New Series Ordnance Map on the scale of one-inch to one mile. The original survey was executed by De la Beche and the results were published by him in 1839 on the Old Series one-inch Sheets 31 and 32, and in his classic Report on the Geology of Cornwall, Devon and West Somerset. The district has now been re-surveyed on the six-inch scale by Dr. Flett and Mr. Hill, and the new geological map, on the one-inch scale, to which this memoir refers, is based on that re-survey.

The area in question is divided into two strongly contrasted geological regions by a fairly well marked line which follows a somewhat irregular course from Porthallow on the east to Polurrian on the west. The southern region is composed of a varied series of igneous and metamorphic rocks and is usually referred to in geological literature as the Lizard District although it forms a part of Meneage, an old Cornish expression for the promontory which lies to the south of the Helford River.

The southern region has been surveyed by Dr. Flett. It presents problems of great scientific interest relating to the sequence of the rocks, their relations to one another and the history of the metamorphism.

The northern region has been surveyed by Mr. Hill. It consists mainly of highly folded and comparatively unmetamorphosed sediments; partly of Devonian and partly of pre-Devonian age. In the old maps these sediments were grouped together under the general term, *killas*; but the Devonian rocks have now been delimited and the pre-Devonian rocks have been separated into four distinct groups.

Dr. Flett and Mr. Hill have written the chapters descriptive of the areas which they respectively surveyed, and have collaborated in the preparation of the chapters on Physical Features, the Lizard Boundary, Recent Deposits and Economics. They have also dealt with the very extensive literature relating to the district.

Dr. W. Pollard and Mr. E. G. Radley have made a number of chemical analyses of rocks and minerals for this memoir, and Mr. D. A. MacAlister has furnished notes on some of the mines. The photographic illustrations are from negatives taken by Mr. T. C. Hall, who also prepared the Bibliography. Dr. Flett wishes to acknowledge assistance received from Mr. Clement Reid with reference to the Pliocene Deposits and the raised beaches, and from Professor Bonney who visited the district when the re-survey was nearly completed and discussed the more obscure problems of the geology of the Lizard District with him on the ground.

J. J. H. TEALL,
Director.

Geological Survey Office,
28, *Jermyn Street, London,*
26*th March,* 1912.

(21355—17.) Wt. 16179—40. 500. 9/12. D & S.

List of the Six-inch Geological Maps included in the area. Of these, MS. coloured copies are deposited for public reference in the Library of the Geological Survey and Museum of Practical Geology; or they can be supplied at the cost of drawing and colouring.

Cornwall.

75 NE., SE., by J. B. Hill; lodes by D. A. MacAlister.
76, by J. B. Hill; lodes by D. A. MacAlister.
77, by J. B. Hill; lodes by D. A. MacAlister.
80, by J. B. Hill and J. S. Flett.
81, by J. B. Hill and J. S. Flett.
84, by J. S. Flett.
85, by J. S. Flett.
90, by J. S. Flett.

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CHAPTER I.

INTRODUCTION.

The Sheet described in this Memoir represents an area of 216 square miles, of which about two-fifths, or a little more than 80 square miles, are occupied by land. The northern boundary passes through Constantine and separates this Sheet from the Falmouth and Camborne Sheet (352); the western border traverses Breage, and for a distance of two miles connects it with the district represented on the Land's End map (358). The land area terminates in the Lizard Point, the most southerly portion of Great Britain, and has a coast line 34 miles long facing the waters of the Atlantic and the English Channel. The sea cliffs are often very bold and rugged and exhibit a remarkable variety of geological structures; the only important indentation is the estuary of the Helford River, which affords a good natural harbour.

The district is on the whole an agricultural one, and the only town is Helston (3,088 inhabitants), which is the terminus of a branch of the Great Western Railway. Much good farming land occurs in the northern part of the area and is in a high state of cultivation; towards the south, however, the soil is often poor and there are wide stretches of barren downs. The greatest density of population is found in the north-west around Breage, Porthleven and Helston. At various places on the coast there are small fishing villages, of which the principal are Porthleven, Gunwalloe, Cadgwith, Coverack and Porthallow, but the scarcity of good harbours and the proximity of Falmouth and Newlyn have prevented the establishment of an important fishing industry. Mining has been carried on in the past in several parts of the district, but the country on the southern border of the Constantine granite is not highly mineralized, and of late years the mining activity has almost ceased. From its southerly situation the Lizard peninsula is favoured with a very mild climate; snow seldom falls and the winter frosts are rarely severe. Sub-tropical plants such as palms, yuccas and eucalyptus are grown in many gardens without special protection. The range of temperature also is small, the average winter temperature being 45°, the summer temperature 62°. For this reason the district is very suitable for those suffering from pulmonary complaints. Many summer visitors are also attracted by the beautiful scenery of the Lizard coasts, some parts of which, such as Kynance Cove (Plate I.) are justly famous on this account. Modern hotels have been built at several of the most picturesque places on the coast including Poldhu, Polurrian, Mullion Cove, Housel Bay and

Coverack. The wooded slopes around the Helford River are also of great beauty. Every year there is an increasing influx of summer visitors to the district who find accommodation at the hotels and in lodgings in the villages.

Although the country can hardly be described as flat it does not present any great surface relief. In the northern part of the Sheet the principal geographical feature is the valley occupied by the Helford River and its branches; the tidal estuary extends as far as Gweek and admits the sea for a distance of five miles from the coast or more than half way across the peninsula. From that point the valley is continued westwards and northwards past Helston. The highest land occurs in the central part of the district and extends from Bonython across Goonhilly Downs to Roskruge Beacon, north of St. Keverne; at the Dry Tree (Goonhilly Downs) the altitude is 370 feet, at Roskruge Beacon 378 feet. By far the greater part of the country south of Trelowarren has an altitude of between 200 and 300 feet.

Viewed from a distance, as from the opposite side of Mount's Bay or from the hills above Helston, the southern part of the Lizard area presents the appearance of a platform (Fig. 1) two or three hundred feet above sea level, abruptly terminating in a range of vertical sea-cliffs. To an observer looking northward from Lizard Town the same impression is at once conveyed; the general flatness of the district can also be well perceived from the cliffs near the Black Head where the sky-line of the serpentine downs can be taken in at a glance.

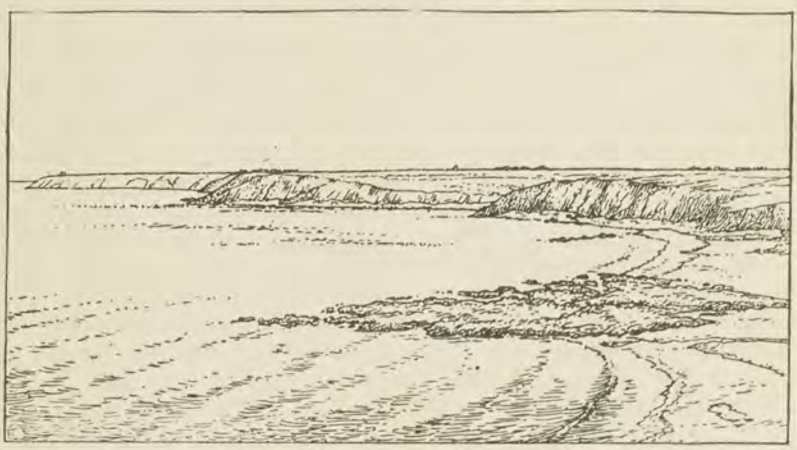

Figure 1.—*The Lizard Platform as seen from the east side of Kennack.*

At the extreme south is Bass Point with Lloyd's Signal Station on the top of the cliff. The conspicuous points on the sky-line are Lizard Town, Grade Church, Ruan Minor and Ruan Major. They stand respectively 238 ft., 248 ft., 212 ft., and 261 ft. above sea-level. The distance from south to north is three miles.

The average height of the plateau is approximately 280 feet and even near the cliffs it does not often sink below 200 feet. All the streams flow in hollows that have been cut in this platform by weathering and the action of running water. There is good evidence to show that at one time the plateau extended north to the granite hills above Constantine, and the broad valley of the Helford River has been for the most part eroded out of a surface that was originally level.

To understand the significance of these facts we must in imagination go back to early Pliocene or Miocene times, when for a very prolonged period this district stood at a somewhat lower level than it does now, and the agencies of denudation, acting very slowly but with irresistible force, planed it down to a flat surface which rose very little above sea-level. Subsequently the land gently sank and the final smoothing of the plateau was achieved by the waves of the Pliocene sea. All the Lizard district was ultimately submerged and the sea extended north to the granite margin beyond Helston. The whole of Cornwall and the south-west of England was involved in these geographical changes; the Land's End district [1], for example, was occupied by a shallow sea above which projected small rocky islets of granite that can still be traced as conical hills rising above the Pliocene platform. The total submergence at this time was about 420 feet, so that Goonhilly Downs and Roskruge Beacon can have been covered by only a few fathoms of water. A similar platform can be traced eastwards into Devon [2], and on the north side of the Bristol Channel is also conspicuous along many parts of the coast [3]. In North Cornwall there is evidence of still higher and older erosion plateaux [4].

The age of this platform is established in the Lizard, as in the Land's End district[5], by its relation to the Pliocene gravels. These rest on its flat surface, near its highest point at Crousa Common, and remains of them are to be found also on Goonhilly Downs at a similar elevation. Their location indicates that they are older than the existing drainage system, to which they bear no relation, and though they are not fossiliferous there is no reason to doubt that they are of marine origin. Most of the stones are vein-quartz derived from the area of Palæozoic killas to the north and there are also quartz-tourmaline rocks such as occur in the country adjacent to the granite. At Polcrebo, three and a half miles north of Helston, (in the Sheet to the north of this one) similar gravels lie on the granite at an elevation of 400 feet, and at St. Erth there is a deposit of fossiliferous sands and clays which are regarded as being of lower Pliocene age.

In practically all parts of the district there is rock very near the surface, covered only by a few feet of soil and subsoil. Hence it is obvious that the platform consists of solid rock and does not owe its flat contours to the deposit of sheets of horizontal sediment. Moreover all the rocks that occur in the district are reduced to the same

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[1] Clement Reid, in 'The Geology of the Land's End District' (*Mem. Geol. Surv.*), 1907, p. 2.

[2] A. J. Jukes-Browne, 'The Age and Origin of the Plateaus around Torquay,' *Quart. Jour. Geol. Soc.*, vol. 63, 1907, p. 106.

[3] A. Strahan, 'The Geology of West Gower' (*Mem. Geol. Surv.*), 1907, p. 1.

[4] G. Barrow, 'The High-level Platforms of Bodmin Moor and their Relation to the Deposits of Stream-Tin and Wolfram,' *Quart. Jour. Geol. Soc.*, vol. 64, 1908, p. 384.

[5] Clement Reid, 'The Geology of the Land's End District' (*Mem. Geol. Surv.*), 1907, p. 71.

plane ; in other words it is an erosion platform and is entirely independent of the geological structure of the country. As a whole it is best preserved in the southern part of the peninsula, especially in the broad stretch of serpentine that lies to the south of Trelowarren. This arises from the fact that the serpentine, though not a hard rock, disintegrates very slowly and in weathering becomes covered with a thin impermeable clayey soil that prevents the downward passage of water and acts as a protective layer. The hornblende schists, the gneisses and even the killas decompose much more readily, and where they occur the original features of the platform are often much disguised by subsequent erosion.

The drainage system, in its main features at any rate, is post-Pliocene, and the streams flow in channels that have been carved out of the level surface of the platform by the action of running water. Nearly one-half of the whole region belongs to the basin of the Helford River and its tributary creeks ; this must have attained its present configuration at a time when the land stood at a higher level than at the present day and by subsequent submergence the sea has flooded the lower parts of the valley. The Gillan Creek, which passes by Manaccan, may be regarded as a branch of the Helford River. On the west side of the Sheet a river flows between Breage and Sithney, the mouth of which forms the harbour of Porthleven. Further east the Cober, which takes its rise in the Carnmenellis granite, flows past Helston in a deep valley to the Loe ; the latter represents a tidal estuary converted into a fresh water lake by the shingle bar that has been piled across its mouth.

Many small streams drain the southern metamorphic area around the Lizard and St. Keverne ; very generally they enter the sea through narrow rocky valleys but in the upper parts they flow in shallow depressions on the flat surface of the plateau. There is a very marked tendency for the valleys to follow natural lines of weakness such as the boundaries of the various classes of rock that form the platform. Examples of this are furnished by the streams at the Lizard, Mullion Cove, Gwenter, Coverack and Porthoustock. The boundary lines between the different formations are often faults which are occupied by broken rock that would be easily eroded. For a similar reason the areas of gneiss in the serpentine are often the site of important valleys, as for example at Kennack, Cadgwith and Poltesco ; the gneiss is always in a much decomposed condition and is the least resistant to weathering of all the rocks of the Lizard district.

The geological formations represented on the map are as follows : —

SEDIMENTARY.

Recent.	Blown sand. Alluvium.
Pleistocene.	Head. Raised Beach.
Pliocene.	Gravels of Crousa Common.
Devonian.	Manaccan Series.
Ordovician.	Veryan Series (quartzite, slate, limestone, chert,&c.).
Ordovician (?).	Portscatho Series. Falmouth Series. Mylor Series.

IGNEOUS.

PERMIAN (?).	Mica Trap or Minette.
CARBONIFEROUS. (intrusive.)	Elvan, or Quartz Porphyry. Granite.
ORDOVICIAN.	Pillow Lavas or Spilites. Greenstone (intrusive). Granophyre (do). Soda Granite (do).

METAMORPHIC ROCKS OF LIZARD SERIES.

Granite and Granite Gneiss.
Dolerite and Epidiorite dykes.
Gabbro and Flaser Gabbro (with Troctolite).
Serpentine.
Hornblende Schist.
Mica Schist, Granulite and Green Schist.

The district represented on this Sheet may be divided into a northern and southern portion, the former consisting essentially of Palæozoic rocks (principally killas or clay-slate with subordinate bands of grit, limestone and conglomerate) while the latter comprises the metamorphic rocks of the Lizard area including hornblende schist, mica schist, serpentine and gabbro. The Lizard boundary, or line of demarcation between these two areas, follows a sinuous course across the peninsula and is not marked by any well-defined geographical feature. At both ends where it emerges to the coast it is a fault but along most of its length the exposures are far from satisfactory and its nature has not been definitely established. It may be noted that hornblende schists and mica schists, not very different from some of those that occur within the Lizard area are found among the Veryan rocks in the neighbourhood of Manaccan ; but the lithological characters of the formations on the two sides of the boundary line are sufficiently distinct. The northern area was mapped by Mr. Hill, the southern by Dr. Flett.

The great mass of serpentine which forms Goonhilly Downs is the central feature of the geology of the Lizard. It covers an area of approximately twenty square miles and is the largest serpentine outcrop in the British Isles. Around it there lies a belt of hornblende schists, mica schists and granulites, which is not everywhere continuous but has been broken through in many places by the erosive action of the sea. These rocks are older than the serpentine which is a great intrusive stock that has risen through the schists. The relations of the two series of rocks are not unlike those of the Land's End granite to the interrupted ring of altered sediments and greenstones that surround it, but the Lizard serpentine has in many places been folded with the hornblende schists, as is best seen along its northern margin. Subsequently the gabbro of St. Keverne burst through the serpentine, and sent many dykes into it ; the gabbro is mainly confined to the east side of the peninsula where it forms a large boss or stock. A great number of basic dykes (dolerite and epidiorite) cut the serpentine and the gabbro ; the majority of these belong to the epoch that followed the injection of the gabbro and preceded that of the gneisses. The latter occur sporadically through the serpentine, some of the individual injections being of considerable size ; the earliest part of the acid intrusions is a curious banded or mixed gneiss produced by the intermingling of a basic magma, presumably that of the basic dykes, with the acid magma of the granite.

The dominant feature of the geology of the northern area is the occurrence of four bands of rock that stretch obliquely across the map in a north-east and east direction. These are the Mylor, Falmouth, Portscatho and Veryan Series, of which the last-named is the youngest and has been determined by means of its fossils to be approximately of Llandeilo or Arenig age. The other groups underlie the Veryan conformably, but their exact age is not definitely known since they have yielded no fossils except radiolaria. Shales and grits prevail throughout the whole succession, but in the Veryan there are thin limestones, radiolarian cherts and quartzites. Volcanic action also broke out in Veryan time and the sea bottom was covered with flows of pillow lava that are well seen on Mullion Island, where they are interbedded with limestone and radiolarian cherts. Some of the intrusive greenstones near Cury probably belong to the same period.

Between these rocks and the Lower Devonian or Manaccan beds there is a great hiatus, for the Devonian rests unconformably on the eroded edges of the older rocks. During the interval the Ordovician and older strata must have been folded, cleaved and metamorphosed, as the pebbles derived from these formations that are found in the Devonian conglomerate were evidently much crushed and altered before they were detached from the parent rock. The appearance of hornblende schist and mica schist in the Veryan series near Manaccan may also be ascribed to these crustal movements. The Devonian is now represented by a detached series of lenticles or outliers between Nare Point on the east and Gunwalloe on the west. Its main ingredients are derived from the Portscatho and Veryan groups, but it also contains fragments of igneous and metamorphic rocks that are not now represented on the Cornish mainland.

At Fletching's Cove Mr. C. D. Sherborn has discovered a fossil of Ludlow age; this locality lies well within the Veryan outcrop, and unless the slate enclosing the fossil has been brought into its present position by faulting it may indicate the existence of an unconformability between the Ordovician and Silurian strata of West Cornwall.

During late-Carboniferous times violent crustal movements again involved this region and the Devonian rocks were cleaved and folded along with the underlying older strata. In all probability the Manaccan beds lie in synclines that were produced by this folding. The injection of the granites in the northern portion of the Sheet followed these disturbances, and they were succeeded by the elvans that occur as dykes in the Mawgan and Breage districts. During the slow cooling of the granitic rocks the tin and copper ores were deposited along lines of fissure. The dykes of mica trap apparently belong to a later period and may possibly be of Permian age.

No evidence is available within the boundaries of this Sheet regarding the geological changes that took place in West Cornwall during Mesozoic time, for the next deposits are the Pliocene gravels of Crousa Common. The great erosion that produced the rock-platform on which the gravels rest must have occupied a considerable period and is probably in part Miocene. The uplift of the Pliocene sea-floor inaugurated a new epoch of erosion, and while the river valleys were being deepened the land must have stood at a higher level than it does at present; since then, however, considerable oscillations have taken place. Before the formation of the Pleistocene beaches the land had sunk and the valleys were occupied by tidal estuaries somewhat more extensive than those of to-day; during the glacial period the loose rubble or 'Head' that often cloaks the sloping top of the cliffs gradually accumulated under rigorous climatic conditions. At that time or somewhat later there must have been an uplift of about fifty feet during which the valley floors were covered by vegetation that has now been submerged below sea level and forms the 'buried forests.'

The raised beach of Pleistocene age is seen in many places along the eastern coast, where it has an elevation of five to twenty feet above high-water mark; the configuration of the coast line at the present time must be very similar to that which obtained during the period of depression when the beach was formed. On the west coast the beach is not often seen, as the cliffs are yielding to the attack of the sea and are receding more rapidly than on the east.

The changes that have taken place in the district since the close of the Glacial Period are comparatively small and include the accumulation of unimportant deposits of alluvium on the floors of the valleys, and of blown sand at different parts of the coast, particularly at Gunwalloe. Many characteristics of the scenery of the country can be ascribed to the manner in which the rocks decompose under the action of the weather. The granite, for example, is covered with rough sandy soil, or 'growan,' and mostly forms upland pastures. The killas of the northern country yields good agricultural land without bold features, especially where there is an admixture of igneous rock or greenstone. The areas occupied by the Veryan beds are often strewn with large blocks of white quartzite. In the Lizard district each of the rock-formations has its own mode of weathering. The serpentine yields a very barren soil composed of yellow ochreous clays and is often covered with rough rusty-coloured stones. Most of it is left uncultivated and is occupied by gorse and a peculiar flora of which the Cornish heath is the best known and most distinctive member. The gabbro of Crousa downs is often deeply rotted and the soils on this formation may be very good; where the rains have washed away the finer material great residual blocks are left that strew the fields and downs in vast numbers. The Lizard hornblende schists weather deeply to a rich red soil, and the granite and gneiss of the Lizard district are so much more readily decomposed than the serpentine that most of the areas in which they occur are smoothly rounded agricultural land in which few outcrops of solid rock can be found.

Literature.

It has been known for a long time that the rocks of the Lizard district differ in many important respects from those of other parts of Cornwall. In his 'Natural History of Cornwall' (1758) Borlase[1] refers to the 'soap rock,' the serpentine and the asbestos that occur near the Lizard, and Pryce also, in the 'Mineralogia Cornubiensis' (1778) mentions incidentally the soap rock and the steatite.

The first twenty years of the nineteenth century were a period of very active geological speculation and research, and during those years the Geological Society of London and the Royal Geological Society of Cornwall were both founded. The earliest publications of both societies contain memoirs on the geology of this district. Dr. J. F. Berger, in 1811, described the results of a brief visit he had made to the Lizard and St. Keverne two years previously; he recognized the existence of gabbro at the latter locality, consisting of felspar and diallage, and made some notes on the distribution of that rock and the serpentine. Much more valuable is the 'Sketch of the Geology of the Lizard District,' which Ashurst Majendie contributed to the first volume of the Transactions of the Royal Geological Society of Cornwall. This is accompanied by a map in which the areas occupied by slate, greenstone, gabbro (described as 'syenite') and serpentine are delineated with an accuracy that proves that the author was acquainted not only with the coast sections but also with the inland geology of the peninsula. In the same volume papers by Sir Humphry Davy and Dr. Paris contain notes on the rocks, minerals, and soils of the Lizard district.

Professor Sedgwick made a tour of Devon and Cornwall in 1819, and the results appeared in two papers that were published in 1821 and 1822. He examined practically the whole coast from Falmouth to the Loe, and gives a vivid account of the impression the intricate rock structures produced on his mind. Though these papers are full of valuable observations, their author evidently recognized the difficulty of the problems presented by the geological phenomena and did not advance any general explanation of the relations which the different formations bore to one another.

Ten years later (1831) appeared Dr. Boase's 'Contributions towards a knowledge of the Geology of Cornwall.' The thirty pages in which he describes his observations on the geology of the area contained within this Sheet are full of interesting notes which show that most of the petrological varieties of the Lizard rocks were known to collectors by this time, and their components determined so far as was possible by the means then in vogue, but the structural geology had as yet received little attention.

In 1839 De la Beche's Report was published; it marks an epoch in the history of the geology of the west of England. The chapters referring to the Lizard and the Helford river basin are among the most interesting in the volume. De la Beche was well acquainted with the country, not only the coast sections but also the inland parts. The first edition of the geological map (Sheets 31 and 32) appeared in the same year, and shows a great advance on Majendie's map of 1818.

In the Lizard district De la Beche recognized the existence of mica schist and hornblende schist. The outcrops of the various

[1] For titles, &c., of the books and papers referred to *see* Appendix, pp. 264–273, under the respective dates.

rock-formations were laid down with great accuracy on the map, but in the report the author declines to commit himself as to the relations between the serpentine and the hornblende schist. The former he declared to be of igneous origin and he conjectures that the disturbances visible in the schist in the coast section at Porthallow may be connected with the intrusion of the serpentine; but there is other evidence that might be interpreted in the opposite sense and the question is left open. The gabbro, on the other hand, is clearly intrusive into the serpentine and there are, both on the east and the west coast, certain granite veins that are intrusive into both of these.

From the map and the descriptions in the memoir it is clear that De la Beche regarded the rocks that were subsequently called the Granulitic Group as partly an igneous series, cutting the serpentine. In this he was in accordance with the older writers generally, including Davy and Boase; but De la Beche makes no reference to the extraordinary banding and gneissose foliation of these rocks. In the map a part of the gneiss series on the west side of Kennack is coloured as hornblende schist, so that the controversy regarding the origin and history of these rocks that was subsequently to be carried on for many years was already foreshadowed by De la Beche's treatment of them in 1839.

One extraordinary error appears on the map; the rocks at Manacle Point are shown as 'greenstone' and a long strip of this formation is laid down extending westwards past Treleague; it is clear from the memoir that De la Beche regarded the gabbro as forming veins or dykes in the dark epidiorites of this quarter, whereas the reverse is really the case.

The district north of the Lizard boundary was coloured and described as part of the 'Grauwacke' group, but De la Beche seems to have regarded the mica schists of the Lizard as distinct from the 'killas.'[1] The outcrop of the Veryan limestone to the north of Porthallow was not laid down on the map though its existence had apparently been known to Rogers as early as 1818. The Nare Point conglomerate, to which Sedgwick had alluded in 1822, and the evidence it furnishes regarding the age of the Lizard schists, are discussed fully in the Report. De la Beche noted the presence in the conglomerate of some varieties of hornblende rock not unlike those of the Lizard, but remarked at the same time that the gabbro and serpentine are not represented; he declined, however, to hazard the assumption that they are consequently of later age than the sedimentary rocks.

Seventy years have elapsed since the publication of De la Beche's Report and subsequent work has confirmed the accuracy of his observations and justified his caution in drawing conclusions. The marginal relations of the serpentine to the gabbro were not cleared up till 1893, although Professor Bonney showed that the serpentine was intrusive into the schists as early as 1877. The sequence of serpentine, gabbro, and gneiss laid down by De la Beche is accepted in this Memoir. The greenstones, however, are now

[1] In subsequent editions of the map, however, a tablet was inserted showing the Lizard mica schists as 'altered Devonian.'

known to have followed the gabbro and not preceded it ; the relative age of the Lizard rocks and the killas to the north of them is still a subject of discussion.

A number of interesting papers of a minor character were published between 1840 and 1850, principally in the Transactions of the Royal Geological Society of Cornwall, bearing on the geology of this district ; of these we may mention specially the contributions of Canon Rogers and the Rev. E. Budge describing various outcrops of serpentine and schist, the gravels of Crousa Downs and the raised beaches. The most important work, however, during the period that followed the issue of De la Beche's Report was that of Charles W. Peach. In 1841 he discovered fossils in the quartzite of Gorran, and conjectured that the quartzite to the south of Helston might be of the same age and might ultimately prove fossiliferous. Full confirmation of this was not obtained till 1869, when he announced that he had found fossils at Nelly's Cove, north of Porthallow. Meanwhile Sir Roderick Murchison, after an examination of Peach's fossils, had definitely recognized the existence of Lower Silurian rocks in this district, ascribing them to the Caradoc. About the time when Murchison became Director General of the Geological Survey the slaty rocks or 'killas' of the Gorran district were for the first time coloured as partly Silurian and partly Devonian, but no alteration seems to have been made in the colours of the Porthallow district at this time, except that a band of Veryan limestone was shown as occurring on the coast about a mile south of Nare Point.

The application of the microscope to the study of Cornish rocks dates approximately from the year 1870, and shortly thereafter the important papers in which J. Arthur Phillips described the petrography of the greenstones began to make their appearance. In 1876 Samuel Allport's account of the rocks around the Land's End granite was issued. A few references to the greenstones near Helston are contained in these papers. The first to attack the problems of Lizard geology by the methods of modern petrology was Professor Bonney (1877) ; from that time onward microscopical investigation was destined to play a large part in the development of Lizard geology. After discussing the serpentine and its relations to the other rocks of the district in 1877, he devoted a second paper to the consideration of the hornblendic and other crystalline schists. A new epoch of extraordinary activity was thus inaugurated, and, as a great part of the subsequent literature was founded on Professor Bonney's interpretation of the rocks and their structures, it is necessary for us to state his conclusions rather fully.

Professor Bonney regarded the serpentine as truly igneous and derived from the decomposition of an olivine rock ; he described it as intrusive into the schists and gneisses, and considered that these latter had already acquired their metamorphic structures before the serpentine was injected. The schists were divided into three groups— the micaceous, the hornblendic, and the granulitic, with an apparent upward succession in the order named. The whole of these were believed to be sedimentary, and the banding in the hornblende schists and the gneisses was referred to original bedding and lamination, with occasional current bedding. The gabbro, which succeeded the serpentine, comprised two distinct types, one of these being the 'older gabbro' or troctolite, the other the later 'gabbro' which forms the greater part of the Crousa Downs mass. In the Coverack district dykes of olivine dolerite cut both varieties of gabbro, and the black dykes of other parts of the coast were interpreted as dolerites in which the hornblende was presumably secondary. Finally he described on the west coast about Kynance and elsewhere certain granitic injections which were of subsequent date to all the other plutonic rocks of the Lizard.

A wealth of lithological detail is to be found in these papers and many important conclusions were drawn from the characters of the rocks. The principal varieties of the serpentine and the gabbro were clearly defined; it was shown that in the serpentine there is a fluxion banding and also a pressure metamorphism. The evidence of deformation in certain types of gabbro did not escape notice and it was clearly established that the metamorphism of the serpentine was anterior to the intrusion of the gabbro, though the close relationship between these two rocks was equally clear. Conversion of pyroxene and olivine to green hornblende was recognized as having taken place on a large scale in the gabbro and black dykes.

In his first paper (1877) Professor Bonney had regarded the mica schists as of Devonian age, following the correlation at that time accepted on the Survey maps, but before the second paper appeared he had seen reason to modify his opinion, and the schists were considered to be Archean, while the age of the plutonic intrusive rocks could not be precisely defined, except that they were later than the schists and gneisses.

From this point onwards it will be advisable to treat of the scientific investigation into the geology of the Lizard district according to the development of opinion on the more abstruse questions raised by Professor Bonney's papers, and not in strict chronological sequence.

The marginal relations of the serpentine to the hornblende schist had been regarded by Sedgwick, De la Beche, and all the older geologists as especially perplexing. Professor Bonney had cut the Gordian knot by enunciating that the serpentine was clearly an intrusive mass that contained many fragments of the schist that had been caught up during the injection process. Subsequent observers found much difficulty in accepting the evidence adduced to prove this; the difficulty arose largely from the fact that the Granulitic Group or Kennack Gneisses, which are known to be intrusive into the serpentine, were not distinguished from the hornblende schists that are older than the ultrabasic rocks.

In 1884 Mr. J. H. Collins published an important paper on the serpentine and associated rocks of Porthallow Cove. He unfortunately reverted to the old idea that the serpentine was stratified (which had been rendered impossible by Professor Bonney's clear recognition of it as an altered lherzolite or olivine rock), but he brought into prominence two points of great interest. The first is that at Porthallow the serpentine and the hornblende schist are folded together, and the second is that between these rocks there are certain transitional varieties, as had been remarked by De la Beche. There are most reliable grounds for both of these assertions, but the sections at Porthallow are so broken by faults that convincing evidence is not easily to be obtained in that locality.

In 1889 Mr. Howard Fox discovered at Pol Cornick, on the west coast (Plate IV.), what is in some respects the best coast section of the junction of serpentine and hornblende schist in the whole Lizard area. He published a brief note on it, and subsequently (in 1893) returned with Dr. Teall to make a full investigation of the rocks and their mutual relations. A joint paper by these two geologists appeared in 1893, accompanied by a very detailed map, and at once placed beyond doubt the existence of a system of folds involving both serpentine and schists. We now know that this is an essential feature of the margin of the serpentine along nearly its whole extent from Pol Cornick north to Mullion Cove and thence east to Porthallow; and where the junctions appear sharp and simple, as at the Lizard and Cadgwith, the folded margin has really been cut out by faults.

At the same time, by study of microscopic sections they confirmed the observations of De la Beche and Collins that there was a passage between serpentine and schist where these two rocks came in contact. In a subsequent part of this memoir it will be shown that though such transitional rocks occur also at Ugo Dour (400 yards north of Pol Cornick), Traboe and Porthallow, they nowhere have any considerable development. They are of importance as establishing that part of the hornblende schist has very close affinities with the serpentine. In the main, however, Professor Bonney's conclusions hold good, and the serpentine and schist must be regarded as essentially distinct from one another.

That the serpentine was intrusive into the hornblende schist, as Professor Bonney maintained, was regarded as unproved by Fox and Teall at this time. As a matter of fact it can hardly be proved at Pol Cornick except by mapping a larger area than they examined. We believe that some of the sections adduced by Professor Bonney are very good evidence in support of his case, especially those on the north-east side of the entrance of the Devil's Frying Pan at Cadgwith and in the quarries at Polbarrow; but the full proof only comes to hand when the structure of the whole area and the general relations of its rocks are taken into consideration.

In 1889 Mr. Howard Fox added a new chapter to the history of the Lizard rocks by his discovery that the reefs lying to the south of the headland consisted of a corrugated igneous gneiss, which was described by Dr. Teall, and is now known as the Man of War Gneiss.

In the years that followed the publication of Professor Bonney's second paper much criticism was directed to his interpretation of the origin and structure of the 'Granulitic Group.' He had advanced the opinion that they were sedimentary gneisses, no doubt largely made up of igneous materials, and that the banding was due to the persistence of bedding and current bedding.

Dr. Teall challenged these conclusions in 1887. After describing as granite and diorite the varieties of rock that are comprised in this series at Pen Voose, he showed that the acid rock must be regarded as intrusive into the other, veining it and including fragments of it. He was inclined to consider the whole 'Granulitic Group' as an igneous complex. In a subsequent paper he proposed to explain by this hypothesis the intricate relations of the acid to the basic portion of the gneiss and of both to the serpentine.

In a paper that appeared in 1888, Mr. Fox and Mr. Somervail showed that in many places the 'Granulitic' rocks were undoubtedly igneous because they had porphyritic structure. General McMahon (1889), recognised the presence of igneous rocks in the complex, classing them as granite and diorite; at the same time he was not certain that part of the series might not be sedimentary. When this paper was read to the Geological Society of London, Professor Bonney announced that he was prepared to admit the igneous origin of a great part of the gneisses in question.

We shall next consider the history of opinion regarding the age of the 'Granulitic Series' or Kennack gneisses, and especially whether they are older than or subsequent to the serpentine. De la Beche thought that in some places they were intrusive into the serpentine, but did not discuss the general problem. Professor Bonney has always maintained that the serpentine is the newer rock. It is evident that Dr. Teall had doubts on this subject in 1893, and was not prepared to commit himself to any definite sequence, though very sceptical about the younger age of the serpentine. In 1887, he had stated that the 'Granulitic' rocks at Pen Voose clearly penetrated the gabbro there; as the gabbro is certainly intrusive into the serpentine in all parts of the Lizard it would appear, *a fortiori*, that the 'Granulitic' rocks were also posterior to the serpentine. The matter was complicated, however, by the existence of granitic and dioritic rocks on the west coast, which Professor Bonney admitted were veins cutting the serpentine but regarded as distinct from his 'Granulitic Group.'

Meanwhile (in 1888), Mr. Somervail had tentatively correlated certain granito-dioritic masses at Pentreath Beach with the 'Granulitic Series' of the east coast, and had interpreted them as intrusions into the serpentine of that locality. In 1890 he very clearly announced the intrusive origin of the whole 'Granulitic Series.' He pointed out that the black dykes cut all the Lizard rocks except these, and seem to have proceeded from them. His argument was weakened, however, by his interpretation of the hornblende schists and the 'Granulitic' gneisses as part of one series, closely connected, the section on the south side of Cadgwith, one of the most puzzling in the Lizard, being taken as evidence of this.

McMahon (1889), admitted that the igneous portion of the 'Granulitic' rocks was in some places intrusive into the serpentine, and he observed that blocks of serpentine had been caught up in it, but in 1891 he accepted Professor Bonney's views on the sequence. In 1896 Professor Bonney reiterated his former opinion.

In 1900 the first of two papers by Mr. Harford J. Lowe on the sequence of the Lizard rocks was published. It is not too much to say that this paper finally settled the age of the much-discussed 'Granulitic' gneisses. He definitely announced that they contain many inclusions of the serpentine, that they truncate the black dykes which cut both serpentine and gabbro, and that in many places the 'Granulitic' series emits veins of banded gneiss that penetrate the serpentine. As all these statements were supported by evidence that can easily be verified on the ground they leave no room for ambiguity on the question.

A few words may be added here on the origin of the banded structure of these gneisses. In 1887 Dr. Teall recognized that they consisted of an acid and a basic portion of which the former veined the latter. He ascribed much of the parallel banding to pressure acting on the rocks after consolidation. Somervail, also in 1887, appealed to differentiation in the magma, and injection of a mixed acid and basic rock. In 1891 Bonney and McMahon suggested that there was intricate injection of an older schistose hornblendic rock by newer granites and diorites, and that the intrusions had softened the included masses by their heat and drawn them out when in a plastic state. Harford Lowe considered that the banding was due to fluxion in a non-homogeneous magma, and showed by many drawings (of a rather diagrammatic character) that this is often the only possible explanation. The phenomena, as will be seen later, are exceedingly complex; no single process will explain them completely, and probably all of those enumerated above have played a part in the development of the foliation and banding.

The study of the foliation of the Lizard rocks has been advanced principally by Bonney, Teall and McMahon. Professor Bonney, since his first contribution to Lizard geology, has consistently maintained that the schists were foliated before the serpentine was intruded, and the serpentine had its fluxion banding and foliation before the injection of the gabbro. Dr. Teall, in his description of the banded gneisses, the gabbro and the black dykes, has appealed rather to dynamic metamorphism, if we use that term as meaning that earth movements had sheared the rocks after they had consolidated; but he has nowhere stated whether in his opinion these movements took place soon after the rocks crystallised or at a later period. McMahon supported Professor Bonney and held that the foliation was often the result of the injection of a highly viscous and partly crystallised magma, and was in fact an 'injection foliation.' Subsequently Professor Bonney and he, in a joint paper, advanced some striking evidence in favour of this hypothesis from the dykes of gabbro in the serpentine at Carrick Luz. After reviewing all the evidence we are of opinion that a satisfactory explanation can be obtained only by means of both the agencies mentioned above. In the plutonic and intrusive rocks of the Lizard there is a foliation intimately connected with the injection of the igneous magma, but it is clear also that earth movements were going on at the same time. The most important fact to bear in mind is that the igneous rocks can be shown to have attained their present metamorphic state as soon as, or very shortly after, they had consolidated.

With the recognition of the Kennack gneisses as a series of intrusions later than the gabbro and the black dykes the way was clear for a definite interpretation of the relation of the Lizard rocks to one another. It seems strange that this was so long deferred, but in 1893 Somervail advanced the hypothesis that all the principal rocks of the district, the hornblende schist, serpentine, gabbro, black dykes and banded gneisses were differentiated from one magma. As he had already arrived at a correct conception of the sequence of these rocks, he may be regarded as the first to solve one of the most fundamental, and at the same time most obscure problems of Lizard geology.

The literature of the northern area will now be sketched. The publications of the earlier observers have already been alluded to. These were followed by extensive researches of Mr. J. H. Collins. In 1881 he assigned the 'killas' of central and west Cornwall to the Devonian, Silurian, Ordovician, and Cambrian formations, all of which he considered to be separated from each other by unconformities. Although his general conclusions as expressed on his sketch map cannot be sustained, he recognized in his publications that the 'killas' of west Cornwall was mainly of Lower Palæozoic age, and placed the Ponsanooth Beds, which to some extent represent the Mylor series, at the base. He likewise correlated the conglomeratic series of Meneage with the Ladock Beds (the latter being, in part at least, equivalent to the Grampound and Probus grits), and assigned them to the Lower Devonian.

Mr. A. Somervail controverted some of Mr. Collins' conclusions, but agreed with him as to the pre-Devonian age of a large part of the 'killas,' some of which extending westward from Gerrans Bay he suggested was Llandeilo.

In 1891 Mr. Ussher published a highly suggestive sketch-map in which he placed the Grampound grits at the base of the series classed as undoubted Devonian, and the killas to the south was represented as (?) Pre-Devonian.

A notable addition to our knowledge of the Palæozoic rocks of this sheet was made by Mr. Fox and Dr. Teall, when they described the pillow lavas of Mullion Island and the shales, limestones, and cherts with which they are associated. At the same time (1893) Dr. G. J. Hinde gave an account of the radiolaria in the cherts, and pointed out that 'the recognizable forms belong to simple generic types which are all represented in Palæozoic strata, and with one exception as low as the Silurian, but that they do not afford any trustworthy indication of the age of the chert in which they occur.'

The subsequent investigations of Mr. Fox and Dr. Hinde have shown that the radiolaria are not confined to the horizon of the pillow lavas, and have demonstrated their existence throughout the entire Ordovician sequence of west Cornwall.

Since the publication of Messrs. Fox and Teall the pillow lavas were recognized by Dr. Prior in certain inland localities across the Meneage peninsula.

In recent years Mr. Upfield Green has been engaged on the study of the Cornish 'killas.' In 1904 he referred the Mylor, Falmouth, and Portscatho groups to the Lower Devonian, the Dartmouth slates representing the upper member and the conglomerate of Meneage, &c. (Manaccan Beds) marking the base of that formation.

The re-survey of west Cornwall was commenced by Mr. Hill in 1897, since which the results of his investigations have appeared in various publications, an outline of which is given in the introductory chapter of the 'Geology of Mevagissey.' The following is a brief summary of his conclusions :—

(*a*) The 'killas' is enormously plicated and faulted, and the repetition of the beds by isoclinal folding is such that the great thickness of the strata given by previous writers was fictitious. He also showed that in addition to these structures wide-spread crush breccias of a regional type were represented.

(*b*) He separated the 'killas' into the Manaccan, Veryan, Portscatho, Falmouth, and Mylor divisions, in descending order as named, of which the first represents the Lower Devonian, and the remainder forms a continuous sequence of the Ordovician.

(*c*) He showed that the deformation of the 'killas' was brought about at two epochs, the first of which was pre-Devonian, and the second, late- or post-Carboniferous. The Devonian formation exhibits in consequence a lesser degree of metamorphism than the Ordovician.

(*d*) He demonstrated the presence of an unconformity between the Lower Devonian and the members of the Ordovician above enumerated. He likewise suggested that an unconformity may exist between Silurian and Ordovician strata in west Cornwall.

(*e*) Following Murchison's determinations of the fossils discovered by Mr. C. W. Peach, he at first referred the Veryan beds to the Caradoc. On his discovery, however, in 1901, of pillow lavas within the Veryan group at Gorran Haven he suggested that its age was Arenig.

(*f*) In 1906 he referred a band of pillow lava at Roskruge to the Devonian. His subsequent field work, however, has shown that it must be included with the Ordovician pillow lavas of the Meneage peninsula.

The relation between the crystalline and metamorphic rocks of the Lizard and the Palæozoic sediments and pillow lavas to the north of them has always been a subject of perplexity. De la Beche (1839) regarded the mica schists of the Lizard series as distinct from the grauwacke or killas, which was then supposed to be Devonian. Professor Bonney (1883) was clearly of opinion that the schists were Archaean. Mr. Collins (1884) believed that at Porthallow the schists might be Lower Silurian, though he recognized the existence of a boundary fault at that locality; but saw no reason why the mica schists at the Lizard might not be Archaean. In 1893 Mr. Howard Fox and Dr. Teall compared the Lizard serpentine and hornblende schists with certain metamorphic crystalline rocks of Norway and north-west Scotland, and Dr. Teall stated that 'he did not think that a determination of the age of the Mullion Island sediments would throw any light on that of the crystalline schists of the Lizard.' In discussing the probable age of the Lizard rocks in 1894, Mr. Somervail summed up in favour of the hypothesis that some of them were intrusive into the Ordovician and hence must be post-Ordovician and pre-Devonian. From the account of the Veryan rocks and their relations to the Lizard series that appears in a later part of this Memoir (Chap. XVIII) it will be seen that this difficult problem is not yet by any means settled.

CHAPTER II.

SYNOPSIS OF THE GEOLOGY.

As the succession of formations in this district is a long one and the structures are remarkably varied, we propose to give a brief synopsis or general sketch of the geology, showing the nature of the problems involved and outlining the evidence from which we have arrived at the conclusions that are set forth in this Memoir. It will be convenient to describe first the metamorphic rocks of the Lizard and St. Keverne country, and thereafter to proceed to the discussion of the rocks of the districts north and south of the Helford River.

The Metamorphic Rocks of the Lizard.

In the Lizard there are both sedimentary and igneous rocks, and while most of them are highly metamorphic, there are others that have undergone little change since they were formed. By far the greater part of the country consists of igneous rocks, some of which were poured out at the surface as lavas and ash beds, while others rose from below and were forced into their present positions while in a molten, or at least a plastic condition. These intrusions exhibit a remarkable variety since they range in composition from ultra-basic masses, like serpentine, to acid granite and gneiss. Earth movements have repeatedly occurred, folding the rocks in a very complicated manner and shearing and crushing them so that their original characters are often obliterated, and we can only infer what they once were from their chemical composition and a knowledge of the changes that are produced in rocks under those conditions. There is also a great deal of faulting, or displacement along lines of fracture, and this makes it often difficult to understand the relations of the masses to one another before the displacement occurred.

The following table shows the principal members of the crystalline metamorphic series of the Lizard peninsula and their sequence or order of succession, the oldest rocks being placed at the bottom of the list.

Granite and Granite Gneiss.
Kennack Gneisses (banded gneisses).
Dolerite and Epidiorite dykes.
Gabbro (with augen gabbro and gabbro schist).
Troctolite.
Serpentine { Bastite serpentine. Tremolite serpentine. Dunite serpentine.
Hornblende schists :—Traboe schists.
Treleague Quartzite.
Man of War Gneisses.
Hornblende Schists :—Landewednack schists.
Old Lizard Head Series { Green schists. Granulites. Mica schists.

Old Lizard Head Series; Mica Schists, Green Schists, and Granulites.—The oldest rocks in the Lizard are presumably the mica schists of Old Lizard Head (Plate II.). These are silvery brownish schists, rich in mica, and were at one time muds and shales that gathered on the sea bottom. With them occur thin bands of quartzite (or granulite) that represent layers of sandy sediment. At Pistil Ogo, between the Lighthouses and Old Lizard Head, the bedding of this series is very well preserved, and one can trace the alternating deposits of sand and mud that were laid down at the earliest period to which we can follow back the history of the Lizard rocks. These mica schists and granulites have been folded by earth movements, and the beds are bent in zig-zag fashion, and piled up in great flat folds on top of one another. They have been intensely heated by the intrusion of two great masses of molten rock into them, first the gneiss of the Man of War rocks and subsequently the serpentine on the north. Hence they show both contact alteration (development of andalusite and sillimanite) and folding or regional metamorphism.

Among the rocks above mentioned there are bands of dark green colour, which, on microscopic examination, prove to be rich in hornblende, chlorite and felspar. Their composition shows that they are igneous, but in the coast sections, where they are well displayed, it is often perfectly clear that they are stratified rocks. From this we infer that they were beds of volcanic ashes that were deposited on the sea floor and mingled with the sediment; in this way we can explain also the frequent transitions between fine hornblendic rocks and quartzose granulites that are obvious in the cliffs between the lifeboat station and the Old Lizard Head. The metamorphism through which they have passed has crumpled them and imparted a highly schistose structure (green schists), at the same time filling them with epidote and other metamorphic minerals.

The mica schists, granulites and green schists of the Old Lizard Head series are best studied in the cliffs about the south-west side of the Lizard Point. They cover also an extensive area between Porthallow and Porthoustock, at a distance of ten miles from the Lizard. Their wide distribution shows that they are really an important part of the Lizard schists. In many places on the north of the serpentine they occur in small patches surrounded by hornblende schists. The same types of rock occur in all these districts in very much the same metamorphic condition and they often contain minerals developed by the heat of intrusive masses (cordierite, andalusite, sillimanite, &c.).

Hornblende Schists; Landewednack Schists.—The remainder of the Lizard Point, including all that part of it which lies east of the Lighthouses and extends to Church Cove, consists of moderately coarse-grained hornblende schists. They are dark green rocks often striped with bands of grey felspar or yellow epidote. No doubt can be entertained as to their igneous origin, for both their mineral and chemical composition are such as occur typically in metamorphic igneous rocks. They present a wonderful uniformity and may be considered as a group of basic intrusive sheets, probably mixed with lavas, bearing in some degree the same relation to the serpentine and gabbro as the

' plateau basalts ' of Skye bear to the large intrusive masses that have risen into them. There is seldom any admixture of sedimentary material in these hornblende schists, but at several places on Pen Olver there are thin intercalations of mica schist which serve to establish the intimate relation between these more coarsely crystalline schists and the thin banded ' green schists ' we have previously mentioned as intercalated in the Old Lizard Head Series.

Similar rocks occur in a broad strip extending from Mullion Cove (Porth Mellin) to Porthallow on the north side of the serpentine (Plate IV.). Many varieties of them can be recognised; some are pale green and full of pyroxene; others yellow with epidote, or dark green from abundant hornblende. In most of them there is a very pronounced banding, which seems to have developed during the metamorphism. Like the mica schists they have undergone profound alteration, for they have been not only crushed and drawn out during the folding, but intensely heated by the great intrusions which they surround. Their original structures have entirely disappeared, and they are among the best examples of hornblende schists that can be found in the British Isles.

Man of War Gneisses.—Subsequent to the formation of the rocks we have described, but before they had attained their present state of metamorphism, a great intrusive mass of liquid rock welled up in that district that lies to the south-west of the Lizard cliffs. It was essentially of acid composition (granite, tonalite, &c.) and forced its way into the older rocks, splitting them apart and sending dykes and veins into them. These apophyses are to be found at Old Lizard Head and in the reefs below Polpeor, where they are represented by compact grey granulites that ramify in the mica schists and green schists. The main mass probably covers a considerable area, but is seen only in the uninhabited islands and dangerous rocks that lie off the Lizard shore (Plate I.). Many blocks of gneiss, swept from these skerries by the waves, occur on the beaches at the Lizard, and are easily recognised as distinct from those of the mainland. They have been greatly metamorphosed, being now hornblendic gneisses with a peculiar wavy or corrugated foliation. A similar character is found in the mica schists, and a study of the junctions of the gneiss and schist leads to the conclusion that the foliation was impressed on both of these rocks after the Man of War granite was injected and had cooled down.

The rest of the metamorphic rocks of the Lizard (with one exception) are igneous and intrusive, that is to say they have all risen from beneath in a state of fusion and, after coming to rest in their present positions (relative to the other rocks), have slowly cooled down. Not one of them was discharged on land surface or on sea bottom as a lava flow. Moreover, though they are very diverse, they are intimately connected together, and must belong to one series, since there are many transitions between them. Probably no great time (in a geological sense) was required for the injection of the whole complex; they include hornblende schist, serpentine, gabbro, dolerite, epidiorite, and several kinds of gneiss.

The Treleague Quartzite.—Before considering these rocks, however, we must describe another sedimentary formation, the Treleague quartzite. It occurs in a narrow strip along the edge of the gabbro to the north of St. Keverne, and is a hard grey quartzose rock in which the original pebbly structure is well preserved. Grey phyllites occur with it, hardly so crystalline as mica schists. The Treleague rocks are very badly exposed, as they nowhere emerge on the coast, and can be examined only in small pits and roadside banks; still it is pretty clear that they are not the same as the Lizard mica schists and granulites, for the latter are found quite close to them and have many characters (in addition to the higher state of metamorphism) that render them perfectly distinct. Now, if the Treleague quartzite belongs to a different series from the Lizard schists, there is probably an unconformity between them, and a break must be introduced somewhere in the succession of the Lizard rocks. It seems probable that there are two kinds of hornblende schists, one connected intimately with the green schists and mica schists of the Old Lizard Head group, and the other representing the basic intrusions that immediately preceded the serpentine.

Traboe Hornblende Schists.—In many places on the edge of the serpentine there is a coarse gnarled hornblende schist that has sometimes the characters of a crushed gabbro. It is abundant, for example, at Traboe, and occurs also near Mullion and at Predannack. This schist sometimes exhibits transitions to the serpentine; and at Pol Cornick and the south side of Predannack it is folded repeatedly with the margin of the ultrabasic intrusion. It represents the coarse dolerites or gabbros that immediately preceded the great basic plutonic intrusions that form the central feature of the geology of the district.

Serpentine.—The serpentine of the Lizard is its most famous rock, not only because it has long been used for ornamental purposes, but also because it is the only large serpentine mass in England. It presents much variety in its mineral characters and external appearance. The broad flat downs that spread over most of the interior of the peninsula south of Trelowarren are almost all on serpentine; and their barren heathery surfaces, dotted here and there with pools of stagnant water, are among the most characteristic types of Lizard scenery. The outlines of the mass are more or less circular, though its actual boundaries are not seen except on the north, and parts of the west and south sides. In the east and south-east the sea has eroded away the girdle of schists that once encircled the serpentine. The northern margin is very complex as there are many infolded patches of coarse hornblende schist; at Cadgwith and near the Lizard the junctions are well defined, but prove on inspection to be due to faults that apparently run nearly parallel to the original edge. The general shape of the serpentine mass so closely resembles that of the great Cornish granites in the country north of Helston as to suggest at once that this also is a great laccolite or intrusive stock.

In the serpentine outcrop there are certain zones or belts that have a rudely concentric arrangement (Plate IV.). The central and largest portion consists of a coarsely crystalline rock with large shining plates of enstatite or bastite. This is the common rock of

Ruan Minor, Goonhilly Downs, the shores of Kennack, and the cliffs about Coverack. Traced outwards, this merges gradually into a streaky, banded, rather fissile rock, usually fine-grained and not rarely schistose. In this variety the large bastite plates are scarce, but there is much pale hornblende or tremolite, often visible as light green spots. It is very common along the northern margin of the serpentine, about Traboe, and extends also in a broad strip south from Mullion, over Predannack Downs, to Kynance; smaller areas occur on the south and south-east edges of the serpentine, at the Lizard, and Cadgwith.

Near the junction with the hornblende schist another type of serpentine may be found, very compact, with a lustrous hollow fracture rather like a piece of dark green glass. It is often traversed by many fine satiny veins, and, though sometimes streaked with pale green, is not a handsome or ornamental stone. This variety occurs only at the actual margin or within a very short distance of it, and is not uncommon about Traboe and Trelowarren woods, though found also in a broader or narrower zone all the way round from Porthallow to Pol Cornick. The small outlying patches of serpentine to the north of the main mass are often of this type. It has been observed also at two places south of Cadgwith, but only in immediate contact with the hornblende schist.

The zoned structure is clear evidence that the serpentine is an intrusive stock that welled up and forced outwards the surrounding schists. The fine 'flinty-looking' serpentine was the earliest, and the coarse bastite serpentine was the last portion of the intrusion.

Gabbro.—Vast numbers of gabbro dykes from a few inches to many yards in width are to be found in the serpentine (Plate VIII.). They are least common on the west coast, but at Coverack and the east side of Kennack a dozen of them may often be seen in every little cove. The largest is that which forms the promontory of Carrick Luz. Their distribution proves that they have proceeded from the gabbro mass that covers a wide area in the St. Keverne district, extending from Coverack north to Porthoustock, and from Trelan east to the Manacle rocks. The gabbro is a coarse aggregate of grey plagioclase felspar, greenish augite, and hornblende. Many specimens of it show a flaser structure, that is to say, the component minerals have been crushed and rolled out in a definite direction, but other parts are quite massive or normal igneous rocks.

On the shore at Coverack harbour and also at the south side of that village there is a distinct variety of gabbro, known as troctolite. It consists of olivine and plagioclase felspar, and is intrusive into the serpentine, but must have preceded the ordinary gabbro, which emits veins that cut the troctolite in many places.

Basic Dykes.—When the gabbro had cooled down it was followed by a renewed injection of basic material that took the form of narrow black dykes filling nearly vertical fissures (Plate X.). They are exceedingly abundant in the gabbro at Manacle Point (Fig. 3) and occur also in great numbers in the serpentine about Coverack and Kennack. Some of them are very fresh olivine dolerites; others are much decomposed, and many have been converted by pressure into epidiorites and hornblende schists.

Kennack Gneisses.—As the period of injection of the black dykes was drawing to a close an acid magma made its appearance. At first it is seen only as thin strings of reddish granitic material in the dark basic dykes (Fig. 7). Some intrusions of this type are known on both sides of Kennack Cove. This was followed by an uprush of mixed material, partly basic, partly acid, and only imperfectly commingled, so that banded rocks were formed showing alternate stripes of lighter and darker colours, that had been flowing along side by side when the intrusion came to rest (Figs. 9 and 10). In this heterogeneous banded gneiss there are blocks of the older basic rocks that had consolidated before the acid material arrived; these were heated, softened, drawn out and partly absorbed as they were carried forward. Finally a red granite was forced upwards; it veined the banded rock in all directions (Fig. 8), and was ultimately intruded in sufficient quantity to form the large laccolitic masses of pink and grey gneiss that occur in the serpentine in several places. The banded gneisses now lie on the borders of the larger granite gneiss intrusions, and occur in large numbers as dykes, sills, and bosses in the serpentine. The red granite and granite gneiss were the final intrusions, and brought the history of the Lizard eruptives to an end.

The Lizard Metamorphism.

In any account of the geology of the Lizard district, however brief, it is necessary to consider the phenomena of the metamorphism, which are perhaps even more interesting than the structure of the peninsula and the sequence of its rocks. It is believed that the crystalline schists and gneisses of many parts of Great Britain were all at one time normal sediments and granites, &c., and that the region in which they occur was involved in earth movements which transformed all the rocks simultaneously into metamorphic types. Theories of this kind are held, for example, to explain satisfactorily the origin of the schists of the north-east Highlands of Scotland. In the Lizard, however, they prove quite insufficient, for it is perfectly clear that the rocks were not all foliated at the same time, or by one great epoch of movement, but that the metamorphism was going on hand in hand with the intrusion of the successive members of the complex.

As an instance of this we may take the case of the serpentine. This has a well-marked fluxion banding, such as is common in rocks of its class, with alternating streaks rich in pyroxene and in olivine (Plate V., Fig. 1). The fluxion banding near the edge of the mass is parallel to its junction with the older rocks. The serpentine is also foliated, and its larger crystals are often crushed, dragged out, and altered in their mineral characters by the action of powerful pressures. The flow-banding and the foliation are parallel to one another; in fact they are so intimately connected that they seem to be parts of one phenomenon, and must be closely allied in their origin. This leads us to conjecture that the rock was forced upwards in a plastic state under severe pressures, and that the foliation was produced as the injection went on, being really an '*injection foliation.*'

Confirmatory evidence of the most satisfactory kind can readily be obtained. Thus we can prove that the serpentine had acquired its foliated structure before the rock had cooled down. Many gabbro veins, often very coarsely crystalline, intersect the serpentine; they cut across the foliation but are not affected by it. As no great pause can have elapsed between the crystallisation of the serpentine and the injection of the gabbro veins, it is clear that the foliation in the former rock was produced during or immediately after its consolidation.

Furthermore, we can show that the margins of the serpentine intrusion have been folded in a very complex manner with the hornblende schists that surround it. This folding implies the operation of pressure and earth movements. Now the folds are cut across by the coarse gabbro veins, and the folding certainly took place before these veins were introduced. Hence powerful earth movements affected the serpentine during its consolidation and cooling.

In the gabbro the same phenomena are repeated, and the dykes of this rock that traverse the serpentine (Plate VIII.) furnish some of the most beautiful illustrations of injection foliation that could be desired. The great dyke of Carrick Luz, for example, is foliated parallel to its length, but cuts the foliation of the serpentine almost at right angles. In this neighbourhood there are many smaller dykes with the same characters; they run in all directions, but they are foliated lengthwise, and when they bend or branch the foliation also is deflected. These gabbro veins are not folded, but on the margins of some of them the serpentine is crushed for a distance of a few inches, and this proves that the walls of the dyke were pressed against the gabbro at a time when it was solid, though softer and more easily broken down than the older rocks around it.

There is little fluxion banding in the gabbro, but in the banded gneisses both fluxion banding and injection foliation reach their highest development. The dark green basic and red acid bands of these gneisses give them a characteristic striping; they are nearly all foliated and the banding and foliation are closely accordant. Where a sill of gneiss gives off a vein the foliation and fluxion take a new direction parallel to the length of the minor intrusion, and where an obstacle has deflected the flow of the gneiss the bands curve round it like the foam streaks on the surface of a brook. That the rock was solid and often not very plastic before the injection movements ceased is proved by the manner in which the smaller inclusions of serpentine in the gneiss have been squeezed out to form pale tremolite chlorite schists.

Another distinctive and unusual feature of the metamorphism of the Lizard intrusives is its excessive variability. Thus some parts of the serpentine are quite massive; other parts are schistose rocks consisting of tremolite and olivine. Some of the gabbro and black dykes are so little sheared or altered that they might be Tertiary eruptive rocks (Plate IX.), while other portions are squeezed out into gabbro schists and fine hornblende schists.

In the banded gneisses, while the mass of the rock is highly metamorphic, there are late acid veins that show no foliation.

An examination of the dykes of gabbro and dolerite throws a good deal of light on this problem. The foliation has nothing to do with the relative age of the rocks; it is not the oldest rocks which are foliated while the later intrusions are of normal structure. Thus for example, at Coverack highly foliated dykes of gabbro schist cut through massive troctolite, which in turn cuts banded serpentine; and the dykes of gabbro schist are themselves traversed by perfectly unsheared olivine dolerites. At Kennack dolerite, gabbro, and serpentine that are nearly massive are cut by veins and sills of intensely foliated gneiss. Nor does the foliation depend in any way on the locality. At Coverack there are dykes of perfectly normal gabbro (both fine and coarse), and dykes of gabbro schist within a few yards of one another (Fig. 2).

The dyke rocks that have the structure of ordinary basic igneous rocks must have been injected in a thoroughly liquid state, and must have cooled down and solidified without being affected by later movements. The schistose dykes, on the contrary, must have been modified by pressure either during or immediately after their consolidation. There were epochs of rest when the rocks crystallised as dolerite and gabbro, and epochs of pressure and movement when they were transformed into schists. Once a dyke had cooled down below a certain point its rigidity and crushing strength were greatly increased, and subsequent pressures were not likely to give rise to foliation in it. Rocks, on the other hand, that though crystallised were still hot, became readily foliated. We know from experiment that crystals at high temperatures are much more plastic than at low temperatures. After the whole intrusive complex had cooled down many important faults have rent it and produced great displacements, but there was no further manufacture of schists and gneisses except locally and on a small scale.

The intrusive rocks of the Lizard were injected during a period of earth pressure, and many of them were foliated before they had cooled down. In the Tertiary eruptive rocks of Skye we have an example of great basic and acid intrusions that have many points of resemblance to the Lizard rocks; but they are everywhere of normal igneous structure; they solidified and cooled under the uniform weight of the superincumbent strata during an epoch of comparative rest. In many parts of the Scottish Highlands we have basic intrusions that are foliated throughout in a similar manner to the sedimentary rocks around them; these, we believe, consolidated as normal igneous rocks and subsequently were involved in folding and pressure that metamorphosed the whole assemblage simultaneously. Perhaps the Man of War gneisses of the Lizard belong to this type, but so much movement has gone on since these rocks attained their present state that it is not easy to make certain. The serpentine, gabbro, black dykes, and gneisses of the Lizard crystallised under conditions of stress and folding. Moreover, the stresses were not continuous but intermittent, and when the pressures were renewed it was always the weakest part of the complex that gave way. No factor appears to be more important in determining the strength of a rock than its temperature; and the local variations in the intensity of metamorphism in the different members of the complex depend principally on whether the rocks in question had cooled down or were still hot when the increase in pressure supervened.

The Killas.

The formations that occupy the northern area are mainly killas (or clay-slate) which has been subjected to much deformation by earth stresses of at least two geological periods, by which the various rock bands have been folded, contorted, cleaved, brecciated, and fractured. Nevertheless it has been found possible to divide the killas into well marked stratigraphical groups varying in general lithological type, and notwithstanding the dearth of organic remains and the absence of rock sections over much of the cultivated areas, the demarcation of these rock bands has been accomplished with sufficient accuracy to bring out the main tectonic features of the district.

As the extreme plication over the area renders the dips of the outcropping strata of no value for purposes of stratigraphy, the thickness of the various rock bands cannot be estimated, but there can be little doubt that it bears but a small proportion to the width of their outcrops even when the individual strata appear to incline at high angles. For the same reason a clue to the general order of succession must be sought in other data than those of hade, as the folding very frequently results in the apparent superposition of more ancient on younger strata.

The four lithological divisions enumerated below represent the older Palæozoic strata, and succeed one another from north to south in the order named:—

Mylor Series.
Falmouth Series.
Portscatho Series.
Veryan Series.

A fifth, the Manaccan Series, which represents the newer Palæozoic, forms outliers confined to the southern part of the killas area. The lithological distinctions of the various groups are as follows:—

Mylor Series.—The killas of this group consists of blue argillaceous and fine textured sandy beds, some of the latter being very siliceous and approaching quartzite in character, but the distinguishing feature is the banding, due to very fine interlaminations of quartzose and argillaceous seams, or at other times to the alternation of different types of argillaceous material, varying in colour. While this characteristic banding is almost universally present in the Mylor group it is not confined to that division, but in the other members of the sequence it is of subordinate importance and is usually absent.

Falmouth Series.—This division comprises both argillaceous and fine sandy beds, the marked characteristic of which is their proneness to decomposition, and their bright buff and brown colours with sometimes pale greenish hues. With these are intermixed the normal blue killas similar to that of the adjacent Mylor and Portscatho groups. In the Sheet to the north (352) this division includes a well marked zone of purple and green slate, which in this area is usually absent or but feebly represented.

Portscatho Series.—This group consists of blue and grey clay-slates divided by more solid bands ranging from sandy silts to fairly strong grits. The coarser beds include much clastic mica, but largely consist of quartz grains with subordinate felspar; the latter, however, is often very abundant towards the margin of the series that is adjacent to the Veryan group.

Veryan Series.—This is a more heterogeneous group, for in addition to sandy and argillaceous members not markedly different from the Portscatho division, there is calcareous material, not only diffused through the killas, but occasionally concentrated as limestones, together with a marked development of chert beds and quartzite, while its igneous rocks are equally characteristic. Moreover, the sandy members of this division contain abundance of felspar which also distinguishes some of the quartzites. As will be seen later, the deformation of this division has resulted in various stages of metamorphism, so that besides the normal killas some of its members are now represented by phyllites, as well as by quartzose schists and mica schists.

Manaccan Series.—This group consists of coarse conglomerate, sandstone, and clay-slate, the two latter being frequently calcareous. The material of the conglomerate is largely derived from the Portscatho and Veryan rocks, among the derivatives from the latter, fragments of quartzite, chert, and pillow lava being especially conspicuous. The sandstones are characterised by an abundance of felspar, and the conglomerate includes fragments of granite and gneissose rocks, and various types of schist, most of which represent rocks not known in Cornwall.

Geological Age of the Palæozoic Divisions.

The four members of the Lower Palæozoics form a continuous sequence. Their marginal features present, however, no sharp indications of lithological change, and the different members grade into one another by a natural transition. Although the chert beds which frequently contain radiolaria specially characterise the Veryan group, they are likewise represented, but to a subordinate degree, in the other members of the Lower Palæozoic sequence. The only series that has hitherto yielded other organic remains in this area is the Veryan group, and these only in rare instances. Such fossils however as have been obtained clearly point to their Ordovician age, but beyond this broad generalisation little further can be safely asserted. The quartzite in this district has only in one instance yielded fossils[1], but this band where it occupies a corresponding horizon in the Gorran and Veryan areas, is fossiliferous, and was formerly supposed to be of Caradoc age, but palæontologists have latterly assigned a lower horizon to these beds. When it is considered that the Veryan beds are characterised by pillow lavas, associated with radiolarian cherts,

(1) Mr. J. H. Collins found *Orthis* (Lower Silurian) in some of the blocks removed for road making. See *Trans. Roy. Geol. Soc. Corn.*, vol. x., p. 51.

that have such a marked resemblance to a similar association in the south of Scotland at Girvan[1], that are known to be of Arenig age, it would perhaps be safer, in view of the unsatisfactory evidence at our disposal in Cornwall, to assign these rocks, at any rate, provisionally, to the Arenig period. The order of succession of the Lower Palæozoic sequence can be ascertained in this area only by the relations of the overlying Manaccan Series that represent the basal beds of the Lower Devonian. The fact that the conglomerate is mainly lying on the Veryan group, that it is more rarely in contact with the Portscatho group, that it is in only one instance associated with the Falmouth division (where it may be the result of faulting), and has never been found in contact with the Mylor group, is probably attributable to the fact that pre-Devonian denudation had only exposed the upper members of the sequence, which therefore is descending from the Veryan to the Mylor groups. It must be confessed that while the balance of evidence at our disposal favours this reading of the succession, it is very far from being conclusive; and until it is confirmed by palæontological evidence we are altogether unable to form a conclusion as to the extent of either the pre-Devonian folding or the pre-Devonian denudation.

We may now turn to the consideration of the Newer Palæozoic as represented by the Manaccan Series and to the evidence in support of its Lower Devonian age. An examination of the conglomerate shows that the detritus from the Veryan and Portscatho groups was in practically the same condition as it exhibits to-day, when the conglomerate was laid down. Not only were the rocks cleaved and brecciated, but the quartz veining which traverses them was also developed. The included quartzite boulders are of precisely similar type to the bands that are now seen in the Ordovician strata.

Between the deposition of the Veryan Series and their pre-Devonian denudation there must have been an enormous interval of time. In that period they gradually subsided and a vast pile of strata must have accumulated upon them. The thickness of the overlying column cannot be estimated, but it may have been thousands of feet, as only deeply buried strata could have been seriously affected by the crustal movements: all that immense pile must have been upheaved and removed before the deposition of the conglomerate.

In this part of Cornwall only plant remains and parts of brachiopods have been found in the Manaccan Series. Its Devonian age, however, is demonstrated in the area to the north where rocks with a similar composition lie at the base of the Devonian.

Structures of the Killas.

The Palæozoic sediments of West Cornwall have been modified by crustal compression in at least two geological periods, the earlier in pre-Devonian times and the later at the close of the Carboniferous. The metamorphism thus effected compressed the

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(1) 'Summary of Progress of Geological Survey for 1901,' pp. 17–18.

sandy and argillaceous deposits and superinduced secondary structures, principally cleavage. As the later stresses were probably at least as powerful as those of pre-Devonian age they have had the effect of largely masking or obliterating the earlier structures in the Ordovican killas, but in spite of this we can to some extent disentangle the two sets of structures. We necessarily know far less of the pre-Devonian metamorphism than we do of that brought about by the Carboniferous movements, this being the last epoch of powerful folding in the West of England. The pre-Devonian cleavage was in large measure effaced and replaced by another. Doubtless in parts of the area where the later stresses were less intense the earlier structures have been partially preserved, but owing to the complexity of the post-Carboniferous structures we have no means of separating the one from the other. The brief description which follows refers in the main to the late-Carboniferous movements. It must be borne in mind that plication, cleavage, and fracture have been brought about by these stresses in no strictly definite order, but that they are closely interrelated.

Isoclinal Folding.—Although a cursory examination of the killas would suggest that the slaty cleavage was the dominant structure, this is more apparent than real, owing not only to the ease with which the fissility can be detected, but also to its masking effect on the plication, especially in argillaceous strata. The folding being mainly of the isoclinal type, in which both limbs have the same direction, its existence can only be detected when the crests of the isoclines happen to be exposed at the surface. A critical examination of the coast sections, especially where sandy and argillaceous beds closely alternate, shows this type of plication to be universal over the district, and it is evident that the dips can only be regarded as the inclination of folded limbs and for stratigraphical calculations must be absolutely neglected. Normal anticlines and synclines are also occasionally exhibited, and where this is the case the evidence of folding in the coast sections is conspicuous. The isoclines are of small amplitude and readily resolved themselves into faults; it is evident that the killas found relief from the stresses in disruption, and it is probable that the pre-existing deformation contributed to this result. Thus, while deep folds are apparently absent in the Ordovician of West Cornwall, they have been shown to be prevalent in the Cornish Devonian strata which have experienced only one epoch of deformation.

Cleavage.—The cleavage planes have been among the last mechanical changes effected by the strains, and traverse the strata independent of the stratification and to some extent of the folding; although bearing no relation to the original bedding they show a marked tendency to lie parallel with the axial planes of the folds. In this area the slates are mostly of heterogeneous composition, and they have, moreover, been subjected to two epochs of disturbance, so that slate of commercial value is rare and does not appear ever to have been successfully wrought.

In the highly argillaceous beds the cleavage is much more perfect than in sandy strata, which, in fact, are sometimes almost uncleaved; in passing from fine-grained to coarser beds the cleavage often changes its direction.

Secondary Cleavage, Overfolds, and Shear Structures.—The movements have often produced a succession of small slips across the cleavage planes setting up a secondary or slip-cleavage which may be locally more conspicuous than the primary set. When the folding has reached its maximum, fractures arise, severing the arches of the folds. They allow one part of the mass to override its neighbour so that the rock forms a series of segments bounded by minature faults and thrusts. While the beds have been thus modified on the large scale interstitial movements have taken place on a small scale in the bands themselves so that the individual laminæ have been minutely folded with tiny cleavage planes and small thrusts severing the crests of the folds.

Pseudo-Conglomerates and Breccias.—The deformation of the killas has set up a wide-spread brecciation that has in this area affected a considerable tract of country and materially contributed to the complexity of the problems to be unravelled. This particular type of deformation is met with in all the members of the Lower Palæozoic sequence, but is represented on the most extensive scale in the Veryan rocks, both sedimentary and igneous. The crush-breccias were evolved in pre-Devonian times although subsequent to the early cleavage. They are represented in the fragments incorporated in the basal Devonian conglomerate, but the Devonian rocks are not similarly crushed. The breccias present various types apart from the nature of the rock fragments; while some bands consist of fragmental material throughout, in others the rock acts as a matrix in which lenticles are enclosed. There is every variation in the proportion of the matrix to the enclosures, and where the former sufficiently preponderates over the latter, the rock automatically passes out of the category of crush-breccias. While the bulk of the breccias consists of angular or sub-angular fragments, in others the material has been rolled out and closely simulates the products of erosion. In fact there is often the greatest difficulty in distinguishing the Ordovician breccias from the Devonian conglomerates, and, as the two sets of rocks are often closely adjacent, considerable caution has to be exercised, more especially in inland areas where the sections are poor. These structures will be further referred to in the chapters dealing with the local stratigraphy.

Fractures.—Although major faults are rare in the area, and few are sufficiently important to be depicted upon the map, yet the whole district is simply permeated with fractures which have profound effects on the tectonics of the region. Plication and fracture have gone hand in hand. The stresses have often been so severe that no part of the killas has escaped them although some zones have experienced more deformation than others. An examination of the coast shows that faults often occur every few yards, both parallel to the strike and in oblique directions, and reversed faults are frequently just as numerous as normal dislocations. Although these fractures are too closely disposed to show on a small scale map, and, moreover, have individually but a very small displacement, if they were seen on ground plan the killas belt would present the appearance of a huge mosaic. The whole rock-mass is made up of irregular segments that may be compared to a regional breccia, and the divisions between the segments represent fractures of such slight displacement that the general dip is not seriously affected. Moreover, the individual segments are themselves full of disturbance, and minor thrust planes are almost everywhere prevalent, while the crush-breccias, previously alluded to, are further manifestations of local dislocation and crushing. But the system of rock-fractures so intimately penetrated the killas that it is frequently to be detected only under the microscope where the rock in the field shows little or no evidence of its occurrence. It cannot be doubted that the enormous reduplication of the strata is not the result of isoclinal folding alone, but the slicing and thrusting of the killas has largely contributed to this effect. While the greater proportion of these small faults were the result of the Carboniferous movements others must represent the pre-Devonian fractures. The absence of major thrusts is easily understood when the condition of the killas has been recognised. Being extensively fractured, it was nowhere sufficiently solid to retain its coherence under lateral stress, and instead of finding relief by moving forward along major thrust planes involving great lateral displacement, it has responded to the stresses by an incipient but extensive system of thrusts that have in the aggregate yielded analogous results.

Relation of Cleavage to Bedding.—Notwithstanding the cleavage the original bedding is almost everywhere apparent. Besides the deflection of cleavage in traversing beds of diverse material, to which allusion has already been made, there is a general tendency for the cleavage to cross the bedding somewhat obliquely. That direction, however, does not bear a constant relation to the bedding planes, for as the cleavage and folding have been brought about by the same agencies, we see every variation depending on the character and curvature of the fold, so that the cleavage traverses the stratification at different angles over portions of the same fold. Although the cleavage often crosses the bedding at a high angle, there is a general tendency for the beds to be thrown into a set of isoclinal folds with a uniform hade, and for the cleavage to cross somewhat obliquely at a low angle.

Schistose Structures.—When the killas was subjected to thermal metamorphism by the irruption of the Carboniferous granites, the mineralisation set up resulted in the production of mica schists. In this case the micaceous and knotted schists are the result of a two-fold metamorphism, the killas having first been deformed by the stresses, and shear planes set up in the rock, and subsequently the mineral growth from thermal metamorphism has been built up on the sheared killas and has perpetuated the pre-existing structures. There are also schists and phyllites brought about by the pre-Devonian stresses and therefore primarily the result of dynamic metamorphism, although there are grounds for the assumption that thermal action was also present and materially contributed to this result. The latter occur in the Veryan Series, and the former in the Mylor Series, and they will be more particularly described in the chapters devoted to those groups.

Direction of Stress.—In spite of much disturbance and many local deflections in the dip of the isoclines, and of the cleavage, the general hade of both folding and cleavage inclines approximately south-east or south-south-east, and there can be little doubt that the Carboniferous stresses emanated from that direction.

Strike.—In this area the rock groups have trends varying from east and west to north-east and south-west, and their curvature cuts obliquely the folding axes and the cleavage strikes. There is very little discordance in strike between the Devonian and the older Palæozoic groups. We know, however, that while the former have only experienced the late Carboniferous movements, the Ordovician killas was also deformed by the pre-Devonian stresses. Whereas the strike of the Devonian rocks therefore has been determined by the later movements only, that of the Ordovician has resulted from the combined effects of two periods of stress. As the earlier deformation has been largely masked by the Carboniferous movements it is not easy to determine the direction of the older strike, but such evidence as remains, and more especially that of the quartzite bands, which will be referred to in the sequel, indicates a trend that varies from north to north-west.

In South Wales the Ordovician and Silurian rocks have likewise experienced both sets of movements, and their strike is approximately east and west, in accord with the Old Red Sandstone and Carboniferous bands of that region. In Wales, moreover, the earlier movements were in a contrary direction to the later, and if these conditions extended to Cornwall the pre-Devonian stresses were towards the Lizard rocks. The great zone of breccias therefore in the Ordovician belt flanking the Lizard group is probably the result of the resistance offered by the latter to those earlier stresses.

Igneous Rocks.

The igneous rocks associated with the 'killas' include both volcanics and intrusives. The former consist of pillow lavas and tuffs, while the latter are represented by hornblende schist, greenstone, granite, elvan, and mica trap. With the exception of the three last named all these rocks have been involved in the stresses that have deformed the sediments, while the granite and elvans closely followed the post-Carboniferous movements, and the mica traps are possibly of still later age.

The greenstones are represented in the north-west corner of the Sheet along the horizons of Helston and Porthleven. They consist of epidiorite sills that have been intruded into the Mylor Series, and although no original augite remains they show very little foliation.

The hornblende schist occupies a belt immediately south of Manaccan. This rock is practically sheared throughout, due probably to its intrusion in the Veryan Series during a pre-Devonian epoch of stress, and to its being foliated before cooling. Subsequent to its consolidation it was extensively brecciated.

The pillow lavas are found in the Veryan Series in a tract extending from Mullion Island to Porthallow. With these lavas are some sills the intrusive character of which is most clearly brought out in the neighbourhood of Cury, where they have effected contact action on the sediments. The tuffs contain such a small proportion of igneous material that their detection can only be accomplished by the use of the microscope. The pillow lavas of the mainland are lying in the zone of brecciation already referred to, and are often much shattered, but their original igneous structures are exceptionally well preserved.

Granites and Elvans.—The Carboniferous granite has been intruded into the Mylor Series and is represented on the horizon of Constantine by the southern border of the Carnmenellis intrusion, and at Breage by the eastern margin of the Godolphin granite. These masses have effected much contact alteration on the killas, and it is within that aureole of metamorphism that the tin and copper lodes mainly occur.

The elvans represent the dyke phase of those granites and are principally granite porphyries, micro-granites, or felsites. In this area they have a north-east and south-west direction, and although far from numerous are found in all the members of the Lower Palæozoic sequence.

Mica Traps.—The mica traps consist of small sills mainly restricted to the easterly portion of the Helford Basin, where they have been intruded into the Portscatho Series and have effected a limited amount of contact alteration. To the east of Nare Point a dyke of this class cuts the Devonian conglomerate.

Tertiary and Recent.—With the close of the Carboniferous period the rock-building of the area had been practically completed. The Pleistocene beaches are restricted to mere shreds along the coastline, and the alluvium lining the valley floors is meagre in amount.

CHAPTER III.

SEDIMENTARY SCHISTS OF THE LIZARD.

THE OLD LIZARD HEAD SERIES.

In this group we place the sedimentary schists of the Lizard area (with the exception of the Treleague quartzite) and the fine green chloritic and hornblendic schists which invariably accompany them. It is sufficiently clear from their nature, state of metamorphism, and relations to the other rocks that this is the oldest portion of the Lizard complex. The main hornblende schists, the older granites, serpentine and gabbro are intrusive into the Old Lizard Head Series[1], and have produced considerable contact alteration in them. The best exposures are found in the cliffs adjacent to Old Lizard Head (Plate II.) at the south-west corner of the Lizard Point, but the largest area occupied by the rocks of this series lies in the extreme north-east part of the district, around Porthallow, Tregaminion, and Trenance. Small outcrops of mica schist and felspathic granulite occur at many places, as for example at Pen Olver (where they were discovered by Mr. Howard Fox), at Gwealeath and other places around Cury Cross Lanes, at Tregarne Mill, Mill Mehal, and Polkernogo, among the hornblende schists on the north side of the gabbro.

The occurrence of mica schists in the Lizard peninsula was noted by many of the older observers; among others by Majendie[2], Berger[3], and Sedgwick[4]. De la Beche[5] also refers to them briefly and to the varieties of hornblendic schist with which he found them interstratified. Fuller accounts of these rocks have been given by Bonney and McMahon[6] in their papers on Lizard geology; while all other authorities had regarded this group as entitled to recognition as a distinct series these authors proposed in 1891 to include them in their 'hornblendic group,' as owing their peculiarities mainly to excessive shearing in the vicinity of thrust planes. We have reverted to the older classification, partly because we do not consider that the thrusts visible at the

[1] Old Lizard Head is the highest part of the cliff at the south-west corner of the Lizard Point.

[2] Ashhurst Majendie, 'A Sketch of the Geology of the Lizard District,' *Trans. Roy. Geol. Soc. Cornwall*, vol. i, 1818, p. 34.

[3] J. F. Berger, 'Observations on the Physical Structure of Devonshire and Cornwall,' *Trans. Geol. Soc.*, vol. i, 1807, p. 130.

[4] A. Sedgwick, 'On the Physical Structure of the Lizard District in the County of Cornwall,' *Trans. Phil. Soc. Cambridge*, vol. i, 1822, p. 317.

[5] Sir H. T. De la Beche, Report on the Geology of Cornwall, Devon and West Somerset, 1839, p. 29.

[6] T. G. Bonney, 'On the Serpentine and Associated Rocks of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 33, 1877, p. 887.

'On the Hornblendic and other Schists of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 39, 1883, p. 11.

T. G. Bonney and C. A. McMahon, 'Results of an Examination of the Crystalline Rocks of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 47, 1891, pp. 482 and 489.

Old Lizard Head are to any large extent responsible for the metamorphic state of these rocks, but principally since their lithological peculiarities are singularly constant throughout their extent and indicate that as a sedimentary group they are distinct in origin from the typical hornblende schists of the Lizard.

The most characteristic member of this series is a reddish brown mica schist, coarsely crystalline, soft and fissile. Its mica is principally white muscovite (Plate III., fig. 2), but many specimens are rich also in brown biotite, and when this is weathered to chlorite the rocks become green with a silvery lustre which undoubtedly led many of the older writers to describe them as talcose or talco-micaceous schists. Small brown garnets, hardly visible to the unaided eye, are very frequent in these schists; in microscopic sections they are pale pink, often occur as perfect little crystals (rhombic dodecahedra) and are usually nearly free from enclosures. In some specimens there is much felspar, principally albite and oligoclase, but orthoclase occurs also; it forms lenticular or rounded crystals which may be altered to white mica, kaolin, or chlorite. Quartz is rarely an important constituent though thin quartzo-felspathic laminæ may often be seen. The abundance of felspar has led in many places to the segregation of nests and veins of pinkish orthoclase and quartz (segregation pegmatites); these are numerous for example at Polpeor and Pistil Ogo (at the Lizard Point), and at Porthallow. The only other minerals of the normal mica schists are apatite, zircon, and magnetite, which are never in large crystals and occur only in small quantity.

Next in importance are quartzo-felspathic granulites passing into felspathic types of gneiss. Like the schists these rocks are often garnetiferous, and the garnets have the same appearance in both types of rock. Many of these granulites contain both muscovite and biotite, the latter often weathered to chlorite; there are also bands which are nearly free from mica and consist entirely of quartz and felspar. A small amount of pale green hornblende in minute prisms or tufted, very fine needles is by no means uncommon in these granulites. The most striking peculiarity of this type is the abundance of felspar which indicates that they must have been originally arkoses. The felspar is oligoclase, albite, and orthoclase, and often forms rather large rounded grains without crystalline outlines, which have much of the appearance of original clastic fragments. From a study of a large series of slides of these rocks, however, we have arrived at the conclusion that these felspars are always authigenic or recrystallised, and that clastic sedimentary structures have invariably been obliterated in the rocks of this group.

Their highly felspathic character gives these granulites a great similarity to acid igneous rocks, and as granulitic aplites and fine-grained granites occur in some numbers in this series, it becomes a matter of great difficulty at times to separate them. In the field this cannot always be done, as both types are fine grained and weather with a pinkish colour; moreover the granitic veins often follow the bedding of the schists and appear interstratified; with the help of the microscope it becomes more easy to distinguish them. The granite gneisses often show remains of porphyritic structure where they are least crushed, and the phenocrysts may still be idiomorphic. The sedimentary granulites, on the other hand are often more micaceous and have closer affinities to the mica schists; they are also more frequently garnetiferous.

Mr. Radley has made an analysis of the brown mica schist on the shore at Porthallow a few yards south of the great boundary fault. We quote also two analyses of the rocks of this group which were made by Mr. Collins.[1]

Analyses of Lizard Mica Schists.

<table>
<tr><th>—</th><th>I.</th><th>II.</th><th>III.</th></tr>
<tr><td>SiO_2 ... ...</td><td>55·92</td><td>58·10</td><td>81·70</td></tr>
<tr><td>TiO_2 ... ...</td><td>0·88</td><td>—</td><td>—</td></tr>
<tr><td>Al_2O_3 ... ...</td><td>22·14</td><td>21·33</td><td>10·40</td></tr>
<tr><td>Fe_2O_3 ... ...</td><td>3·75</td><td>2·10</td><td rowspan="2">3·04</td></tr>
<tr><td>FeO ... ...</td><td>3·72</td><td>8·30</td></tr>
<tr><td>MnO ... ...</td><td>0·21</td><td>—</td><td>tr.</td></tr>
<tr><td>(CoNi)O ... ...</td><td>0·03</td><td>—</td><td>—</td></tr>
<tr><td>BaO ... ...</td><td>n.f.</td><td>—</td><td>—</td></tr>
<tr><td>CaO ... ...</td><td>0·30</td><td>0·72</td><td>0·40</td></tr>
<tr><td>MgO ... ...</td><td>1·77</td><td>1·15</td><td>0·70</td></tr>
<tr><td>K_2O ... ...</td><td>4·26</td><td rowspan="2">4·60</td><td>1·33</td></tr>
<tr><td>Na_2O ... ...</td><td>2·25</td><td>1·54</td></tr>
<tr><td>Li_2O ... ...</td><td>tr.</td><td>—</td><td>—</td></tr>
<tr><td>H_2O at 105° C. ... ...</td><td>0·43</td><td rowspan="2">2·80</td><td rowspan="2">0·85</td></tr>
<tr><td>H_2O above 105° C. ... ...</td><td>3·94</td></tr>
<tr><td>P_2O_5 ... ...</td><td>0·07</td><td>—</td><td>—</td></tr>
<tr><td>FeS_2 ... ...</td><td>0·23</td><td>—</td><td>—</td></tr>
<tr><td>CO_2 ... ...</td><td>0·21</td><td>—</td><td>—</td></tr>
<tr><td>Total ... ...</td><td>100·11</td><td>99·10</td><td>99·96</td></tr>
</table>

I. Mica Schist, Porthallow, E. 6,523 (Anal. E. G. Radley).
II. do. , do. (Anal. J. H. Collins.)
III. do. , Lizard (Anal. J. H. Collins).

It is clear, from an inspection of these analyses, that none of these rocks is of igneous origin. The Porthallow mica schist is obviously an argillaceous sediment with abundant alumina and rather more alkalies than is usual in rocks of this kind; the latter feature explains the frequent occurrence of felspar. The Lizard rock, as Mr. Collins points out, is different in composition from the Porthallow schist and must have been one of the quartzose granulites which occur in plenty at that locality; its composition is that of a quartzose arkose.

The third type of rock which forms part of the Old Lizard Head series is a green schist, usually hornblendic, but sometimes rich in chlorite or epidote. It is always fine grained with a silky lustre and a green colour that distinguish these rocks from the

[1] J. H. Collins, 'On the Serpentine and Associated Rocks of Porthalla Cove,' *Quart. Jour. Geol. Soc.*, vol. 40, 1888, p. 464.

coarser hornblende schists of the Lizard which are often nearly black. In hand specimens the puckered or crinkled folding of these schists (Plate III., fig. 3) is very striking and is similar to the corrugated foliation of the mica schists. Very good examples of these crumpled, silky, hornblende schists are to be found on the south-west corner of the Lizard Point opposite the Quadrant and along the cliffs to the north of this. Fine-grained hornblende schists accompany the mica schists of the Porthallow area, but in that district both of these types have flat or plane foliation.

Under the microscope these rocks present a great variety of characters. Their principal component is always green hornblende in minute acicular prisms forming an aggregate that is sometimes so dense as to be almost irresolvable with the microscope. Chlorite is much less frequent, though abundant in some examples, and may be for the most part secondary after hornblende. Epidote is rather common in small yellow grains scattered through the hornblende and sometimes it forms a considerable part of the rock ; in this way transitions are provided between the hornblende schists and fine schistose epidosites, consisting of quartz and epidote. The green schists contain also a variable amount of felspar, sometimes fresh and clear, but occasionally reduced to a granulitic mosaic. Quartz is by no means rare, and in some of these rocks occurs in considerable quantity. Of the accessory minerals iron ores, sphene, rutile and zoisite may be mentioned.

Although these fine hornblendic schists are very typical metamorphic rocks there are cases in which they preserve traces of original igneous structures. Near Porthallow village, in the steep slope behind the inn, and along the road leading south-west from Pengarrock Mill, the fine silky green schists contain broken porphyritic felspars and hornblende crystals in an exceedingly fine-grained and highly schistose matrix; some of these rocks also are very rich in epidote. About Old Lizard Head the coarser varieties of the green schists show occasionally small, nearly eumorphic felspars which have the optical properties of andesine. Unless the exposures are unexceptionable it is not always possible to make sure that these porphyritic hornblende schists are not derived from the later basic dykes which cut the Old Lizard Head group in many places, and are often converted by movement into schistose rocks, but from their distribution we may be certain that some at least of them belong to the older series. The occurrence of porphyritic structure in this way is entirely against the hypothesis that the fine green schists are merely crushed examples of the coarser hornblende schists.

Epidosites of several different kinds occur in plenty among the green schists and the granulites, but they are facies of the other rocks rather than types entitled to recognition as a distinct group. Some of them are segregations, nodules and vein-like masses in the hornblende schists, produced either by weathering before shearing or by chemical segregation during movement; they share in all the flexures and crumpling of the schists. Others are probably due to weathering of fine types of hornblende schist and hornblendic granulite, for they contain much chlorite, and the chlorite and epidote seem to have replaced actinolite or hornblende. Others are quartzose granulites, very rich in quartz with a variable amount of felspar, and granulitic or even mylonitic in texture. In these the epidote may represent volcanic detritus or ashes, or may be a secondary infiltration before metamorphism. All these epidosites are easily recognised in the field by their yellow colour.

The purer varieties of fine hornblende schist, consisting of green hornblende and felspar with more or less epidote, are clearly igneous rocks. Their composition and the preservation of porphyritic structure are sufficient evidence of this. Some of them may be thin, fine-grained intrusions, but the majority are in all probability lava flows of contemporaneous origin. With them certain rocks occur which are presumably tuffs or ashy grits.

Over the whole area of its distribution the Old Lizard Head Series yields rocks which indicate a mixture of volcanic and sedimentary materials. The commonest types are quartzose hornblende schists and hornblendic quartzites or granulites (Plate III., fig. 1). The presence of a small amount of quartz in a hornblende schist is by no means exceptional, but the quartz-hornblende schists of the Lizard often contain these minerals in about equal proportions, and only a very subordinate amount of felspar and epidote. By increase in quartz and felspar every transition is afforded between the true hornblende schists and the quartzo-felspathic granulites. This phenomenon is so general that only a few localities need be cited where it can be seen clearly.

At the top of Old Lizard Head, opposite the Quadrant Island, there is much crumpled green hornblende schist. Small pits have been opened for stone near the edge of the cliff and among the green schists thin bands of dark green quartzite are obtained, which in microscopic section are thoroughly granulitic, contain a fair amount of felspar and small needles of dark green amphibole. They are quartzo-felspathic hornblende granulites (5,066, 5,068). More quartzose specimens may be observed about a furlong to the north of this; in the slide (5,058) the quartz and felspar form a granulitic mosaic the individual grains of which are pierced by small, well-formed prisms of green hornblende. At Pistil Ogo also (the small cove about 200 yards west of Polpeor), there are granulites rich in hornblende (5,184), interbedded with mica schist and green schist. At Porthallow fine banded greenish epidosites are seen in the mica schist, but the shore section is of limited extent and much disturbed by faults; in the quarry at Parkantidno (half-a-mile south of Porthallow), however, there are micaceous granulites full of small garnets, epidote and greenish prisms of hornblende (5,245). At Trenoweth Mill, one mile south of Porthal'ow, the thin beds of quartzite are rich in epidote and often also in hornblende (6,235, 6,239, 6,240).

Some of the best examples of these rocks are to be found in association with the patch of mica schists near Polkernogo (Plate III. fig. 1). In these inland exposures it is often difficult to obtain fresh material for microscopic examination but there are small pits and roadside cuttings which furnish specimens ranging from quartzose hornblende schists, dark green, with thin lenticular folia of quartz, to greyish-green granulites which on fresh fracture have the lustrous appearance and hardness of quartzites, but weather with a brownish crust from the decomposition of the felspar and hornblende that they contain. Rocks of this kind outcrop at Polpidnick and Polkernogo (6,000, 6,382) but they are especially well seen in small quarries along the southern bank of a streamlet 250 yards south-west of the last-mentioned farm, where they are associated with cordierite hornblende schists.

In the coast sections of these rocks at the Lizard Point and at Porthallow their stratified character is never for a moment in doubt. The larger exposures of mica schist, as at the lifeboat-house at Polpeor, and of green schist at Old Lizard Head show perfect foliation but little stratification. But where a mixed series of rocks occurs, varying in character, the bedding is always conspicuous. Beds of mica schist, quartzo-felspathic granulite and green schist, perfectly well-defined, alternate with one another, each preserving its identity; some beds are several feet thick; others only an inch or two, but they can often be followed for many yards though folded in the most intricate fashion. To demonstrate this no better locality could be chosen than Pistil Ogo, the small cove two hundred yards west of the Polpeor lifeboat station, where steps have been made down to the beach. Looked at from a short distance the bedding is so perfect that one can hardly imagine that the rocks are so highly metamorphic that in them the microscope reveals no trace of clastic structures. From this place northwards to the edge of the serpentine many of the coves and headlands furnish beautiful examples of stratification in the schists.

In the other areas of the Old Lizard Head group the same phenomena can be seen, but as the inland sections are always of small extent the beds cannot be followed for the same distance as along the cliffs. There is one exposure, however, which is so clear that it deserves to be mentioned in this connection. At the south-east corner of the patch of mica schist which terminates at Porthallow there is a narrow lane running down to Trenance Farm and Trenoweth Mill; the roadside sections are in places six to ten feet deep and have been quarried every here and there. The rocks are green schists, granulites, mica schists and epidosites, and, as the folding is of a very flat type and the road is parallel to the strike, the different beds are exposed with their edges nearly horizontal. The quartzose granulites are in thin beds, often less than an inch in thickness, alternating with quartzose hornblende schists; the series has a gentle dip to the west and individual beds can be followed for many yards along the outcrop. They are so well stratified and show so few folds that it is difficult to believe that they are metamorphic rocks. Yet under the microscope even the hardest quartzites in this series are completely granulitic and may often be described as mylonised, so great is the recrystallisation that they have experienced.

Contact alteration in the Old Lizard Head Series.

The rocks of the Old Lizard Head group are typical metamorphic schists and granulites; very rarely is anything to be detected in their external characters that would indicate thermal metamorphism. Some of the granulites, indeed, have a mosaic structure, which, under the microscope, resembles that of certain hornfelses, but this is not a criterion that can be relied on with much confidence. Seeing that these schists occur within very short distances of great plutonic intrusions of serpentine, gabbro and granite, it is only to be expected that minerals indicating thermal alteration would be found in them. Professor Bonney[1] has observed in slides of the schists of the Lizard Head district certain minerals which he suspected might be sillimanite and kyanite.

Microscopic examination has shown that a limited number of these rocks, taken from widely scattered districts in the peninsula contain andalusite, sillimanite, and cordierite.

Andalusite mica schists are found along the coast line to the north of Old Lizard Head for a distance of about a quarter of a mile. They are brown mica schists, not different in external characters from the mica schists of other parts of the Lizard district, and the small dark-brown prisms of andalusite can only be seen with the aid of a lens. Under the microscope they

[1] T. G. Bonney, 'The Hornblendic and other Schists of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 39, 1883, pp. 12 and 14.

are colourless or occasionally have a pink tint with weak dichroism (Plate III, fig. 2). Their shape is that of imperfect four-sided prisms but they are often irregular or lenticular in outline. The principal inclusions are small grains of quartz, brown mica and black iron oxides and these often lie in curving lines which reflect the foliation of the schist, a feature common in 'porphyroblastic' minerals in metamorphic rocks. This indicates that the andalusites developed in this schist either after or during the production of the foliation; that is to say the rock was a schist before the andalusites had finished crystallising. The lines of inclusions are not parallel to the foliation of the mica schist but are often oblique and sometimes at right angles to it; a relationship often found in the porphyroblastic garnets, albites and chlorites of metamorphic rocks and a consequence of the rotation which these large crystals experience through the movement of the schist-matrix around them.

For sillimanite-bearing rocks two localities can be given. Sillimanite occurs in felspathic granulites among the mica schists on the east side of Pen Olver (6830); the rocks in question are merely felspathic varieties of the brown mica schist. They contain much alkali felspar,—orthoclase and albite in small rounded grains (optically negative and positive respectively),—and like the andalusite mica schist of Venton Hill Point are very rich in brown biotite with comparatively little white mica. The sillimanite needles lie in the felspars or form clusters with the biotite. There is a quarry a few yards east of the Lizard road where it passes the south-east lodge gates of Bochym House, in which a coarse variety of hornblende schist is at present much worked for mending the local roads. Mixed with the hornblende schists are grey felspathic granulites having much of the appearance of quartzites. In section some of these rocks are garnetiferous granulites containing much quartz and alkali felspar, a little biotite, muscovite and iron oxides. Sillimanite appears in tufted needles arranged along the foliation and often penetrating the quartz and felspar (5980, 5981). The presence of homogeneous yellow pseudomorphs also suggests that they may also have contained cordierite, but that mineral has not been observed in a fresh state.

It is very unlikely that this list exhausts the localities for sillimanite in the Lizard. It seems to occur sporadically, and of several slides cut from the rocks of one exposure, only one may show sillimanite. Many of the granulites carry small needles and hair-like prisms which might quite well be this mineral but hornblende also occurs in this form (especially in the Treleague quartzites) and to make certain it is advisable to attack the powdered rock with hydrofluoric acid and isolate the mineral. This was done in the two cases mentioned above and the isolated needles subsequently proved by optical tests to be sillimanite; experiments on the other rocks proved unsuccessful.

Only one of the outcrops of the Old Lizard Head Series has as yet yielded cordierite. This is the small area of mica schists and granulites which lies to the south of Polkernogo. Near the old mill in the valley at Trelease Vean mica schists are exposed in small quarries above the banks of the stream. A steep road leads up to the slope to the east of the mill and in the roadside cuttings slabby gneisses are found, very compact, and having a distinctly blue colour when seen in a strong light. These gneisses are rich in fresh cordierite which has vivid pleochroic halos around enclosed zircons. The other minerals represented in the slides are quartz and alkali felspar, muscovite, biotite and iron ores, and probably fine needles of sillimanite. The foliation is of a very pronounced type but the cordierite is often developed in large irregular grains, with penetration twinning; through these pass streams of the other components, such as the micas and iron ores, following the curving foliation of the rock though sometimes rather oblique to it.

About a quarter of a mile north of the mill, in a small wood on the west bank of the stream (250 yards south-south-west of Polkernogo), quarries have been opened in greyish banded gneisses and green quartz-hornblende schists. The latter are flat-foliated, highly granulitic aggregates of quartz, hornblende and alkali felspar which have much of the appearance of greenish quartzites in the hand specimens. The grey gneisses also are well banded and look like flaggy quartzites, but in microscopic sections they prove to be very rich in fresh cordierite with numerous yellow pleochroic halos. The other minerals present are anthophyllite, biotite, quartz and alkali felspar, with small quantities of iron ores, sagenitic webs of rutile, stray needles of sillimanite and small prisms of zircon. The cordierites sometimes tend to form rather large rounded and elliptical grains but occur also as small crystals in exactly the same way as the granulitic quartz and felspar. Foliation is obvious in the slides owing to the parallel orientation of the prisms of anthophyllite and scales of brown mica; these lie in bands between which are straight folia of quartz, felspar and cordierite. In polarised light the whole rock has the appearance of having been much crushed and in places even mylonised.

These cordierite-anthophyllite gneisses are a type of metamorphic rock which has hitherto been seldom encountered. They resemble somewhat the cordierite-hornblende rocks which have been described from the aureole of the Land's End granite mass at Kenidjack Castle,[1] with this essential difference that in the latter the cordierite has developed after the crushing and production of the foliation, and the new minerals which were formed by the thermal action of the granite tended to obliterate and heal the effects of antecedent crushing. In the Polkernogo gneisses the contact minerals take part in the foliated structure of the rock in very much the same manner as the other minerals present.

As the occurrence of anthophyllite in cordierite gneisses is rare, and as the mineral in question is not identical in its properties with the anthophyllite of the other Lizard rocks or with any anthophyllite hitherto described we take occasion to give a few particulars regarding it. In thin section the mineral is pale green or greyish green and only feebly dichroic. It occurs as long narrow prisms often frayed out at their ends. Long sections have mostly a straight extinction and cleavage fragments separated from the crushed rock by levigation in water uniformly extinguish parallel to the principal planes of the nicols. The optical sign referred to the elongation is positive. Cross sections show the amphibole cleavages and give the emergence of a positive bisectrix in the centre of the conoscopic field. The optic axial angle measured in cedar oil is 80 degrees (rather less than that of normal anthophyllite). The optical sign of the mineral is always positive. The optical orientation is that which is usual in amphiboles c Z, b Y, a X.

The most abnormal features of the mineral are the colour and pleochroism, which are Y and Z pale greyish green, X paler green, with a yellow tinge; the colour is paler than that of the hornblende of the associated rocks and the pleochroism far less intense.

It may be noted that Mr. Hutchings has recorded the development of anthophyllite in the contact rocks of the great Whin Sill (*Geological Magazine*, 1898, p. 69 & p. 123), and Professor Lacroix has described the occurrence of cordierite gneisses containing gedrite (anthophyllite) in the contact aureoles of the granites of the Pyrenees. (*Bulletin des Services, Carte Géol. France* vol. xi., p. 40.)

Folding in the Rocks of the Old Lizard Head Series.

The excellent preservation of the bedding in many of the best exposures of the rocks of this series and the generally low dips of the beds are apt to give an entirely misleading impression as to the intensity of the folding to which they have been subjected. At the base of Old Lizard Head, for example, there are sills of a greyish gneiss which have been folded into great S curves, the axes of which are lying nearly flat. A similar granite sill at the south-west corner of the headland (Plate II.), in places about forty feet thick, is bent back on itself till the limbs of the fold are parallel and dip gently to the west or north-west. These are best seen from a boat a short distance off the shore; but a careful examination of the cliffs from Polpeor to Caerthilian Cove, about a mile north of the Lizard, will convince any geologist that the rocks in this quarter have been thrown into large flat folds which have been piled on one another so as greatly to increase the apparent thickness of the series. In the inland exposures there is much to confirm this opinion, but as the ground is covered with vegetation

[1] 'The Geology of the Land's End District,' (*Mem. Geol. Surv.*) 1907, p. 28 & Pl. v., fig. 5.

Old Lizard Head.

it is not possible to map out the outcrops of the individual bands of rock. On a smaller scale also, intense plication is often observable, as for example at Pistil Ogo, where the thin bands of granulite can be seen involved in little horizontal folds. Six of these flat folds may occur in a vertical distance of no more than six feet. This minor folding passes gradually by diminution in its amplitude into the crumpling which is so marked in many exposures of the mica schist and green schist.

As a rule the coarser types of hornblende schist, or typical Lizard hornblende schists, are absent from the areas occupied by the Old Lizard Head Series. Coarse schists occur with the fine silky green schists of the Lizard Head, but they are few and are not exactly similar to those which are the dominant forms elsewhere in the district. The boundary line of the mica schist area at both ends is a fault which brings the mica schists and granulites in contact with the coarse hornblende schists. At Porthallow this is also the case. The presence of small patches of mica schist in the coarse hornblende schists, as was first shown at Pen Olver by Mr. Howard Fox[1], is of considerable importance, since it proves that there is really no good reason to doubt that the two series have the closest possible relations. On the north of the serpentine and gabbro several small areas of mica schist are known, and at Gwealeath, Bochym, and Bonython Plantations there are exposures of mica schists and garnetiferous granulites (some of which contain sillimanite) that might almost be described as interbedded with the coarse hornblende schists.

Owing to the faulting and to the intense folding nothing can be inferred from the apparent sequence or dips as to the real stratigraphical succession of these two subdivisions of the Lizard rocks.

The Treleague Quartzite.

The quartzite of Treleague is the only important group of rocks in the Lizard district of which the existence was not known to the older geologists. It is nowhere exposed in the coast sections, but forms a narrow strip of country inland along the north side of the gabbro in the vicinity of St. Keverne. This ground is all under cultivation and opportunities for examining the rock *in situ* are accordingly few.

From the hornblende schists to the north the quartzite is separated by a fault which is the westerly continuation of the great fracture that runs out to sea in Porthoustock Cove. The straight course of the boundary line and the marked dissimilarity between the rocks on each side of it are sufficient evidence of the presence of a dislocation though it cannot be demonstrated in any actual section in the field. The nature of the southern boundary of the quartzite is somewhat more obscure. There is evidence which will be detailed subsequently that veins of greenstone cut the quartzite, and it might be supposed that this rock was resting on the gabbro and formed part of its original aureole. The absence of marked contact alteration in the sedimentary rock,

[1] *Trans. Roy. Geol. Soc. Corn.*, vol. xi., 1890, p. 327.

however, even where it is in juxtaposition with the basic intrusion, and the fact that the gabbro maintains its coarse crystallisation along its whole northern edge are against the hypothesis that the junction is unbroken. This boundary describes a gentle curve with its convexity towards the south, a feature in which it recalls the thrust that forms the southern boundary of the serpentine at the Lizard. Its position can be laid down within a few yards at all parts of its course, and though it does not correspond with any natural feature in its western part, it evidently has determined the course of the streamlet that flows past St. Keverne to Porthoustock. So many of the Lizard valleys follow lines of fracture that this might be advanced as confirmatory evidence of the presence of a dislocation. Finally we may add that at several places along the north slope of the valley above mentioned the Treleague quartzite may be found in a much brecciated condition, which renders it practically certain that faulting has taken place in that quarter. For these reasons we consider that the area occupied by this rock is a lenticle bounded on each side by faults or thrusts.

In the field exposures the Treleague quartzite appears as a hard grey rock, weathering with a brownish surface. The bedding is often fairly well indicated and there is little variety in the rock-types, though finer-grained, rather shaly beds are occasionally seen. The quartzite breaks with a smooth fracture that indicates considerable induration, but the clastic quartz grains are often visible with the aid of a lens. Many of the specimens show brecciation, and are traversed by minute veins of quartz. The best localities for examining the quartzite are the farmyard of Treleague and the roadside east of the farm, also the side of the road leading east from Tembraze, but there are about a dozen places in the fields and on the roads where small exposures of rock *in situ* may be found.

In microscopic character (Plate III., fig. 6) the rock shows a remarkable uniformity. In all the slides the clastic nature structure is perfectly obvious; the pebbles are small, rarely exceeding half a millimetre in diameter, and are mostly quartz, though some felspar also occurs. With polarised light it is obvious that there has been a considerable amount of granulitisation, as many of the pebbles break up into a mosaic, and between these a finely granulitic matrix is recognisable. A few crystals of zircon and epidote are present and one of the slides contains a few nearly colourless garnets (6338).

The special feature of the Treleague quartzite, however, that makes it distinct from other altered sedimentary rocks of the west of England is the presence of much hornblende as an interstitial substance between the quartz grains. This mineral is so abundant that sometimes the slides are darkened and rendered semi-opaque in places by it. It takes the form of minute needles that lie in tufts and bundles in the cementing material of the rock and often penetrate the quartz grains for a considerable distance. In its mode of occurrence it has some resemblance to sillimanite, but chemical tests prove that it is rather readily soluble in hydrofluoric acid. Even the most delicate needles have a pale green colour, and when they are somewhat thicker their pleochroism and slightly oblique extinction may often be observed; in these characters they resemble hornblende. Moreover in a limited number of the sections rather larger irregular crystals of greenish amphibole occur and so much resemble the fine needles in appearance that there can be little doubt as to the identification of the mineral (6337). In the more decomposed rocks it seems to have been replaced by chlorite.

The universal presence of acicular amphibole in the Treleague quartzite serves to distinguish it from the Veryan quartzites to the north of the Lizard boundary; it is also on the whole a more metamorphic rock and contains small garnets which have not been found in the Llandeilo quartzite. The acicular hornblende, on the other hand, may perhaps indicate affinities between this rock and some of the Lizard granulites and gneisses, for they contain a similar mineral that penetrates quartz in exactly the same fashion. In other respects the Treleague quartzite is very different from the Lizard granulites. The latter rocks are seen in typical development at Trenoweth Mill, less than a quarter of a mile east of the east end of the quartzite; and there as everywhere else in the Lizard they are completely granulitic (Plate III., fig. 1) and show no remains of clastic structure.

In the farm yard on the north side of Treleague small outcrops of dark green rocks occur which prove on microscopic examination to be greenstones of exactly the same type as those which penetrate the gabbro at Manacle Point. Some of them are ophitic, but have had their augite converted into green hornblende (7442); another variety is very rich in felspar with a little interstitial hornblende (7472). There seems little room for doubt that these basic rocks are intrusive into the quartzite, and if that is the case this rock must belong to the Lizard Series and must be older than the greenstone dykes. No intrusive masses of similar type are known in the Palæozoic sediments to the north of the Lizard boundary.

Now the Treleague quartzite is far less metamorphic in its structure than the quartzites and granulites of the Old Lizard Head Series. It seems possible, then, that there are two sets of metamorphic sedimentary rocks in the Lizard peninsula, both older than the great basic intrusions and of these the Treleague quartzite is the uppermost or youngest. This reduces us, as we have already stated, to the necessity of searching for a break somewhere in the Lizard succession. It is clear that the greenstones, the gabbro, the serpentine, and part of the hornblende schist belong to one sequence since they are intimately connected together; and it is no less certain that the green schists that are interbedded with the mica schists of the Old Lizard Head Series are inseparable from the epidotic hornblende schists of Landewednack type. Hence the only place where the Treleague quartzite can be intercalated is between the two main types of hornblende schists in the Lizard peninsula, a conclusion which though not discordant with any of the known facts of Lizard geology would require to be supported by independent confirmatory evidence to raise it above the rank of a hypothesis.

CHAPTER IV.

THE LIZARD HORNBLENDE SCHISTS.

The hornblende schists of the Lizard district, as may be seen on the map, have four principal areas of distribution. On the north of the serpentine they form a broad belt extending from Porthallow and Porthoustock to Polurrian and Mullion Cove (Porth Mellin). They occur also on the west coast at Predannack, on the south at the Lizard Point, and on the east at Cadgwith. They are covered with fine red soils of high fertility and almost entirely under cultivation. The sub-soil is a reddish 'marl' sometimes twenty feet deep, and inland exposures of fresh rock are not often met with, though the fields may be strewn with fragments of hornblende schist and epidosite.

The schists of the northern area emerge to the coast both on the east and west sides of the peninsula, and the cliff sections north of Porthoustock and Mullion Cove afford splendid opportunities for investigating the structure and lithological peculiarities of this group of rocks. Mica schists and garnetiferous granulites must occur among the hornblende schists in considerable abundance, though not exposed on the coast except at Porthallow. They are often found among the *débris* on the fields but cannot be indicated on the map because the outcrops are very small; at Porthallow, Polkernogo, Mill Mehal and Tregarne Mill, and Gwealeath, however, sufficiently extensive areas of mica schist have been found to be indicated on the one-inch map of the district. On their northern side these mica schists and hornblende schists reach the Lizard boundary, except for a short distance near Trevassack where the serpentine is in contact with the Veryan Series. The maximum breadth of the belt is one and three-quarter miles and its area about eight square miles.

On the south these schists are brought against the gabbro and Treleague quartzite by a thrust that can be traced from Porthoustock at least as far as Trelease. At Bonython also, on the north-west of the serpentine, their margin is defined by a thrust that runs out to sea at Polurrian; and another thrust can be followed inland between the serpentine and hornblende schists for about a mile from Mullion Cove. Elsewhere the southern margin of this belt is of a different type, readily distinguished on the map and still more readily in the field. The north edge of the serpentine from Kernewas to Bonython is folded with the schists along axes that are nearly vertical and have generally a north-west strike. A great number of infolded patches of hornblende schist appear in the serpentine; their areas vary from more than a hundred acres down to a few square yards. The largest are found in the downs north of Traboe Cross, and since quarries for road metal have been opened in them good specimens can be obtained, but the boundaries of the schist areas can be traced only by means of the *débris* on the moors.

The smaller infolds are seen in quarries in the serpentine near Trezise, Traboe, Kernewas, and between Kernewas and Trelanvean. They may be only a couple of feet thick and take the form of long canoe-shaped infolds.

There is evidence that most of the hornblende schist along this northern belt is resting on the folded top of the serpentine, for that rock rises at Porthkerris, Porthallow, Halwyn and Pengarrock (¾ mile east of Tregarne) in rounded outcrops that seem to be the summits of anticlines, since at their margins the foliation has an outward dip. At Meaver (near Mullion), also, the serpentine rises from below the hornblende schists, and on the promontory of Henscath, near Mullion Cove, there is a synclinal infold of schist in the serpentine which is laid bare in section on the northern face of the islet. The patches of schist among the serpentine of Goonhilly Downs represent, accordingly, the folded roof of the serpentine laccolite not yet completely stripped off by denudation.

If the serpentine underlies the whole of this northern area we can understand the frequent signs of contact alteration that the schists exhibit. About Porthoustock, Tregarne and Tregowris the hornblende schists are often very rich in epidote that forms streaks and patches irregularly scattered through the rock. The epidote is accompanied by pyroxene and sometimes garnet. These schists are splintery, very hard, and split with difficulty along the foliation; they seem to have undergone much induration subsequent to the development of the foliation. As already described the sedimentary schists of this area are often full of cordierite and sillimanite; hence we are probably right in regarding this broad band of schist as forming the contact aureole of the serpentine.

Hornblende schist also occupies the western part of the Predannack district, over an area of nearly half a square mile. It is well exposed in the cliff sections from Pol Cornick north to Ryniau. The former locality is known to geologists as furnishing excellent proof that the serpentine and schists are folded together and tend to pass into one another at their junctions; similar phenomena can be seen in the coves on the south side of Predannack where the serpentine rises in arches from beneath the schist. The north-east boundary of this area of hornblende schists is a straight north-west fault. The Predannack schists are rarely epidotic and show little sign of contact alteration; they often belong to the coarse gnarled type that is common near Traboe. Their prevalent strike is almost due north and south, and they are intensely folded in close-packed vertical folds.

The third area in which the hornblende schists have an important development is at the Lizard Point, of which they constitute the whole eastern side; on the west coast they appear for a short distance south of Pentreath Beach. Magnificent sections of this series are provided by the cliffs from Polbream round to Church Cove, especially on both sides of Housel Bay and on Pen Olver. On the south-west the boundary is a fault, at any rate for part of its extent; on the north there is a great thrust by which the serpentine has been driven southwards over the schists. This thrust runs through the centre of Lizard Town, but is not marked on the surface by any distinct feature; at its terminations it can be seen in section at Pentreath Beach and at The Balk. Mica schists occur among the hornblende schists at several places on Pen Olver (as was shown by Mr. Howard Fox), but on the west coast the hornblende schists are apparently faulted against the mica schists.

The schists in this area lie very flat and the dips of the foliation are rolling, but the strike is pretty constantly north-west. Near Church Cove and Pentreath Beach the dips tend to swing round to the north under the influence of the boundary thrust. These rocks are rich in pyroxene and epidote which occur as pale yellow bands alternating with dark hornblende schist, and the striped appearance of polished specimens is very striking. There is no doubt that they have suffered much contact alteration, and the mica schists of this district contain both andalusite and sillimanite.

Around Cadgwith there is a fourth area of hornblende schist forming a narrow strip along the cliffs. Where their junction with the serpentine can be seen, as at the Devil's Frying Pan, it is a fault, though probably of no great magnitude as the fine marginal varieties of the serpentine are found at the edge of the schists both on Carn Barrow and at the entrance to the Frying Pan. There is comparatively little evidence that the two rocks have been folded together on this side and, as Professor Bonney pointed out[1], there is good reason to believe that the serpentine is intrusive into the schists.

The Cadgwith schists are highly epidotic and strongly banded; often they contain pyroxene and sometimes garnet. Excellent sections of them are visible on the north side of Cadgwith Cove, but on the south side they have been invaded by intrusions of banded gneiss. They have as a rule gentle dips to north-west, and a north-east strike; in this respect they are exceptional among the Lizard schists. At both ends this strip of hornblende schists is terminated by faults.

The Landewednack Hornblende Schists.

The hornblende schists have received much attention from those geologists who have investigated the structure of the peninsula. As early as 1818 Majendie[2] prepared a map showing the main areas in which they occur, and De la Beche's map in 1839 gave their outcrops with substantial accuracy. Of subsequent writers, Professor Bonney and the late Major-General McMahon have paid most attention to their lithological characters and microscopic structure, while their origin and metamorphic history have been discussed by these authors and

[1] *Quart. Jour. Geol. Soc.*, vol. 33, 1877, p. 893.

[2] Ashhurst Majendie, 'A Sketch of the Geology of the Lizard District,' *Trans. Roy. Geol. Soc.*, *Cornwall*, vol. 1, 1818, p. 36.

H. T. De la Beche, 'Report on the Geology of Cornwall, Devon and West Somerset' (*Mem. Geol. Surv.*), 1839.

by many other geologists, including Mr. Howard Fox and Dr. Teall, Mr. Collins and Mr. Somervail[1].

Several types may be recognised, the prevalent one being composed of hornblende and plagioclase felspar almost to the exclusion of other minerals, though sphene, iron oxides, epidote and apatite are nearly always present in small quantity. The hornblende of these rocks is in most cases of a rich green colour in thin section, with marked dichroism ; pale green varieties of amphibole are far less frequent, and there are a few of the members of this group in which the hornblende is almost colourless ; yellow-brown and reddish-brown colours may also be noted, and seem most frequent in those schists which occur as inclusions or infolds in the serpentine, or lie near the junction of these two rocks. The felspar may be perfectly colourless and fresh, or cloudy from decomposition ; often it is transformed into a nearly opaque, turbid substance of the saussurite order. The fresh felspar is mostly andesine, but it often approaches oligoclase in specific gravity and optical properties ; it is usually polysynthetic but many grains appear quite free from twinning. The occurrence of quartz is very exceptional, and biotite and garnet have not been seen in any of the rocks sliced.

Many of the Lizard hornblende schists contain pyroxene, as was first reported by McMahon.[2] This mineral is usually pale green and sometimes practically colourless (Plate III., fig. 4) in thin sections. The rocks in which it occurs may be regarded as a distinct type,—the pyroxene hornblende schists. They have no distinctive distribution, but are found alternating with the pure hornblende schists in practically every part of the Lizard where these rocks occur ; consequently it is not necessary to give localities for them. The pyroxene-bearing bands of the hornblende schists may often be identified in the field by their brighter green colour and their less perfect schistosity owing to the comparatively small number of bladed prisms of hornblende in the dark folia. The rocks of this group also are frequently rich in granular yellow epidote, and some of these pyroxene epidote schists contain no hornblende. Another peculiarity is the presence of a small amount of alkali felspar in some of them (5,025, 6,841) ; many are rich in granules of sphene.

As the epidote increases in quantity yellow epidosites are developed, usually granular and sometimes banded, but not schistose or fissile, except when traversed by hornblendic folia. Lumps and streaks of almost pure epidote occur frequently in the hornblende schist ; they vary from a foot to less than an inch in thickness and are wonderfully sharply defined, showing little tendency to mingle with the dark hornblende schist though transitions to the pyroxene-bearing varieties are more frequent. Quartz occurs in some of these epidosites, but is not really common, a fact which distinguishes them from the quartzose epidosites and epidotic granulites that accompany the mica schists. The epidosite bands in the hornblende schist of Relowas quarry contain pink garnets.

In a typical exposure of the Landewednack hornblende schists these types alternate in thin bands, and the dark hornblendic

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[1] T. G. Bonney, 'On the Serpentine and Associated Rocks of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 33, 1877, p. 884. 'The Hornblendic and other Schists of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 39, 1883, p. 1. 'Presidential Address to the Geological Society,' *Proc. Geol. Soc.*, vol. 42, 1886, p. 86.

C. A. McMahon, 'Notes on the Hornblende Schists and Banded Crystalline Rocks of the Lizard,' *Quart. Jour. Geol. Soc.*, vol. 45, 1889, p. 519.

T. G. Bonney and C. A. McMahon, 'Results of an Examination of the Crystalline Rocks of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 47, 1891, p. 464.

T. G. Bonney, 'The Serpentine, Gneissoid and Hornblende Rocks of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 52, 1896, p. 17.

Howard Fox and J. J. H. Teall, 'Notes on some Coast Sections at the Lizard,' *Quart. Jour. Geol. Soc.*, vol. 49, 1893, p. 199.

J. H. Collins, 'On the Serpentine and Associated Rocks of Porthalla Cove,' *Quart. Jour. Geol. Soc.*, vol. 40, 1884, p. 458.

A. Somervail, 'On the Schists of the Lizard District.' *Geol. Mag.*, 1890, p. 161. 'The Origin and Relations of the Lizard Rocks,' *Trans. Roy. Geol. Soc. Cornwall*, vol. 11, 1894, p. 536.

[2] *Quart. Jour. Geol. Soc.*, vol. 45, 1889, p. 523.

layers contrast strongly with the pale-green pyroxene schists and yellow epidosites; the appearance simulates bedding in the most extraordinary way when seen from a short distance, but on closer inspection the epidotic folia are found to be often discontinuous and markedly lenticular. Very excellent exposures of the rocks of this type may be seen on the north side of Cadgwith Cove, at Church Cove, around Housel Bay, on Pen Olver Head, and on the north side of Porthoustock Cove. From their extensive development at the south-east portion of the Lizard Point we propose to call these rocks the Landewednack hornblende schists.

There is practically a consensus of opinion among the geologists who have investigated the Lizard district that these rocks are of igneous origin. Their mineral nature indicates this; a chemical analysis of a rather fine-grained hornblende schist of this group which is extensively worked for road-metal in a quarry at Lower Relowas (about 400 yards north of Trezise, St. Martin's Bridge) has been made by Mr. E. G. Radley in the Survey's laboratory, and shows that these rocks have the composition of basalts or dolerites[1]. We may compare it with the analysis of a

—	I.	II.
SiO_2	48·64	46·61
TiO_2	1·90	1·81
Al_2O_3	14·99	15·22
Fe_2O_3	3·42	3·49
FeO	7·76	7·71
MnO	0·30	0·13
(CoNi)O	nt. fd.	tr.
BaO	nt. fd.	—
CaO	9.60	10·08
MgO	7·76	8·66
K_2O	0·52	0·67
Na_2O	3·52	2·43
Li_2O	tr.	—
H_2O at 105° C	0·10	1·10
H_2O above 105° C	1·25	2·07
P_2O_5	0·16	0·10
FeS_2	0·06	—
CO_2	0·23	tr.
Cr_2O_3	—	tr.
Total	100·21	100·08

I. Hornblende Schist, Lower Relowas Quarry, St. Martin in Meneage, Cornwall, E. 5,797, (Anal. E. G. Radley).

II. Olivine Basalt lava, near bridge over Allt Fionnfhuachd, Drynoch, Skye (Anal. W. Pollard); cited from A. Harker, 'Tertiary Igneous Rocks of Skye' (*Mem. Geol. Surv.*), 1904, p. 31.

[1] Other analyses of Lizard hornblende schists, less complete than the above, will be found in Mr. Collins's paper (*loc. cit.*, p. 468). A rather abnormal variety of the schist has been analysed by Mr. Player, and the analysis is given by Mr. Howard Fox in his paper, 'On the Junction of Hornblende Schist and Serpentine in the Ogo Dour District,' *Trans. Royal Geol. Soc. Cornwall*, vol. 11., p. 217, 1889. An analysis by Hudleston will be found in his 'Notes on the Chemical Composition of some of the Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 33, 1877, p. 924.

basalt lava from Skye; the two are very similar except that the Lizard rock contains rather more alkalies and rather less lime, but the segregation of epidote along certain bands of the hornblende schist may help to account for these differences.

Whether these rocks were tuffs, lavas, or intrusive sills has been much discussed. Professor Bonney[1], who at one time regarded them as bedded tuffs, has seen reason to doubt that conclusion. On that hypothesis the scarcity of intercalated sediments would present great difficulties; they must have consisted entirely of igneous materials. The quartzose hornblende schists described in a previous chapter have much more of the character of schists derived from basic ashes. Moreover the coarse crystallisation of the epidotic hornblende schists makes it more likely that they were crystalline lavas or dolerite sills. To go further than this is impossible; they are so highly metamorphic that their original stratigraphical relationships cannot be completely made out. It is sufficient for our purposes to be sure that they are a complex of basic igneous rocks and, like the plateau basalts which surround the plutonic bosses of Skye they may include doleritic sills, basaltic lavas and even thin seams of basic ashes.

They have certainly undergone extreme metamorphism. Traces of original igneous structures are very seldom to be observed in them, though Professor Bonney records that they are sometimes ophitic[2], and porphyritic felspars have been noted by him and by Dr. Teall[3]. In our experience, however, these 'relict structures' are exceedingly rare. Usually all the minerals are devoid of crystal outlines or give only feeble indications of them.

Most of these schists are well crystallised, but here and there we meet with specimens which are in a mylonitic condition, with their felspar and their hornblende crushed to a mosaic of minute grains (5351, 6043). Lenticles of coarser schist are found somewhat infrequently in the normal schist especially at Porthoustock and Mullion Cove, as has been described by Professor Bonney[4]; these may have been coarse pegmatitic veins or segregations in a dolerite sill, or even intrusive dykes of gabbro. They are always intensely metamorphic, and consequently their relationships are obscure. We have never found any dykes of the later gabbro (Crousa Downs gabbro) in the hornblende schists.

As metamorphic basic rocks the epidotic hornblende schists present some peculiarities such as the abundance of pyroxene (Plate III., fig. 4), which call for some remarks. McMahon[5] has argued that all the hornblende of these rocks is secondary after augite. This may indeed be true, but if these schists are altered dolerites the augite they contain is not their original

[1] T. G. Bonney, 'The Serpentine, Gneissoid and Hornblende Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 52, 1896, p. 22.

[2] *Op. cit.*, p. 18.

[3] In 'The Micaceous Schists of the Penolver District,' by Howard Fox, *Trans. Roy. Geol. Soc. Cornwall*, vol. 11, 1891, p. 333.

[4] *Op. cit.*, p. 19.

[5] *Op. cit.*, p. 524, also in *Quart. Journ. Geol. Soc.*, vol. 50, 1894, p. 355.

augite, but a colourless malacolite or diopside which is foreign to the dolerites. We have shown that the sedimentary schists of the Lizard have undergone much thermo-metamorphism and it is in every way probable that the pyroxene of the hornblende schists is due to contact alteration, or to their metamorphism and folding having taken place at high temperatures. It can be proved that during the injection of the serpentine these rocks were being folded and their peculiar mineral composition may be ascribed to the unusual conditions by which they attained their present state. Similar pyroxene hornblende schists are found in the Kolar district of Mysore, and Dr. Smeeth[1] has attributed their pyroxene to contact action by adjacent intrusive masses. In the west of Cornwall pale green augite is often found in the hornfelsed greenstones near the granite.

The epidosite banding in these schists is also a very remarkable and unusual phenomenon. Its regularity has undoubtedly led many geologists to regard these rocks as bedded sediments. Comparison with the bedded schists at the south-west corner of the Lizard makes it clear that this is not stratification, and leads to the conclusion that the epidosite streaks and nodules are due to some kind of segregation during metamorphism. How or why this takes place is not clear, but similar processes can be seen in other districts of metamorphic rocks. In the Lizard, however, the development of epidosite banding has attained a perfection which cannot be paralleled anywhere else in Britain.

The Traboe Hornblende Schists.

Around the northern border of the serpentine hornblende schists are found which differ in some important respects from those of Mullion, Landewednack, Cadgwith, and Porthoustock. Schists of this group fringe the serpentine to the south of Traboe, and all the included or infolded areas in the northern part of the serpentine are of this type. Though individual hand specimens of some of the Traboe schists might not be distinguishable from the Landewednack schists there are important features which distinguish them both in the field and in microscopic sections.

The epidotic hornblende schists weather readily and yield a rich fine soil; the Traboe schists, on the other hand, are barren rocks and over a considerable part of their extent the land is not worth cultivating. The enclosures of schist in the serpentine are with few exceptions left waste (constituting the only uncultivated areas of hornblende schist in the district). Where tilled, the land is poor, as for example around Kernewas and Polkerth; while the epidotic schists in the same district yield some of the best land in Cornwall. North-west of Traboe the two types of schist are brought together by a fault and the difference in the agricultural value of the land and the state of the crops in adjacent fields on opposite sides of the line is very marked. This can also be seen to the west of Trezise, where the fields south

[1] W. F. Smeeth, 'The occurrence of Secondary Augite in the Kolar Schists,' *Mysore Geol. Dept.*, *Bulletin* 3, 1905.

of the road to Newtown are Traboe schists while those to the north are on epidotic hornblende schists. A further difference in the character of the ground is that the areas of Traboe schists are often strewn with enormous boulders of rock. In the downs west of Polkerth some of them are twenty feet long and as large as a small cottage; many also occur further east beside Polkerth and to the south of it, and on the farm of Kernewas. These blocks are of a grey colour, resembling those of the Crousa Downs gabbro, but distinguished from the latter by a very well developed foliation of a peculiar type. The banding is interrupted or discordant; for a few inches or a foot there may be a parallel foliation, then another banding sets in which crosses this obliquely. Professor Bonney[1] has noted the presence of this structure. In other cases it is contorted and very irregular, never continuing long in one direction. Some of the weathered surfaces of these schists look like a gnarled tree trunk or a piece of rough-grained wood. Traces of this structure may be seen in the epidotic Landewednack schists but are uncommon and never attain the same development as in the rocks under consideration.

In microscopic section these schists prove to consist of the same minerals as the Landewednack schists, only epidote is much less common, and epidosite banding is conspicuous by its absence. Many of them contain green pyroxene (Plate III., fig. 5), but in these rocks it has the schiller enclosures and fluid cavities of diallage in the gabbros, and has all the properties of a primary mineral. Often this augite is surrounded by green hornblende, and in many specimens it is replaced by secondary pale green amphibole or chlorite. The felspars are often very fresh and clear, with complex polysynthetic twinning on both albite and pericline laws; at other times they are represented by aggregates of turbid saussurite, sericite, &c. In five examples the nature of the felspars was tested and proved to be either labradorite or acid bytownite; in other words it is more basic than that of the epidotic schists. In one slide of these rocks grains of olivine (Plate III., fig. 5), weathering to serpentine, are to be seen (6255). The hornblende varies in colour from pale green to dark green, brownish-green and brown.

Some of these rocks are hornblende schists with typical schistose structure, all the minerals being of irregular form and the rock well crystallized. Many others, however, are granulitic or cataclastic with rounded grains of felspar surrounded by smaller grains of the same mineral and of hornblende, and the structure is often of the type known as 'mortar structure.' These specimens, with their pale green augite and crushed labradorite, are granulitic gabbros. They are in fact so similar to the finer crushed varieties of the Crousa Downs gabbro that it was not till an advanced stage in the mapping that it became certain they were not outlying intrusions from that mass. Some of the rocks are dark and rich in hornblende, with well-developed schistosity, while others are pale greyish-green, rich in felspar and pyroxene, and granular in appearance exactly like certain common types of the Crousa Downs gabbro. The name 'older gabbro' could be very well applied to the Traboe hornblende schists, had it not been already used by Professor Bonney for the troctolite of Coverack.

These hornblende schists represent an intrusive facies of igneous activity which preceded the injection of the serpentine. Their relations to the epidotic hornblende schists are difficult to make out. Sporadic occurrences of rocks of this type appear among the epidotic schists, at Pedn Tiere (Porthkerris Point, to the east of Porthallow), Halwyn (west of Porthallow) and in many other places. They are folded with the epidotic schists till their

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[1] T. G. Bonney, 'On the Hornblendic and other Schists of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 39, 1883, p. 15 and Pl. 1.

original relationships are no longer decipherable, but there is nothing to forbid the supposition that they are intrusive gabbros and dolerites which invade the other group. With the serpentine they have much closer affinities. As already remarked they fringe a large portion of the northern border of the ultra-basic rocks from near Penhale on the Lizard Road to Kernewas at the margin of the gabbro. They are always folded with the marginal serpentine and show transitions to it. In the Predannack area of hornblende schists rocks of this class containing primary diallagic pyroxene are well represented. Good examples may be seen on the east and south sides of Predannack Head; and Mr. Fox and Dr. Teall have shown that at Pol Cornick the serpentine exhibits a transition to the schists; on the other hand the epidotic hornblende schists where they come in folded contact with the serpentine, as at Cadgwith, have never been proved to merge with it. The Traboe schists also (though often intensely metamorphic and always much crushed) retain traces of their igneous structures more frequently than the epidotic hornblende schists or Landewednack group. We may say that the latter have close affinities to the green schists and epidosites which accompany the mica schists, while the Traboe schists are attached to the serpentine and in no case are known to occur at a considerable distance from the margins of that rock.

Folding in the Hornblende Schists.

The Landewednack and Traboe schists, like the mica schists and granulites, are everywhere intensely folded. Often this is not apparent on first inspection as the limbs of the folds are usually straight and parallel, but a closer search will reveal the presence of flexures and the repetition of similar bands in a way which can only be explained as the result of a highly compressed system of folds. In the cliffs at Mullion Cove, Predannack, Church Cove, Pen Olver, and to the north of Porthoustock these structures may always be detected; in other places, like Cadgwith Cove, the epidotic banding is so regular and parallel that it is difficult to grasp the fact that there is much folding.

In the epidotic hornblende schists the dip of the foliation is often very low and the rocks look like gently bedded sediments. This is especially noticeable at the Lizard Point from the lighthouses round Housel Bay to Church Cove; in some parts of that coast the schists lie as flat as bedded limestones and the jointing makes the faces of the cliffs resemble a stratified sequence. Good examples of this type of coast scenery are furnished by the west side of Pen Olver, Bass Point, and Church Cove. The Traboe schists, on the other hand, are nearly always vertical; this is the character of the hornblende schists at Predannack and all along the northern boundary of the serpentine. A few exceptions to it may be noted at Pedn Tiere and Halwyn, near Porthallow, but they are only local.

Especially in the flat-bedded schists of the south part of the district the dips of the foliation roll about and are very variable.

Careful inspection, however, will convince the observer that there is a prevalence of north-west to northerly strikes, as was remarked many years ago by Professor Bonney[1].

On the north side of the serpentine, also, the strikes vary a good deal from place to place; along the shore sections from Porthoustock to Porthallow the general tendency is to a north-north-east strike, but the course of the infolds of mica schist at Porthallow and Polkernogo shows that here also a north to north-west strike prevails. Around Mullion the strike is much disturbed, probably by faults, but in the cliffs it is often due north and at Predannack it is north to north-west. On the north-east side of the serpentine, around Traboe, the north-west strike is singularly constant, both in the serpentine and the schists.

Where the schists are brought against the serpentine by a fault, as in the neighbourhood of Lizard Town and Landewednack they often strike directly against the boundary. But where the marginal relations of serpentine and schists have not been disturbed by faults it is practically invariably true that the two rocks have the same strike, and that its direction is parallel to the boundary. We shall deal with this more fully when we have described the serpentine; in the meantime it is sufficient to point out that in spite of local irregularities we can distinguish the following features in the strike of the Lizard schists;—a general tendency to a north or north-west strike over their whole area, modified by a tendency at the margin of the serpentine to assume a direction parallel to the mutual boundary of the two series of rocks.

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[1] T. G. Bonney, 'On the Hornblendic and other Schists of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 39, 1883, p. 12.

PLATE III.

PHOTOMICROGRAPHS OF LIZARD SCHISTS.

Fig. 1.—*Quartz hornblende schist* (5989), 250 yards south-west of Polkernogo, magnified 13 diameters. The rock has a perfect foliation and consists mainly of clear quartz with subordinate turbid felspar, prisms of green hornblende and black iron oxides.

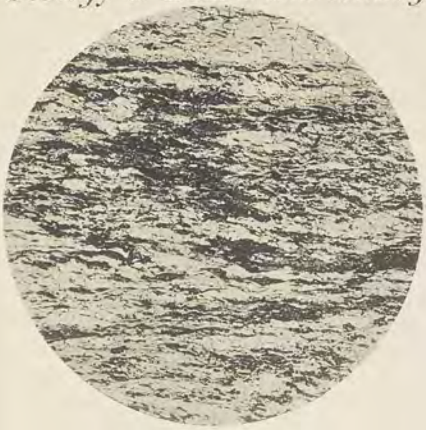
„ 2.—*Andalusite mica schist* (5059), quarry on Venton Hill Point, magnified 22 diameters. Several crystals of pale coloured andalusite occur in the field and contain numbers of dark inclusions. The matrix of the schist is principally pale brown biotite, with quartz and felspar. The mica plates are arranged in winding folia that embrace the crystals of andalusite.

„ 3.—*Hornblende schist* (5060), about 70 yards south of Venton Hill Point, magnified 19 diameters. The foliation shows intense crumpling, with traces of slip-cleavage. Hornblende and weathered felspar make up much of the rock, with small lenticles of clear transparent quartz. This is an example of the 'green schists' of the Old Lizard Head Series.

„ 4.—*Pyroxene hornblende schist* (5030), Lloyd's Signal Station, Bass Point, magnified 19 diameters. The component minerals are colourless felspar, pale green pyroxene and dark green hornblende, with a little sphene and iron oxides. The pyroxene in the photograph is not so dark as the amphibole. The foliation is well marked and the minerals have little crystalline form. This schist is of the Landewednack type.

„ 5.—*Hornblende schist* (6255), 400 yards north-east of Traboe Cross, magnified 36 diameters. The dark grains are partly clear green augite and partly olivine which is weathering to serpentine; pale brown hornblende is present also but not distinguishable in the photograph. The felspar is perfectly fresh and clear. This rock belongs to the Traboe group of schists.

„ 6.—*Hornblendic quartzite* (6215), Treleague farm-yard, magnified 31 diameters. Many clear, somewhat angular pebbles of quartz lie in a matrix or cement that is partly granulitic and is filled with small needles of green hornblende which make it dark in the photograph. The excellent preservation of the clastic structure in the Treleague quartzite contrasts strongly with the thoroughly metamorphic character of the quartz hornblende schists (of similar composition) of the Old Lizard Head series (cf. fig. 1).



1.

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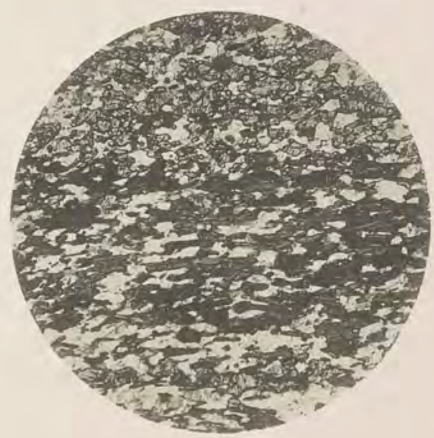

4.

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PHOTOMICROGRAPHS OF ROCK-SECTIONS.

CHAPTER V.

THE OLDER INTRUSIVE GNEISSES.

There are two groups of acid intrusive rocks in the Lizard peninsula, both of which are more or less foliated and gneissose. As they never come in contact with one another it is not possible to prove their relative age by showing that one series has been injected into the other, but there are certain distinctions between them, which, though not easily defined, indicate that one group is much older than the other. The earlier gneisses are always thoroughly metamorphic, but the later series, though in places intensely foliated, often show transitions to ordinary granites, and at times are nearly normal igneous rocks. From this we might infer that the first group had been involved in folding and metamorphism, that the second had escaped; but it is probable that there is also a difference in the character of the metamorphism. The older gneisses have very much the same kind and degree of foliation as the hornblende schists and mica schists among which they occur, and their metamorphism seems to be of the type often described as regional or dynamometamorphic, if we imply by these terms that it originated through folding and pressure after the rocks had cooled. The newer gneisses, which will be described in a later chapter, had their metamorphism induced on them as they were injected, and before they cooled down.

In their distribution there is also a marked difference between these two groups of gneisses, for the earlier occur only in the hornblende schists and mica schists, while the later are principally found invading the serpentine and gabbro. The probable explanation of this is that the older intrusions were anterior to the injection of the serpentine, while the later gneisses followed the serpentine and gabbro.

Among the older gneisses we recognise three types:—

(1.) The Man of War Gneiss, with the dykes and veins proceeding from it.
(2.) The Porthallow Gneiss.
(3.) Certain gneiss veins in the schists.

Although these rocks have a fairly wide distribution, they nowhere cover a considerable area, and it is impossible to show their outcrops on a small scale map.

The Man of War Gneisses.

The islands and reefs off the Lizard Point (Plate I.) were shown in 1888 by Mr. Howard Fox and Dr. Teall[1] to consist of hornblendic gneisses and schists, essentially different from any Lizard

[1] Howard Fox, 'On the Gneissic Rocks off the Lizard; with notes on the Specimens, by J. J. H. Teall.' *Quart. Jour. Geol. Soc.*, vol. 44, 1888, p. 309.

rocks described up to that time. They divided the islands into two groups, the outer ones consisting largely of coarse 'tonalite gneisses,' and the inner ones of granulites and granulitic gneiss. Associated with the gneisses and granulites there are basic eruptive rocks, some of which form well defined dykes, with porphyritic crystals of plagioclase felspar. All the rocks have suffered much dynamic metamorphism. They pointed out also that some of the rocks of the Labham reefs were intermediate in character between the granulitic rocks of the inner group of islands and the mica schists of Polpeor.

The coarse gneisses of the outer islands have a marked foliation; occasionally they show augen structure, but their especial characteristic is the sinuous or corrugated foliation with dark bands of hornblende and biotite alternating with grey quartzo-felspathic laminæ. Many boulders of these rocks may be seen on the beaches at the south end of the Lizard Point, and they are quite different from any of the metamorphic rocks of the mainland. The dark minerals are green hornblende and brown biotite, the latter usually weathered to chlorite and epidote. The felspars are orthoclase and plagioclase, often much decomposed, and may be replaced by aggregates of white mica and of prehnite. Many of the rocks prove on microscopic examination to have been severely crushed.

The islands which consist of rocks of this type are the Man of War, Taylor's, the Stags, Sanspareil, Mulvin, Men Par, Pen Ervan, and the Clidgas.

The fine-grained rocks of the inner islands are grey or yellowish granulites with a small amount of biotite, often weathered to chlorite, in a mosaic of granulitic quartz and felspar. Hornblende occurs also as small greenish prisms and needles, and many of these rocks contain a few pale-coloured garnets. Secondary muscovite, prehnite, epidote, and limonite are very common in the slides, but as mica is not abundant the rocks are not really schistose and are best described as grey banded granulites.

On the Quadrant, the Canker Drang, the Shag Rock and the Wiltshire the fine granulites preponderate; moreover, it is evident that they are merely the fine-grained margins of a laccolitic mass, as in all these islands coarse types like those of the Man of War Rock can also be found, and these coarser gneisses have the typical corrugated foliation. This relationship is especially evident on the Labham rocks and the Labham reefs. The former consist principally of a moderately coarse corrugated gneiss, but as we pass shorewards we meet with finer grained rocks of the same type, till, at the junction with the Lizard schists, the intrusive mass assumes the facies of a grey or pinkish, felspathic granulite, with a highly developed crush-banding parallel to the junction. Some micaceous granulites are also seen here, but they are igneous rocks, and the schist which they penetrate is the green hornblendic schist that is so common among the reefs at Polpeor.

This margin is very interesting as it is the best locality for examining that transition between the Lizard schists and the Man of War gneisses which was recognised by Mr. Fox and Dr. Teall. Bands of fissile, platy green schist alternate with bands of grey quartzo-felspathic granulite, both having a perfect linear foliation. There are also yellow, quartzose epidosites which might be sedimentary rocks or segregations in the gneiss. It is clear that there has been *lit par lit* injection of the green schists by the granites, from the frequent repetition of each type of rock, and that subsequently the whole complex has been sheared and has thus acquired its foliation.

Still clearer evidence of the intrusive character of the Man of War gneisses is obtained on the mainland at the south-west corner of Old Lizard Head. At the base of the cliff there is a great mass of grey granulite which is folded back and reappears in the grassy slope above (Plate II.). This granulite is exactly similar in its characters to the fine-grained rocks on the Quadrant and the Canker Drang; that it is an intrusive sill is proved by the rapid manner in which it thins out when followed eastwards along the base of the cliffs. Near its junction with the green schists the fine margin is full of porphyritic felspars, and the foliation in the granulite and the schist are concordant and similar. Not many yards to the north of this, at the base of the Old Lizard Head, there is another granulite sill, while to the east a smaller one makes its appearance in the green schists and the mica schists. At the upper margin of the last sill, in the path along the top of the cliffs a short distance east of the Quadrant Point, there seems to be a transition between the sill and the schist. This may be partly due to absorption, but is more probably the result of fine veining of schist with granite. The phenomena described prove that the chilled edges and apophyses of the Man of War gneisses are really in their normal position, and the faults or thrusts that occur along this coast in considerable numbers are not of great importance.

As was shown by Fox and Teall certain of the islands contain dark green basic types of gneiss or hornblendic schist. The Enoch Rock and the reefs which lie to the north of it consist mostly of a dark, coarse-grained hornblendic schist with weathered felspar and a tendency to augen structure; it contains veins and patches of epidote. With these occur finer hornblende schists, well foliated, and not unlike some of the schists around Housel Bay. On one of the islands close in below the cliffs of the Lizard Point (the Wiltshire) basic rocks of dark green colour also occur, with much hornblende and cloudy masses of decomposed felspar. They are very imperfectly foliated and may be regarded as crushed gabbros. Probably all these rocks represent basic marginal modifications of the Man of War gneisses; they may have sent apophyses into the Lizard schists, but these can no longer be distinguished.

The dominant north-north-west strike of the Lizard rocks is very well marked in these islands and reefs. It is conspicuous in the Man of War and the Quadrant, as was remarked by Mr. Fox, and is especially well seen in the Enoch Rock and the skerries to the north of it. On the Shag, the Wiltshire and other rocks close up under the cliffs the strike varies from north-west to west-north-west. Wherever these intrusives are in contact with the Lizard schists the two series have the same strike and foliation; hence we may infer that these gneisses were injected before the schistosity was developed in the older rocks of the Lizard.

Basic dykes of porphyritic hornblende schist cut the gneisses of the outlying islands in a great number of places. They are always much modified by pressure; as they seem to belong to the same group as the dykes in the mica schists of Polpeor and of Venton Hill Point, their description will be deferred till the whole series of basic dykes is described.

The Porthallow Granite Gneiss.

On the shore a little to the east of the inn at Porthallow, large angular blocks of pinkish granite gneiss are very common, and, in the cliffs above, this rock is seen forming a sill several feet thick in the brown mica schists. The junction of the two rocks is not well exposed but no distinct contact alteration can be made out. The granite gneiss is very well foliated with a typical gneissic structure, and shows abundant pinkish felspar, quartz, and a little white mica. Its nature was first recognised by Mr. J. H. Collins, who also made an analysis of it, and an excellent representation of its microscopic characters is given in one of the plates (No. XLII., Fig. 1) of Dr. Teall's 'British Petrography' [1].

The appearances presented by this rock in microscopic section vary with the amount of crushing which it has undergone. Often the porphyritic felspars have idiomorphic outlines fairly well preserved, but when the shearing has been extreme they are reduced to lenticular phacoids. They are orthoclase and albite, the latter preponderating. Much white mica is present, partly in large plates of irregular shape but chiefly as dense aggregates, presumably of secondary origin. The parallel arrangement of the mica gives the rock a distinct schistosity. Quartz is abundant, and always occurs as a granulitic mosaic mixed with felspar, which includes water-clear, re-crystallised albite. Biotite, sometimes weathered to chlorite, is present in small quantity; and there are the usual accessories, apatite, magnetite, and zircon. As in the fine granulites of the Man of War gneisses a few small pale-coloured garnets are visible in the slides.

An analysis of this rock has been made by Dr. Pollard in the Survey's laboratory; we quote along with it Mr. Collins's analysis. These show that the rock is a true granite, but exceptionally rich in soda. As this gneiss very closely resembles some of the more felspathic portions of the red mica schist of the same locality, there was a possibility that the latter rock was not

[1] J. H. Collins, 'On the Serpentine and Associated Rocks of Porthalla Cove,' *Quart. Jour. Geol. Soc.*, vol. 40, 1884, p. 464. T. G. Bonney and C. A. McMahon, 'Results of an Examination of the Crystalline Rocks of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 47, 1891, p. 482.

a sediment but only an extremely crushed form of granitic intrusion, in which the felspars had been to a large extent replaced by white mica, but a comparison of the analyses of the two rocks will dispel any uncertainty on this matter. (*See* analysis p. 35.)

—	I.	II.
SiO_2	74·35	72·95
TiO_2	0·18	—
Al_2O_3	14·70	11·50
Fe_2O_3	0·79	} 5·15
FeO	0·62	
MnO	0·07	—
(CoNi)O	? tr.	—
BaO	0·02	—
CaO	0·70	1·62
MgO	0·81	0·31
K_2O	1·67	} 5·41
Na_2O	5·29	
Li_2O	tr.	—
H_2O at 105° C.	0·11	} 1·60
H_2O above 105° C.	0·72	
P_2O_5	0·12	—
FeS_2	n. f.	—
CO_2	n. f.	(loss 1·46)
Total	100·15	100·00

I. Granite Gneiss, E. 6,625, intrusive into mica schists, shore east of Porthallow (Anal. Dr. W. Pollard).

II. Granite Gneiss, intrusive into mica schists, shore east of Porthallow (Anal. J. H. Collins[1]).

Gneissic Bands in the Hornblende Schists.

In many of the coast sections of the hornblende schists pale bands, rich in felspar and sometimes containing quartz, may be seen. In field work they are conveniently divided into two sets, (*a*) those which obviously cut the foliation of the schists in such a manner as to prove that they are subsequent to the development of the schistosity—these will be described with the later granites and the Kennack gneisses—and (*b*) those which show all the foliation of the hornblende schists and are concordant with it. The latter group probably includes thin veins which have been injected into the schists by the older granites anterior to the development of the foliation.

In the cliffs south of Porthallow, at Porthkerris and thence south to Porthoustock there are often pink quartzo-felspathic folia which vary from less than an inch up to a foot in thickness. They consist of alkali felspars and quartz, with sometimes muscovite, but more generally biotite and hornblende, and occasionally epidote and orthite; some of those at Porthkerris have exactly the same structure and composition as the granite gneiss of Porthallow (5241). Similar bands are seen in the quarries at

[1] *Loc cit.*

Carn Barrow, south of Cadgwith, very highly foliated, and in microscopic sections show also a great abundance of quartz and alkali felspar with remains of porphyritic structure. On Pen Olver also red granulitic bands may be seen in the hornblende schists. While many of these may be early granitic intrusions others might be interpreted as acid pegmatites, such as occur frequently in thick sills of dolerite.

In the coarse hornblende schists of the Traboe type felspathic folia are sometimes conspicuous. They seldom contain quartz and are often saussuritised; good examples are to be seen about Ugo Dour, near Pol Cornick. They probably represent anorthosites or highly felspathic streaks in the original gabbros, and have no connection with the older gneisses.

CHAPTER VI.

THE SERPENTINE.

The serpentine is undoubtedly the rock that gives its distinctive character to the geology of the Lizard. It occupies an area of approximately twenty-one square miles and no British serpentine mass rivals it in size except perhaps that which forms a large part of the islands of Unst and Fetlar in the extreme north of Shetland. The beauty and variety of the ornamental serpentine obtained in the Lizard have made this rock famous throughout the world.

On north and south it is bounded by outcrops of hornblende schist and mica schist except at Bochym and Chygarkye, where for short distances it is in contact with the less crystalline Palæozoic rocks of the Veryan Series. The gabbro boss of Crousa Downs penetrates it on the eastern side, and the granites and gneisses have invaded it as smaller masses of less regular shape that lie mostly in its central and south-eastern portions. On about one-half of its margin the serpentine reaches the sea, and its original boundaries cannot be located, but the distinctly rounded shape of the outcrop is sufficiently well indicated by the northern border and by the occurrence of patches of schist at Predannack on the west and at the Lizard Point.

The inland scenery of the serpentine is generally monotonous in character, for no rock has preserved better the flat contours of the Pliocene plateau. It has a pronounced individuality, however, partly from the sterile nature of the soils, which support a distinctive flora such as the Cornish heath (*Erica vagans*), and partly from the rusty brown colour so characteristic of the decomposition of this rock. Where the streams have cut valleys in the serpentine table-land another type of scenery prevails, as the rock emerges on the sides of the valleys in many pyramidal knolls with dark brown fretted surfaces. This is well seen at Kynance, Porth Mellin, and Arrowan. The serpentine furnishes some of the boldest cliff scenery in the Lizard, and the coves at Kynance and at Mullion are well known for their picturesqueness, being much frequented by landscape painters.

Varieties of Serpentine.

Three principal varieties of serpentine occur in the Lizard, each having distinct lithological features and a special area of distribution. They are all parts of one mass, however, and both in their occurrence in the field and in their minute petrographical characters pass into one another by a gradual transition.

Descriptions of the petrographical characters and microscopic structure of many specimens of serpentine from the Lizard will be found in Professor Bonney's papers enumerated on p. 33. In particular we may note that in 1883, in his paper 'On the Hornblendic and other Schists of the Lizard District,' *Quart. Jour. Geol. Soc.*, vol. 39, p. 23, he suggested a three-fold division of the serpentine similar to that adopted here. In Dr. Teall's 'British Petrography' (1888), p. 120, &c., a full account of the more prominent varieties is given, and five of the coloured plates of that book represent the microscopic structure of serpentines from the Lizard. Exigencies of space prevent us from quoting these descriptions *in extenso*, but it may be said that very few of the mineralogical and petrographical particulars given in this chapter have not already been pointed out by these writers. *See also* Harker's 'Petrology for Students' (1908), p. 105 ; Adye's 'Twentieth Century Atlas of Microscopical Petrography.' p. 43 ; Professor Bonney, 'Remarks on Serpentine,' *Geol. Mag.*, 1884, p. 406 ; 'On the Rauenthal Serpentine, *Geol. Mag.*, 1887, p. 68 ; 'Felspar in the Lizard Serpentine, *ibid.*, p. 238 ; Dr. Teall, 'The Lizard Serpentines,' *ibid.*, p. 137 ; Prof. Bonney and Miss C. A. Raisin, 'On the Microscopic Structure of Serpentine,' *Quart. Jour. Geol. Soc.*, vol. 61, 1905, p. 695 ; Miss C. A. Raisin, 'On the Nature and Origin of the Rauenthal Serpentine,' *Quart. Jour. Geol. Soc.*, vol, 53, 1897, p. 263 ; Dr. Teall, 'Notes on some Minerals from the Lizard,' *Mineralogical Magazine*, vol. viii., 1888, p. 116 ; J. H. Collins, 'On the Serpentine and associated Rocks of Porthalla Cove,' *Quart. Jour. Geol. Soc.*, vol. 40, 1884, p. 458, also 'On the Geological History of Cornish Serpentine Rocks,' *Geol. Mag.*, 1885, p. 298 ; F. Rutley, 'On a specimen of Banded Serpentine from the Lizard, Cornwall,' *Trans. Roy. Geol. Soc. Cornwall*, vol. 11, 1889, p. 239 ; R. Pearce, 'Note on Chrome Iron in the Serpentine of the Lizard,' *Trans. Roy. Geol. Soc. Cornwall*, vol. 9, 1870, p. 99 ; Howard Fox, 'Picotite in Serpentine' ; *Trans. Roy. Geol. Soc. Cornwall*, vol. 11, 1890, p. 336 ; Thomas Clark, 'Mineralogy of the North-eastern portion of the Lizard District,' *Jour. Roy. Inst. Cornwall*, vol. 10, 1890, p. 176 ; W. King and T. H. Rowney, 'On the Serpentinite of the Lizard,' *Phil. Mag.*, series 5, vol. i., 1876, p. 280.

The Lherzolite or Bastite Serpentine.—Of these varieties the best known is the serpentine that contains large crystals of bastite. This rock has usually a dark green fine-grained matrix of weathered olivine. The bastite crystals scattered through the rock are sometimes half-an-inch in length and are readily distinguished by their smooth platy cleavage and somewhat metallic lustre. Practically all the serpentine which is polished and used for ornaments is of this kind. Its varied appearance is due to the mode of decomposition of the original minerals. Sometimes the bastite has a yellow colour, forming blotches in the rock; or the olivine of the matrix may have its iron oxidised to red hæmatite, while the bastite remains dark green. In other specimens oxidation has taken place along certain cracks or veins, and streaks of bright red or yellow traverse a dark green background.

Under the microscope the olivine is granular and is enclosed in a mesh-work of serpentine and magnetite ; the alteration to serpentine is rarely complete and most specimens contain fresh olivine. The bastite in thin section is colourless or pale yellow, and when the rhombic pyroxene is fresh it is not dichroic and belongs to enstatite or bronzite ; it never forms crystals of regular shape and does not contain the dark schiller inclusions so frequent in this mineral. The cleavages are very perfect and in polarised light a lamellar structure is often visible as if the mineral were made up of alternating thin plates. From their oblique extinctions and higher polarisation colours it is probable that many of the lamellæ are diallage in parallel growth with the enstatite, but this can be proved only when the plates are not of extreme thinness, as they usually are. Colourless diallage is another common mineral of the coarse-grained serpentines (Plate VI., fig. 5), and hence, as Professor Bonney has pointed out, these rocks must be regarded as weathered 'lherzolites.' Diallage may not occur in some of the slides but it is so frequent that it must be considered a normal mineral of this group of rocks ; it decomposes less readily than the enstatite, passing into chlorite and tremolite. Dark schiller inclusions are not found in it but it has a very perfect platy structure in addition to the usual cleavage of pyroxene. Like the enstatite it is never eumorphic : its crystals are mostly small and tend to cluster together. Next in importance to these minerals is tremolite, or nearly colourless amphibole, which is rarely altogether absent and may occur in great quantity ; its crystals are always small, irregular and disseminated through the olivine which forms the matrix of the rock ; no brown hornblende occurs in the rocks of this type and the colourless amphibole is never in parallel growth with the pyroxenes—two facts which would lead us to believe that most of this mineral is of secondary development.

A small amount of basic felspar was evidently rather common in the lherzolites, if we are to judge by the frequency with which spots of cloudy 'saussurite' are observed in the sections. Very rarely is it possible to find this mineral in a fresh condition (6,277, 500 yards west-south-west of Trelan) but then it has the same properties as the felspar of the tremolite serpentine, and the manner of its decomposition leaves no doubt as to the origin of the saussurite in the other specimens. Its small grains are always of irregular form, and free from enclosed minerals. Iron oxides, both secondary and primary, occur in the slides but the common accessories are spinels such as chromite, chrome magnetite and picotite. Most of these are in shapeless grains of deep-green or brownish-green colour. Another constituent which, though rarely abundant, is by no means uncommon is chlorite, of a nearly colourless variety, polysynthetic, yielding grey polarisation tints and apparently belonging to clinochlore.

The Tremolite Serpentine.—The second important variety of serpentine in the Lizard district is the tremolite serpentine and tremolite olivine schist (Plate VI., figs. 3 and 4). This is a compact rock, non-porphyritic, and green or dark red in colour according to the state of oxidation of its iron compounds. It very seldom has a variegated or banded appearance and hence is not used for ornamental purposes. In hand specimens its most noticeable feature is the presence of small glittering pale-green crystals of tremolite, and as these often have a parallel arrangement the rocks tend to be fissile and to split into thin slabs.

The microscope shows that the principal component of these rocks also is olivine, which usually forms more than half their mass. It is more or less altered to serpentine with dusty magnetite which may have been oxidised to red hæmatite giving the rocks a dark red colour. Tremolite is usually also very common; it is colourless and non-pleochroic in section and with it there is often a brown or greenish brown kind of hornblende which has marginal growths of tremolite. Both of these occur in small prisms. not much longer than broad, and showing in cross section (Plate VI., fig. 3) the outlines of hornblende though these are seldom perfect; the terminations of the crystals are always jagged and irregular. Enstatite occurs frequently both in small grains and in larger crystals which make some approach to eumorphism, though well-shaped crystals are not found; it is colourless, free from schiller inclusions, and the larger grains are often intergrown with augite exactly as is the case in the lherzolite serpentine. A small amount of augite can be found in many of the slides; it is colourless and not schillerised, resembling the enstatite; and can be distinguished from that mineral only by its stronger polarisation and its smaller axial angle. The augite has never crystalline form, but may sometimes be moulded around the grains of olivine. In addition to these minerals felspar is very frequently present, in small rounded grains which may be untwinned or may show twinning on albite and pericline plans. It is a labradorite, approaching bytownite in composition, at any rate in those grains which are fresh enough to be determinable; but most commonly this mineral is replaced by turbid aggregates of saussurite Its presence in the tremolite serpentine was first recognised by Dr. Teall.[1] Iron oxides, chromite and picotite occur in this as in all the serpentines of the Lizard. A nearly colourless chlorite, sometimes with grey but at other times with dark blue polarisation tints may frequently be seen in the sections. It may be added that there is abundant evidence that though the tremolite is much more resistant to weathering than the olivine, it also decomposes with the formation of green aggregates of serpentine, which often retain traces of the hornblende cleavage.

The Dunite Serpentine.—The third variety of serpentine in the Lizard is a very compact rock which rarely shows any recognisable

[1] J. J. H. Teall, 'The Lizard Serpentines,' *Geol. Mag.*, 1887, p. 137.

crystals in the hand specimens. In colour it is dark green, sometimes streaked with pale green or brown; it breaks with a conchoidal fracture yielding smooth hollow surfaces which often have a semi-vitreous or resinous lustre, so that the specimens have much of the appearance of dark green flint or chert. A very distinctive feature of this rock in many of its occurrences is an intricate veining with chrysotile and other fibrous secondary kinds of serpentine. This is exceedingly well marked at Porthallow, in the quarries on the St. Keverne Road at Trelowarren lodge gates, and in many other places in the northern part of the serpentine area.

Under the microscope sections of this serpentine prove to consist almost entirely of olivine (Plate VI., fig. 1), with its secondary products serpentine and iron oxides. Hence the rounded mesh structure of rocks of this origin is perfectly exemplified. The commonest accessory mineral in this serpentine is probably tremolite which often occurs along certain bands or streaks and may be so abundant that the rock becomes a fine tremolite serpentine or tremolite rock. Scattered porphyritic crystals of enstatite occur also in many specimens; augite or diallage is far less common. Very frequently grains of chromite (Plate VI., fig. 1), chrome magnetite or picotite may be noted in the slides. None of the minerals, except occasionally the enstatite, forms well developed crystals.

Chromite Serpentine.—In addition to those three varieties which are the most important, other types of serpentine are present in the Lizard which may be regarded as local variations. One of the best marked is the chromite serpentine; this occurs in bands that vary from less than an inch up to two or three feet in thickness. They are frequently recognisable by their pale green or bright yellow matrix in which lie small black crystals of magnetite, chromite, or picotite. The latter are not over half an inch in size, and very rarely have crystalline faces. These chromite serpentines are always very rich in olivine and are fine grained; sometimes they contain tremolite, but large crystals of enstatite are hardly ever seen in them. They are evidently segregations of a basic character, and though the thin seams often look like dykes it is always clear that they are really fluxion bands. In the Tertiary peridotites of the Inner Hebrides exactly similar rocks occur and have identical relations with the peridotites[1]. As a rule the amount of chromite is quite small (one or two per cent.) so that there is no possibility of working these rocks as ore-deposits. They may occur in any of the types of serpentine described above, but are most noticeable and probably most numerous in the coarse lherzolite serpentine. Every good exposure of that rock along the coast line will yield examples of chromite banding; often they are repeated every ten or twenty yards. From Kynance to Carrick Luz they are generally pale yellow in colour, but along the coast east of this to Coverack they are commonly dark brown, and being very fine grained might easily be confounded with the thin black rotten dykes so frequent in this locality. About Dolor Point and Chynhalls several parallel bands, with an average breadth from six inches to a foot, of fine brown chromite serpentine, may often be seen within a space of a few yards; generally they are sharply defined at their edges and very distinct from the bastite serpentine.

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[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' (*Mem. Geol. Surv.*), 1904, p. 76.

Tremolite Schists.—Along narrow belts of crushing and displacement the serpentine is very often converted into pale green talc tremolite anthophyllite schists (Plate VI., fig. 6). The anthophyllite and tremolite are always colourless, and are most easily distinguished from one another by the extinctions of the fine cleavage prisms obtained on gently crushing the rock. Some of the schists contain very little but anthophyllite; others have an admixture of tremolite and talc. In every case the olivine, enstatite, and augite of the serpentine have disappeared, and the rocks have acquired a perfect schistosity. These thin seams may be mistaken for dykes, as the serpentine on each side of them is very little modified; they are common in all districts of the Lizard serpentine and on the coast are often eroded into gullies and recesses. That they are due to displacement can be shown frequently by the shifting of fluxion bands or intrusive dykes. It is possible that the serpentine may sometimes weather to talc, but this must be exceptional and without doubt the vast majority of these thin seams of talc and anthophyllite schist are really due to crushing of the serpentine at a period long after it had consolidated and cooled. The occurrences of these schists are so numerous that it is hardly necessary to cite localities where they may be observed, but specimens may be got at Mullion Cove, Kynance, The Balk, Carn Barrow, and at many points on the shores of Kennack Bay.

Distribution of the Principal Types of Serpentine.

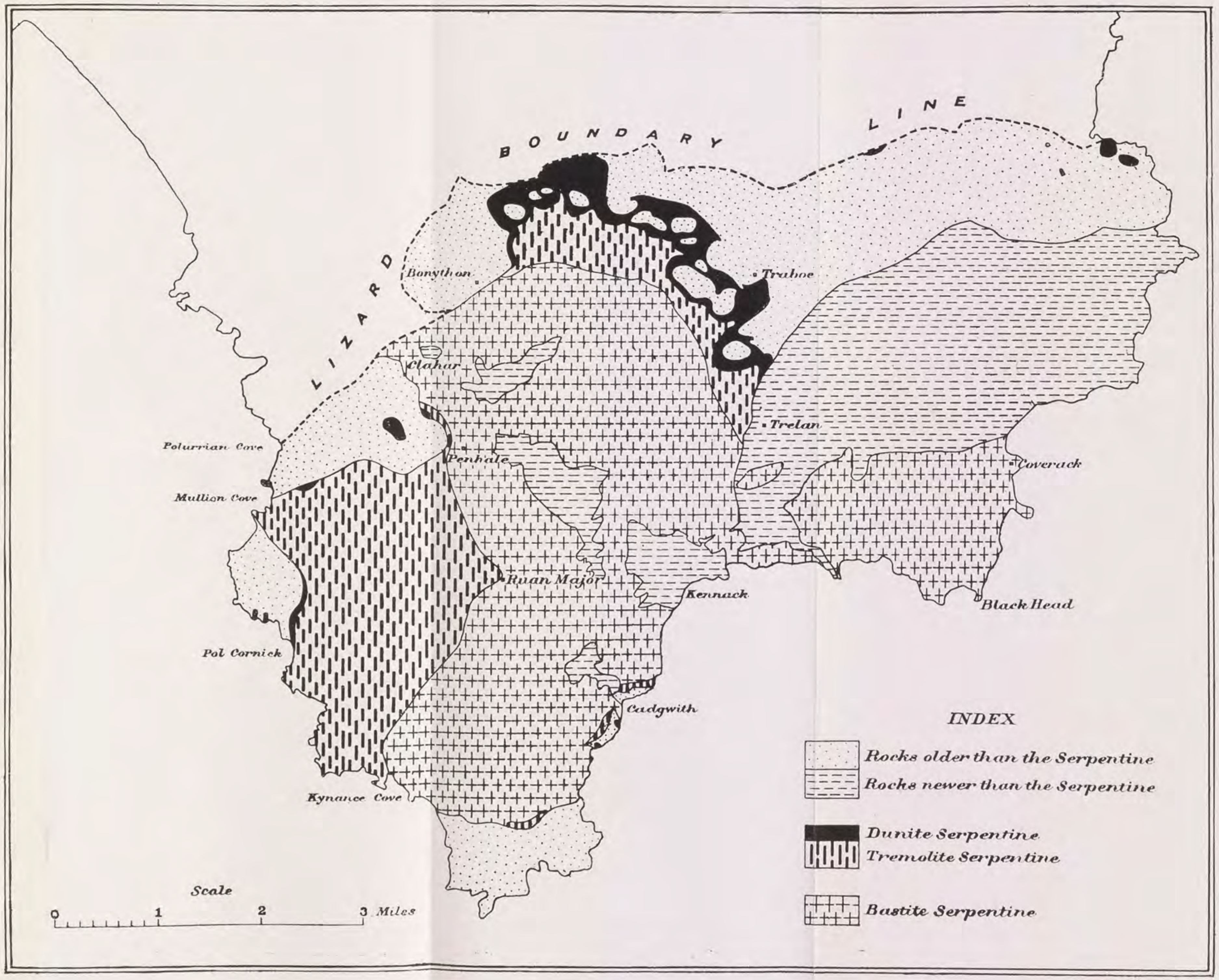
The bastite serpentine or lherzolite occupies the whole of the eastern portion of the serpentine district extending along the shore from Coverack to the Lion Rock at Kynance (Plate IV.). It forms also nearly the whole central area around Ruan Minor and Goonhilly Downs.

The tremolite serpentine extends roughly from Kynance to Mullion Cove, along the west coast. The inland boundary runs from Kynance to the Old Windmill and thence to Ruan Major Church; it passes northwards to the west of Penhale. Rocks of this type occur also, though only scantily, along the margin of the hornblende schists to the fault at Clahar. A strip of tremolite serpentine about a mile in breadth follows the northern margin of the serpentine from Bonython to Kernewas; similar rocks also occur in the small outlying serpentine masses at Mullion, Porthallow and Porthkerris, Pengarrock and Halwyn. Minor areas of tremolite serpentine are found along the eastern and southern edge of the lherzolite, at the Frying Pan at Cadgwith, and from there south to Carn Barrow, where it is well exposed in one of the quarries. North of Enys Head there is a small patch of tremolite serpentine exposed in the cliffs about two hundred yards south of Carleon Cove, and, as Professor Bonney has noted, there is also an outcrop of this rock in the cliffs below the serpentine quarry on Kildown Point. At the Lizard, in a quarry near the Methodist Church, on the south side of the village, tremolite serpentine is at present worked. At all these points the junction of the serpentine with the hornblende schists is a faulted one. There is an area of tremolite serpentine in the bastite serpentine to the south of Ruan Minor, which extends along the northern slope of the Cadgwith Valley from a point about four hundred yards east of St. Ruan to the quarries in the fields behind the cliff at Kildown. This tremolite serpentine is seen in many rocky knolls in the fields. To the south-west of Chyheira, near Grade Church, there are pits in tremolite serpentine, but very little of this rock is to be seen at that locality.

The distribution of the tremolite serpentine shows that it is the peripheral and the lherzolite is the central portion of the mass. Where the boundary is faulted the tremolite serpentine may be absent, or occurs only in detached patches along the line of fault (as for example to the north and south of Cadgwith, and at the Lizard). Where the boundary is of the folded type there is always a broader or narrower zone of tremolite serpentine between the lherzolite and the schists; it is cut out here and there by faults, and becomes very narrow in places, as for example at Clahar, east of Mullion, but broadens out on the north side of Goonhilly Downs and in Kynance Downs to the west of the Lizard Road till it covers an area nearly two miles in width. The small masses of tremolite serpentine in the bastite serpentine near Grade Church are probably enclosures of an older rock in a later one.

The fine dunite serpentine has a very restricted distribution (Plate IV.); it is found only at the very edge of the serpentine where that is in practically unbroken contact with the schists. On the west coast it is first met with at Pol Cornick, where there is not much of it, and it forms also the small outlying masses in the cliffs of hornblende schist on the south side of Predannack. The infolds of serpentine north of Mullion Cove (at Henscath and below the Mullion Cove Hotel) contain dunite serpentine and very fine tremolite serpentine, and the infolded serpentine mass at Meaver, east of Mullion, consists also of these rocks; east of Meaver dunite serpentine is seen in one small quarry, but it is very scarce along this part of the margin. From Bonython, however, all the way round to Kernewas the fine-grained flinty-looking serpentine is the characteristic rock not only in the immediate vicinity of the hornblende schist but also for a variable distance, sometimes amounting to several hundred yards from the margin. Very good exposures of it may be seen at Burnoon, Trevassack, Trelowarren Lodges, Trezise, Traboe, and Kernewas, as in all these places quarries have been opened at the margin of the serpentine. The outlying exposures in the hornblende schists at Porthallow, Porthkerris, Halwyn, Pengarrock, and Rosemorder are either the dunite serpentine or that rock mixed with fine tremolitic serpentine; the peculiarly compact nature and abundant veins of secondary serpentine in the mass at Porthallow have been remarked by more than one observer.

Along the south and east borders of the serpentine, in the neighbourhood of the Lizard and Cadgwith, the junction of the serpentine with the schists takes place with the intervention of a fault. The fine dunite serpentine has been observed in only two spots in this district (Plate IV.). On the top of the cliffs at Carn Barrow there are three quarries very close together; one of



Map to show the distribution of the three types of Serpentine.

these contains hornblende schist and is at present worked for road metal, the two others are in serpentine. The quarry on the north-west is tremolite serpentine for the most part but on the west side some bastite serpentine may be found in a very decomposed state. On the east, however, there is a small old quarry which shows hornblende schist mixed with serpentine. The two rocks may be folded together or the serpentine may be intrusive into the schist, but the exposures are too bad to settle this point. The important fact is that where the serpentine and hornblende schist come in contact the former rock is a fine dunite serpentine with smooth glossy fracture, exactly like the rocks on the northern border.

On the north-east side of the entrance to the Devil's Frying Pan at Cadgwith the cliff is composed of hornblende schist and banded gneisses. Among these one small lenticle of serpentine is visible; it is of the fine flinty, veined type. About fifty yards to the west the main outcrop of serpentine begins, and is exposed on the western side of the interior of the Frying Pan; it belongs to the tremolite serpentine and is clearly faulted against the hornblende schists and banded gneisses. There seems little reason to doubt that the flinty serpentine in the schists on the east face of the cliff is the true intrusive edge of the serpentine mass.

From the facts given above it is clear that the dunite was the marginal facies, the tremolite serpentine adjoins it, forming a broad or narrow zone, and the coarse lherzolite or bastite serpentine is the central rock. Along the north and west boundary of the serpentine these three rocks succeed one another in the order given. This establishes that the serpentine mass is a large intrusion of which the dunite was a fine-grained basic marginal modification. It is not properly a chilled edge, though the most finely crystalline of the varieties of serpentine found in the Lizard, because there is proof, as we shall see, that the schists were intensely hot at the time the serpentine was intruded; in fact there are frequent passages or intermediate stages between the schist and the serpentine.

The dunite passes into the tremolite serpentine and the tremolite serpentine into the lherzolite in a perfectly gradual fashion in many parts of the Lizard area; hence they are to be regarded as facies of one mass and not separate intrusions. The dunite serpentine is often tremolitic, and in it fluxion bands rich in tremolite are also frequent. Around Traboe, especially, many of the quarries yield streaky and banded dunite serpentines, with alternate seams rich in olivine and in tremolite. At Henscath (near Mullion Cove), Meaver (near Mullion), Porthallow, and Porthkerris, to mention only a few localities, there is the most intimate association of tremolite and dunite serpentine. Furthermore, the tremolite serpentine often contains large lenticular crystals of bastite, and these also are seen occasionally in the dunite. Both Dr. Teall and Professor Bonney have recorded instances of this. Excellent examples of these porphyritic tremolite serpentines are to be obtained in the district between Mullion Cove and Predannack, and they may be picked up on the beach at Kynance Cove or found *in situ* in the cliffs to the west of it.

Only in the southern part of the district is the junction between these two rock types a sudden one. Both north and south of Cadgwith tremolite serpentines occur in several places in very close proximity to typical bastite serpentine. As examples we may mention the Frying Pan and the section below the quarry at Kildown Point; in these cases the rocks are either faulted against one another or the lherzolite may have caught up and enclosed portions of the older rock. At Kynance tremolite serpentine forms the district to the west of the Cove, but east of the Lion Rock coarse bastite serpentine suddenly comes in; the junction is exceedingly well-defined and there is no real transition; it is accompanied by brecciation and slickensiding, and for this reason we assume that it is a fault (Fig. 5, p. 124). In contrast with this the north and north-east part of Goonhilly Downs shows these two rocks passing into one another so gradually that it is quite impossible to lay down a hard and fast line between them.

Fluxion Banding in the Serpentine.

In all varieties of the Lizard serpentine fluxion banding is a very common phenomenon (Plate V., fig. 1). It is marked by slight variations in the composition of the rock. On the one hand there are bands very rich in olivine (with chromite and other spinels) weathering to pale yellow or dark brown fine-grained rocks as already described; on the other hand there are bands poor in olivine but consisting nearly entirely of pale green pyroxene (both enstatite and augite or diallage). An exactly similar banding has been described from the peridotites of Skye[1], where, as in the Lizard, the fluxion structure produces a streaked appearance on weathered faces of the rocks. The pyroxenes disintegrate less rapidly than the olivine and project in consequence; where they are abundant the rock has rough prominent ridges; these bands may be three or four inches in breadth but are usually less than an inch, and while the thickest can often be followed for several yards, the thinner soon die out and are replaced by others. This structure though most evident in weathered specimens (Plate V., fig. 1) is also shown very well by many polished sections of the coarse serpentine.

In the finer-grained serpentines the pyroxene bands consist of smaller crystals, like those found in the matrix of the rock; the bands are thin and frequently repeated, so that three or more may be found separated by darker layers of olivine serpentine in a thickness of an inch. Often the green pyroxene has been replaced wholly or in part by tremolite, and many of the bands consist entirely of colourless amphibole. They are very frequent in the Porthallow serpentine where they are often bent into sharp curves and have caused much confusion by being mistaken for inclusions of the hornblende schists; they may be seen also in the quarries on the edge of the serpentine at Traboe and Trezise. The chromiferous bands are thicker and much more persistent; in

[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' (*Mem. Geol. Surv.*), 1904, p. 75 and Plate II.

good shore exposures they can often be followed for many yards. They have generally a winding course and resemble in this respect the fluxion bands in the gabbros of Skye[1].

Augen Structure and Foliation in the Serpentine.

In some parts of the Lizard nearly normal peridotites occur which could with difficulty be distinguished from unmodified igneous rocks. The dunite, for example, when it has consisted entirely of olivine weathers to a serpentine with the usual mesh structure and shows no sign of deformation or foliation (Plate VI., fig. 1). As this rock has been folded with the schists we infer that pure olivine rocks become granulitised but are not much altered in structure. More commonly however, there are bands of tremolite; often also the large enstatites which occur in this rock are crushed and broken, forming augen fringed with tremolite. The tremolite serpentine very rarely is massive and then it may contain a good deal of augite; nearly everywhere it has a fine banding, best seen on weathered surfaces, and in the porphyritic varieties the large crystals of pyroxene are reduced to flattened lenticles surrounded by zones of tremolite. The coarse serpentines of the Lizard are very massive in appearance in some places, as at the west side of Kennack, around Treal, in the district to the south and west of Coverack and along the shore in the cove north of Pen Voose[2] (near the Balk, Landewednack). At other places, however, it has a most perfect augen structure (Plate VI., fig. 5), exactly like that of the augen-gabbro of Carrick Luz. Among localities for these augen serpentines the most accessible are perhaps Pentreath Beach, between the Lizard and Kynance, the north side of Poltesco Cove (below the old serpentine works), and the shore at the east side of Kennack Cove. The large yellow and green crystals of pyroxene have well marked lenticular shapes with their long axes all pointing in the same direction, and are surrounded by an unfoliated matrix of serpentine. This is most readily observed in the large rounded boulders which have been scoured and smoothed by the waves. In these serpentines, especially that of Pentreath, there is also a very large development of tremolite, which forms tails to the elliptical augen of bastite.

Only exceptionally do these serpentines pass into real schists. Near zones of crushing and displacement there is often a development of pale green schists consisting of anthophyllite, tremolite, chlorite, and talc, as has been already described, but this is a phenomenon of late origin, and is in no way to be confused with the primary foliation which is now under consideration. The tremolite serpentine, however, often assumes a schistose character (Plate VI., fig. 4), being filled with small pale green prisms

[1] Sir A. Geikie and Dr. J. J. H. Teall, 'On the banded Structure of some Tertiary Gabbros in the Isle of Skye,' *Quart. Journ. Geol. Soc.*, vol. 50, 1894, p. 645.

[2] Dr. Teall has pointed out (*Geol. Mag.*, 1886, p. 483) that there are two coves in this locality, one called Pen Voose, the other Parn Voose. We make use only of the name Pen Voose in this Memoir, to mean the bathing-cove north of the Balk. Parn Voose is the same as Church Cove.

of tremolite, all of which have a parallel orientation and lie in a matrix of serpentine. This is the tremolite olivine schist, an entirely distinct rock from the tremolite and anthophyllite schists which contain no olivine. When enstatite crystals occur in this rock they are always of very lenticular shape; a perfect fissility is also produced by the orientated crystals of tremolite. Rocks of this type are fairly common but do not have an extensive development in any one place; like the more perfect gabbro schists they are of sporadic distribution. They are frequently met with along the northern boundary line especially where the exposures of the junction of serpentine and hornblende schists are good. In the area between Mullion Cove and Predannack they are often seen, both along the cliffs and inland, and they occur also on the west side of Kynance about Lawarnick Pit (Plate VI., fig. 4) and between that and the Rill.

Microscopic examination of the Lizard serpentines leads to the conclusion that but few of them can be described as normal igneous rocks. In peridotites consisting of pyroxene or hornblende and olivine it is usual to find that the olivine occurs as rounded grains enclosed in large ophitic plates of the other minerals (poikilitic structure or lustre mottling). This is never seen in the Lizard serpentines though occasionally there are traces of it in the coarse lherzolite. An enstatite crystal may surround a few olivines, but the majority of the large pyroxene crystals are free from enclosures of this sort. In the dunite serpentine, though large crystals of enstatite occur frequently they do not contain olivine, and may show traces of idiomorphic forms which prove that they are early crystallisations; but in the bastite serpentine the enstatite is not idiomorphic and often is moulded on the olivine in such a way as to prove that it is a late mineral. Moreover, in all the varieties of serpentine the large pyroxene crystals are very commonly broken or have their cleavage planes so twisted as to indicate that they have undergone severe strains; it is probable that when poikilitic masses of enstatite were formed they were especially liable to rupture during the subsequent movements in which the matrix was involved.

It is a well known fact that under pressure tremolite and other forms of amphibole tend to replace the pyroxenes and olivines of basic and ultrabasic igneous rocks. Now tremolite is one of the most common minerals in all varieties of the Lizard serpentine; in normal igneous peridotites it is rare or absent, as for example, in the Tertiary peridotites of Skye and Rum. In the Lizard rocks which are least sheared or show fewest pressure effects it appears seldom and in small amount, and increases hand in hand with the development of foliation and augen structure. These phenomena are identical with those displayed by the flaser gabbro and the epidiorites, only in these rocks the hornblende is green actinolite not colourless tremolite. The brownish hornblende of the tremolite serpentine is very probably in large part a primary or igneous mineral. But there is convincing evidence that by far the greater portion of the tremolite has arisen in the rock when it was already solid but not yet entirely cold by those crushing stresses which broke down the larger pyroxene crystals and deformed their cleavage planes. The tremolite replaces augite for the most part but develops also from enstatite (or the intergrowth of enstatite and diallage), and possibly even to some extent from olivine.

In discussing the origin of the fluxion banding and foliation of the Lizard serpentines there are two points which are of the highest importance. The first is that the fluxion banding and the foliation were produced before the rock had cooled down; the second that they are practically invariably parallel to one another.

In all parts of the Lizard veins of gabbro cut the serpentine (Plate VIII.); they are often exceedingly coarse grained and never pass into finely crystalline dolerites or show chilled edges against the country rock; this proves conclusively that at the time these veins were injected the serpentine was still hot though perfectly solid. Now these gabbro veins always cut sharply the fluxion banding, the augen structure, and the foliation of the serpentine, and if the gabbro dykes are foliated (as they often are) their foliation is of quite a distinct type from that of the serpentine and very rarely corresponds with it in direction. But massive dykes of gabbro are found in many parts of the district cutting banded and foliated serpentine. A case in point was described by Fox and Teall[1] in 1893 at Pol Cornick, where two gabbro dykes traverse the folded serpentine, near its junction with the hornblende schists, and cross the strike of the foliation.

On the Coverack shore many gabbro dykes are unfoliated or little foliated and intersect the banding of the serpentine (Fig. 2, p. 94); this can be seen (Fig. 6, p. 127) on both sides of Kennack Cove and at Carrick Luz. On the south-east side of Enys Head there is a bare slope of serpentine a little distance above high water mark. The serpentine has the usual banding, and in microscopic sections shows flaser structure due to crushing of the large enstatite crystals. Several dykes of greenish yellow saussuritic gabbro occur in it; they run for ten or twenty yards, often branching, and have a thickness of a foot or more, but taper out rather suddenly. Some of them are shifted by small faults, but they have certainly not undergone any shearing or distortion of importance, as their shapes are in every way similar to those of the pegmatite veins in many granite masses which are entirely massive. These facts show that the banding and augen structure of the serpentine are essentially older than the injection of the gabbro veins. We may remark, however, that in the serpentine there is sometimes a development of foliation which is subsequent to these veins, and involves them also, but this is a local phenomenon, and can easily be distinguished from the foliation with which we are now concerned. It will be considered when we describe the metamorphism of the gabbro veins.

The foliation or flaser structure, and the fluxion banding are parallel to one another. In the coarse bastite serpentine the long axes of the elliptical bastites all point in the same direction, and this corresponds with the orientation of the bands of pyroxene

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[1] Howard Fox and J. J. H. Teall, 'Notes on some Coast-sections at the Lizard,' *Quart. Journ. Geol. Soc.*, vol. 49, 1893, p. 204.

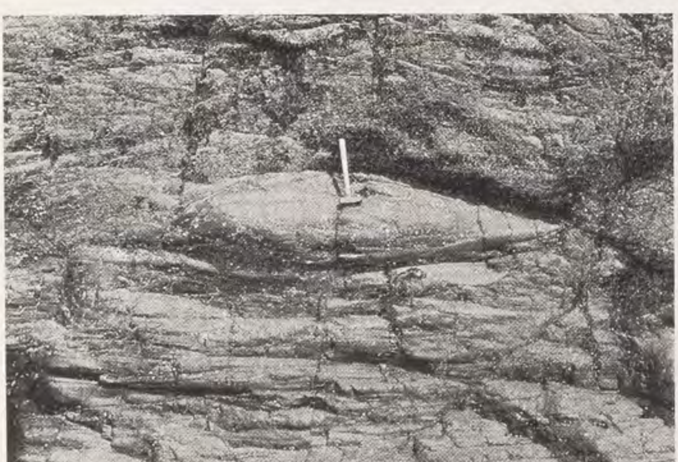
serpentine or chromite serpentine. This is very well seen in many places where there are large boulders on the beach, as for example at Pentreath, Poltesco, the east side of Kennack, and the coves south of Coverack. Very good examples of it may be observed in some of the polished specimens which are sold in the shops, though the broader pyroxene bands are not suitable for ornamental work, and only a narrow banding is found in the polished rocks. At Poltesco serpentine works there are large slabs which have been sawn, and on their plane surfaces, especially when wet, the pyroxene streaks and the augen structure are exceptionally distinct. In these slabs we may occasionally find that, especially when the fluxion bands are sinuous, the direction of foliation and the orientation of the enstatite ellipsoids cross the fluxion structures obliquely, but this is unusual, and the general parallelism is very striking. In the tremolite serpentine the same phenomena are evident, both in the banded marginal rock which has stripes of tremolitic or pyroxenic composition, and in the porphyritic tremolite olivine schist; in these rocks the foliation is more apparent than the fluxion, but wherever structures are visible which may be referred to the flow of a partially differentiated magma, these have the same orientation as the tremolite prisms which give the rock its schistosity. This phenomenon is one of the most remarkable in the Lizard, and our interest in it is not lessened by the fact that in all the later intrusions it is also present, and usually more obvious than in the serpentine.

Relations of the Serpentine to the Hornblende Schists.

It has already been pointed out that the boundary of the serpentine from Kildown Point, north of Cadgwith, to Pentreath Beach, on the west coast between Kynance and the Lizard, is everywhere faulted. At several places along this stretch of coast the actual junction is exposed in the shore sections, as for example at Kildown Point, in the Devil's Frying Pan, at the Balk and the south corner of Pentreath Beach, and in all these localities it is evidently a fault. Moreover, when the margin of the serpentine is followed across country it proves to have a straight or gently inflected course; no masses of schist are known to occur within the serpentine along this edge.

But from Pol Cornick round by Mullion to Kernewas the boundary is of a different type. For long distances its course is sinuous or undulating, so that though in the main the north end of the serpentine describes a great curve with its concavity to the south, this curve it not simple but is complicated by many smaller inflections (Plate IV.). Within the boundary of the serpentine there are very numerous areas of hornblende schist, as may be seen on the map; many of these are of considerable size (a hundred acres or more in extent) while others are very small, and when the exposures are good the small enclosures may be found in great numbers. The serpentine has been folded with the schists along great arches and troughs with nearly vertical axes, and the margin is often very difficult to locate because the rocks are repeated by the folding. In some parts of this district there are sharply

Foliation banding in the Serpentine.



Greenstone Mass in Mica Schists at Polpeor.

defined boundary faults, as for example, on the north side of Predannack, at Mullion Cove, and at Bonython. These faults are all seen in section on the coast, but even if that were not the case the nature of the junction would not be in doubt as the straight, clean-cut, faulted edge maps out in quite a different way from the folded margin. These faults in fact die out when they are traced inland and then the boundary becomes difficult to locate, sinuous, and attended by complicated interfolding of the two rock types.

That there has been extensive folding of schists and serpentine along this margin can be established in two ways: firstly, by the existence of small folds which can be inspected in the coast sections; and, secondly, by larger infolds which have a common foliation with the surrounding serpentine.

At Porthallow, as was shown in 1884 by Mr. Collins[1], interfolding of serpentine and schists may be noted in several places. As in all the coast exposures in the Lizard there are many small faults at this place, especially at the junction of two formations; thus the first mass of serpentine met with on the shore as we go eastwards from the cove, is not certainly in unbroken continuity with the adjacent hornblende schists, though any dislocations which are present are of small magnitude; but about two hundred yards further east, following the raised beach platform exposed at low water below the cliffs, we may find excellent examples of folded bands of hornblende schist in serpentine. Both rocks have a streaky banding or foliation, and this is parallel to their junction. In other words the streaking of the serpentine, which has been very well figured by Professor Bonney[2], is the same thing as the foliation of the hornblende schist. The best of these folds are seen on the west side of a gravelly cove a little to the west of the stone quarry at Pol Gwarra, and about seventy yards west of the point where the beach below the cliff comes to an end. There are at least four localities in this section where excellent folds are visible, though some of them are at times covered by the *débris* thrown out from the stone quarries and washed by storms along the shore. Three of them are sharp with vertical sides, and have the north-north-east trend which characterises all the foliation from Porthoustock to Porthallow. In the serpentine there are also fine greenish tremolitic fluxion bands, and these are often thrown into small steep folds of which hand specimens can readily be picked up among the pebbles on the beach.

At Pol Cornick, on the opposite side of the peninsula the folded margin also emerges to the coast; here it was made the subject of very detailed investigation by Mr. Howard Fox and Dr. Teall[3]. The exact locality which they described and mapped will be found

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[1] J. H. Collins, 'On the Serpentine and Associated Rocks of Porthalla Cove,' *Quart. Journ. Geol. Soc.*, vol. 40, 1884, p. 458.

[2] *Quart. Journ. Geol. Soc.*, vol. 47, 1891, Plate XVI.

[3] Howard Fox, 'On the Junction of Hornblende Schist and Serpentine in the Ogo Dour District (with notes by J. J. H. Teall),' *Trans. Roy. Geol. Soc. Cornwall*, vol. 11, 1889, p. 213.

Howard Fox and J. J. H. Teall, 'Notes on some Coast-sections at the Lizard,' *Quart. Journ. Geol. Soc.*, vol. 49, 1893, p. 199.

by following the grassy slope where the height of the cliff suddenly diminishes from about two hundred feet to less than one hundred; at the base of the slope there is a rock ledge down which one can pass without difficulty to the rocks forming 'Potstone Point.' The rocks there are seamed with gullies, but are bare of *débris*; to the south, however, the cliff faces are covered with broken rock which renders the exposures discontinuous and obscures the geological structure.

They directed attention specially to two points, one being the interbanding of the schist and serpentine while the other is the folding and faulting of the complex. "Serpentine is here the prevailing rock, but it contains thick and thin bands of schist. The interbanding or interlamination, as it may be termed, is often on so minute a scale that microscopic sections may be prepared to illustrate it. One hand specimen from which a section has been cut shows a conspicuous band of hornblende-schist about ¼ inch in thickness, traversing the specimen throughout, and other much thinner and less persistent folia. The main mass of the specimen is composed of olivine, hornblende, serpentine after one or both of these minerals, the characteristic network of magnetite, and a few grains of picotite. The hornblende-schist is composed of pale-brown hornblende, colourless malacolite, and more or less altered felspar. Another specimen from the same locality illustrates the interbanding of the two types of rock in a still more perfect manner. Numerous laminae, no thicker than sheets of cardboard, alternate with one another. The bands of schist are composed of hornblende, malacolite, and turbid felspar. In some bands the hornblende is pale green in colour, in others brown. Detached olivines with strings of magnetite may be observed along certain planes, and by the increase in the number of these olivines and in the thickness of the zone in which they are developed bands of peridotite have been formed, and from these serpentine has been produced in the usual way. As the olivine increases the felspar diminishes, but the hornblende of the serpentine is absolutely identical in structure and mode of development with that of the schist. The serpentines interbanded with the schists belong to the olivine-hornblende variety. They are themselves frequently well banded; and this banding, so far as we have been able to determine, is parallel with that of the schist, when allowance is made for the effects of disturbance.

"We have now to consider the effects of folding and faulting in the banded complex of schist and serpentine. These may be studied at the neck at the small promontory which for convenience of description we have called Potstone Point, and also on the cliff-slopes south-east of it. On the eastern margin of the banded schist the serpentine is distinctly seen to be folded with the schist."

To this account we have nothing to add except that the white pyroxene of the hornblende schist is not only malacolite but also enstatite, and the presence of enstatite as well as olivine in the schist is additional proof that there is here a transition or an intermixture of the two types of rock. The slides cut from the banded complex at the junction show very little evidence of crushing or internal movement in the solid condition; there is little development of tremolite, and the minerals are exceptionally fresh.

At the junction of the serpentine and the hornblende schist we have the following phenomena:—

(*a*.) The fluxion banding in the serpentine as marked by laminae rich in olivine, and others containing more tremolite or pyroxene.

(*b*.) The foliation in the serpentine, as shown by the orientation of the tremolite prisms and other minerals of the rock.

(*c*.) The banding and foliation of the hornblende schist, produced by the alternation of felspathic and hornblendic folia, and by orientation of the minerals.

(*d*.) The actual line of junction between the two sets of rocks.

Now these four structures are always parallel to one another in every satisfactory exposure of the margin of the serpentine which has yet been found in the Lizard district.

We have also to consider:—

(*e.*) The folding of the complex, and

(*f.*) The presence of a zone of intermediate character between the extreme types of rock.

At Porthallow all these phenomena can be seen almost as well as at Pol Cornick, but the transition zone is by no means so well preserved as there has been much weathering and probably also interstitial movement with the production of tremolite, actinolite, and chlorite.

The other exposures of the actual junction, where faulting is absent or unimportant, are less than a dozen in number, but they all show the phenomena above described with more or less perfection. One of the best is on the south side of Predannack about a quarter of a mile to the north-west of Pol Cornick, on the top of the cliff and a few yards below the footpath from Kynance to Mullion Cove. This locality is sometimes called Parc Bean. Here a mass of serpentine rises through the hornblende schists and its top is dissected in the flat rocky ledge at the margin of the cliff; it shows a beautiful fold, pitching to the north and vertical on its sides. The serpentine is very fine grained and has weathered to a brown waxy-looking substance. Folded bands of hornblende schist lie in it and the foliation of both rocks follows their arched junction. Unfortunately the specimens obtainable here are much more decomposed but one slide taken from the schist proves to contain rhombic pyroxene like the junction rocks at Pol Cornick. On Henscath, the rocky islet before the Mullion Cove Hotel, the main junction is a faulted one but in the serpentine there is a canoe-shaped infold of fine rotten hornblende schist and the banding of both rocks is parallel with their junction. The fine tremolite serpentine, which is here the prevailing type, passes into a very fine brown resinous serpentine for a distance of a few feet from the margin.

The inland exposures are necessarily less clear and instructive than those provided by the coast-sections. They furnish, however, a mass of confirmatory evidence which is of great value. The fault which runs up from Mullion Cove seems to die out after passing Trenance, and in a small farm-road about a sixth of a mile south of Tresprison the junction of schist and serpentine is exposed; both rocks have a similar banding and foliation, which strikes due east and west, being parallel to the edge of the schists at this point. The foliation is vertical. No actual junction is seen again till we pass Burnoon, and half a mile to the north-east of this, in a farm road (marked on the one-inch map), bands of hornblende schist occur in the serpentine, striking east-north-east, or parallel to the boundary of the hornblende schists, which here as at Pol Cornick consist very largely of brown hornblende. In the bed of a small stream, at a bend 420 yards north 5° east of Trevassack, Mr. Hill obtained specimens of banded hornblende schist containing olivine, like those at Potstone Point; this is within a few feet of the serpentine. After crossing the St. Keverne road we find a quarry on the south of the road to Newtown, four hundred yards to the west of Trezise (of two quarries by the roadside this is the more distant from the farm). In this quarry the flinty serpentine is worked; the junction with the hornblende schist is exposed on the north side of the quarry; the foliation of schist and serpentine is well seen and is parallel and concordant with the junction. The rocks are shown into sharp folds which strike west to west-north-west and dip under the serpentine. In 1908 the rounded back of one of these folds was laid bare during the quarrying operations. The schist is rather rotten and no transition zone can be made out; moreover there is a considerable development of anthophyllite schist from the serpentine at this spot.

Around Traboe junctions are often seen in the small quarries which are numerous there, and as they are all near the main roads they can be easily visited. There is a quarry in the downs on the south of the village which is at present used as a source of road metal. The rock is mostly serpentine and is broken and slickensided, probably by the fault which comes up from the north-west past Relowas and Trezise. In this quarry there are at least two infolds of hornblende schist. The foliation in these and in the serpentine is very distinct and always concordant. The direction of strike varies a good deal, possibly owing to the faulting, but small folds were evident in 1908 when this ground was mapped. The transition zone here, as at Porthallow, is characterised by an extensive development of tremolitic schists in the marginal serpentine, but some of the fluxion bands still consist largely of pyroxene. Less than 400 yards east of this there is a large quarry, now disused, and on its west side a long narrow infold of schist is seen in the serpentine. A small infold is exposed also in a serpentine quarry, disused and full of water, by the side of the St. Keverne road one-third of a mile east of Traboe Cross. Three-quarters of a mile from Traboe Cross, at the corner where the gabbro, serpentine and hornblende schist come together there is a quarry on the north side of the St. Keverne road where two infolds of hornblende schist in the serpentine are visible, and the similar and concordant foliation in both rocks is very evident. The strike is parallel to the edge of the schists and the dip (as at Trezise) inclines beneath the serpentine. At none of these localities can transitional rocks like those of Pol Cornick be obtained. The serpentine is mostly of the dunite variety but often much banded with tremolitic folia.

The folding of the schists with the serpentine which these sections demonstrate, has produced other effects of a larger order of magnitude. The most striking of these is the presence of a large number of infolded patches of schist through a wide marginal zone along the northern part of the serpentine area. The most important are indicated in the map, but it must be remembered that much of this ground is covered with heather and thorn, and any number of smaller infolds exist which cannot be laid down with accuracy. In fact in some parts of the downs to the south and south-east of Traboe the mixture of *débris* of schist and serpentine, always easily distinguished from one another, is so intimate that the underlying rock complex must consist of an indefinite repetition of the two types. Where exposures of the schist *in situ* can be obtained, as in a considerable number of the inliers marked, the hornblende schist is of the coarse gnarled type, often with an excellent foliation, and, through the whole area, in both schist and serpentine, there is the same direction of the foliation. Although actual junctions are seldom visible there are many places where the two kinds of rock are found within a few yards of each other, and the similarity in nature and direction of the banding leaves no room for doubt that they are of the same origin.

The small outlying patches of serpentine which occur on the north of the main mass among the hornblende schists at Porthkerris, Porthallow, Pengarrock, Halwyn, Rosemorder, Meaver (near Mullion), in the cliffs north of Mullion Cove, and at Henscath, and on the south side of Predannack, owe their present position to the folding of the serpentine with the schists. Some of them are demonstrably the eroded summits of anticlinal arches, as in the case described in the Predannack cliffs; nearly all of them can be proved to have the same foliation as the schists around them. De la Beche[1] remarks that "we find a mass of serpentine amid the hornblende slate between Dranna Point and Porthalla, on the north of the principal mass of serpentine, which has every appearance of having been thrust up among the hornblende slate, twisting and contorting the laminæ adjoining it in directions

[1] 'Geology of Cornwall, Devon, &c.' (*Mem. Geol. Surv.*), 1839, p. 30.

which we should consider inconsistent with the passage of the serpentine in a state of igneous fusion through them." Unfortunately the actual margins of these small outcrops of serpentine are rarely exposed in a satisfactory way even in the coast sections. Occasionally we find evidence that there has been movement at the junction, as on the north side of the Porthallow mass and on the east of the Pengarrock serpentine where a smooth talcose hornblende schist is exposed in the roadside. The Rosemorder mass, which lies on the Lizard boundary, is slickensided and shattered, and probably is a lenticle bounded by faults on both sides. In all these areas the serpentine is either of the fine dunite or fine tremolitic type.

As we pass inwards from the margin of the serpentine the evidence of folding which is so distinct at the junctions with the hornblende schists becomes completely lost. In the central part of the great ultra-basic intrusion coarse serpentine with more or less augen structure prevails. It is a very uniform rock in which folding would be very difficult to prove as there are no well-marked variations in composition which would be repeated by the folds. The foliation is sometimes curved, and in many places varies suddenly in strike and dip in a manner which might have been occasioned by the presence of large vertical folds. The pressures and movements which produced the folding certainly lasted till the injection of the serpentine was completed, and their effects are visible even in the subsequent rocks, but we have been led to the conclusion that in the interior of the serpentine mass these agencies produced a shearing displacement or squeezing rather than folding, and the augen structure is the result of this. Certainly the later rocks such as the gabbro and the gneisses, though showing pressure structures in great abundance, have not been folded to any considerable extent.

Strike of the Foliation.

A consideration of the strike of the foliation and the folding leads to some interesting results. At the margin of the serpentine the hornblende schists always strike parallel to the boundary and the foliation of the rocks on both sides of the junction has the same direction. But in the heart of the serpentine mass there is an extraordinary prevalence of north and north-west strikes. Many exceptions to this may be seen, but they are local and do not invalidate the general conclusion. In some areas none but north and north-west strikes are found. In the tremolite serpentine, for example, from Kynance to Mullion, it is exceedingly persistent; around the shore from Carrick Luz to Coverack[1] there is a steady north to north-north-east banding. In the northern part of the serpentine along its extension from Trelowarren Lodges to Gwenter a north-west strike is everywhere strongly marked. In the central portion of the serpentine also there is a marked prevalence of strikes in this direction, though not so constant as in other portions

[1] J. J. H. Teall, 'The Metamorphosis of the Lizard Gabbros,' *Geol. Mag.*, 1886., p. 488.

of the mass. We have already described the foliation of the hornblende schists as exhibiting a dominant north-north-west trend. The pressures by which this strike was developed in the schists were the same as caused the foliation in the serpentine.

We have in fact to distinguish two sets of phenomena. The main foliation has a north to north-west direction because the general pressures affecting the region during the consolidation of the serpentine acted in a direction perpendicular to this. Around the margins of the intrusion, however, the hornblende schists were pressed in upon the serpentine, which was constantly increasing in volume as new material was injected. The serpentine mass was steadily though slowly expanding, forcing back the schists. The whole group was in a plastic state, thoroughly hot, and not far below its fusion point, and igneous rocks in this condition very readily pass into schists by interstitial movement. At the margins, where the serpentine was comparatively cold, it folded readily with the schists, but the great central mass suffered internal movements with consequent breaking down of the original igneous character, and development of flaser structure.

In conclusion we may state that the hornblende schist which in the Lizard district shows the same banding and foliation as the serpentine, and passes into that rock by transitional varieties, is always of the coarse Traboe type. The epidotic hornblende schist and the fine green schists, though found quite near the margin of the serpentine at several places, as at Porthallow, never exhibit these phenomena. This is one of the principal reasons which have led us to regard the Traboe schists as distinct from the Landewednack schists and probably of later age. The facts described in this chapter prove that certain portions of the hornblende schist are very closely allied in origin to the serpentine; they were probably not entirely solid when the first intrusions of the serpentine began. It is probably not safe to conclude that the hornblende schist and serpentine are really contemporaneous for all the available evidence indicates that the schist is the older rock, and there are certain structures in the Traboe schists, more particularly the gnarled or broken foliation, that are not found in the serpentine and seem to indicate that these hornblende schists may have undergone foliation at two periods.

Chemical Composition of the Serpentine.

Many analyses of Lizard serpentines have been made by different chemists, and Professor Bonney in one of his papers* on the geology of the Lizard has collected thirteen analyses of these rocks. A comparison of them with one another and with the rocks from which they were made shows remarkable discrepancies and is sufficient to indicate that most of them are not up to modern requirements. It seemed desirable to get the chemical composition of the various types satisfactorily determined, and Mr. E. G. Radley has analysed four specimens for us in the Survey's laboratory.

* *Quart. Jour. Geol. Soc.*, vol. 47, 1891, p. 466.

Analyses of Lizard Serpentines.

—	I.	II.	III.	IV.
SiO_2	40·12	40·87	39·58	38·58
TiO_2	tr.	0·16	0·10	0·08
Al_2O_3	0·98	3·93	3·19	2·72
Fe_2O_3	6·52	6·17	4·70	8·75
Cr_2O_3	0·28	0·25	0·20	0·28
V_2O_3	tr.	tr.	nt. fd.	? tr.
FeO	1·21	2·37	2·76	1·02
MnO	0·52	0·29	0·34	0·14
(CoNi) O...	0·15	0·17	0·16	0·07
BaO	nt. fd.	nt. fd.	nt. fd.	nt. fd.
CaO	0·12	2·36	1·09	0·07
MgO	35·78	32·86	36·21	35·72
K_2O	0·08	0·04	0·06	0·19
Na_2O	0·24	0·39	0·28	0·44
Li_2O	nt. fd.	nt. fd.	tr.	tr.
H_2O at 105° C.	1·69	1·09	0·51	1·42
H_2O above 105° C.	12·17	8·95	10·79	11·03
P_2O_5	0·10	0·07	0·16	0·03
FeS_2	0·01	0·01	nt. fd.	tr.
CO_2	0·15	0·11	0·24	0·04
Total	100·12	100·09	100·37	100·58

I. Dunite Serpentine, E 5172, 70 yards W. of Parc Bean Cove, S. side of Predannack (Anal. E. G. Radley).

II. Tremolite Serpentine, E 7590, Lawarnick Pit, west side of Kynance (Anal. E. G. Radley).

III. Bastite Serpentine (Lherzolite), E 5031, Poltesco Mill, Ruan Minor (Anal. E. G. Radley).

IV. Chromite Serpentine, E 5074, Yellow Carn, E. of Kynance (Anal. E. G. Radley).

These analyses prove that the rocks are very similar in composition. All are typical serpentines with little silica and large amounts of magnesia and combined water. The dunite serpentine (I.) is not really the most basic rock if we interpret that as meaning the one containing least silica, though the differences in this respect are very small. The bastite serpentine of Poltesco Mill (III.) has a lower percentage of silica and a higher percentage of magnesia. The dunite serpentine, however, contains least alumina and very little lime, and this explains why pyroxene and tremolite are least frequent in this rock.

The tremolite serpentine (II.) is very interesting. Of the four types it contains most lime, most alumina, and least magnesia; this explans the abundance of tremolite and pyroxene and the occasional presence of lime-soda felspar. In these respects the bastite serpentine resembles it (III.), and consequently we find diallage, tremolite, and occasionally weathered felspar in that rock. With increase in the bisilicates the amount of serpentine diminishes and accordingly there is less combined water in the analyses. The dunite serpentine (I.) is so poor in alumina, lime, and alkalies that it must have originally consisted of little but olivine and iron oxides.

The fourth analysis was made on a specimen of rather pale yellow serpentine containing many black grains which were considered to be chromite or picotite. As a matter of fact the amount of chromium is not exceptionally large but the rock is comparatively rich in alumina and iron oxides. This indicates that the dark grains are spinels (chrome magnetite spinels) and on microscopic examination they proved to be in most cases opaque though not strongly magnetic. This is the type of serpentine that forms fluxion bands in the bastite serpentine. Though rich in alumina this rock contains very little lime.

The minor constituents are of considerable importance as determining certain characters of the rocks. Thus while titanium is present only in small quantity there is a relatively large amount of chromium and also of nickel and cobalt; in these respects they resemble other peridotites. The alkalies and phosphoric acid are very low; this partly accounts for the very sterile character of the soils on the serpentine of the Lizard district. The scarcity of carbonates also is rather remarkable.

PLATE VI.

PHOTOMICROGRAPHS OF LIZARD SERPENTINES.

Fig. 1.—*Dunite* (5180), 200 yards south-south-east of Predannack Wollas, magnified 36 diameters. Essentially a granular aggregate of olivine, weathering to serpentine; a little tremolite occurs in this rock and there are large brown grains of picotite or chromite which appear black in the photograph.

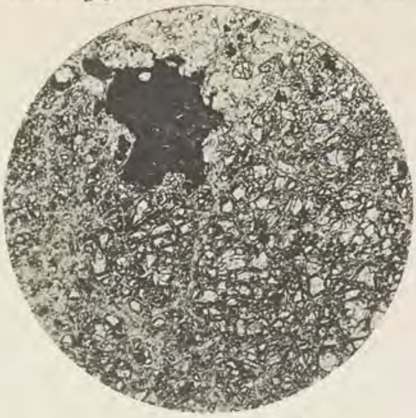
„ 2.—*Dunite serpentine* (5936), 150 yards south-east of Traboe, magnified 24 diameters. This rock is fine grained and very completely decomposed, but it has consisted originally of little but olivine. Many cracks filled with secondary serpentine and magnetite traverse it and give a veined character to hand specimens of this type of serpentine.

„ 3.—*Tremolite serpentine* (5132), Kynance Cove, magnified 26 diameters. In the centre of the field there is a cluster of olivine grains weathering to serpentine; towards the margins there are many crystals of tremolite, cut transversely and showing the characteristic cleavage of amphibole.

„ 4.—*Tremolite serpentine* (7590), Lawarnick Pit, west of Kynance Cove, magnified 44 diameters. The black grains are mostly serpentine after olivine; the clear mineral is tremolite in short prisms. The schistose character of the rock is obvious in the photograph.

„ 5.—*Lherzolite* (6285), Bray's Cot, one mile north of Kuggar, magnified 9 diameters. The view shows a large crystal of diallage (with lamellar twinning) surrounded by olivine weathering to serpentine. The diallage has a lenticular shape which indicates the 'augen structure' of the coarse serpentine.

„ 6.—*Anthophyllite tremolite schist* (7453), south side of Mullion Cove, magnified 26 diameters. This rock, which develops from the serpentine by crushing and pneumatolysis, is a well-foliated mass of nearly colourless tremolite and anthophyllite.



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PHOTOMICROGRAPHS OF ROCK-SECTIONS.

CHAPTER VII.

THE GABBRO.

The gabbro of the Lizard occurs as intrusive bosses and as a multitude of dykes invading the serpentine. The principal boss forms the upland district of Crousa Downs (Plate VII., fig. 1) and on the east coast fronts the sea in the range of low rocky cliffs extending from Porthoustock to Coverack. The south-west portion of this mass is of irregular outline and sends out a long tongue-shaped dyke which terminates in the famous promontory of Carrick Luz. A smaller area of gabbro occurs along the shore below Polbarrow, between Cadgwith and Landewednack Church, but little of this mass is seen in inland exposures though very good sections are found in the cliffs from Polbarrow to The Chair.

The Crousa Downs Gabbro.

The Crousa Downs gabbro is bounded on its north side principally by a fault which describes a great curve passing from the inner corner of Porthoustock Cove in a nearly west direction for two miles, then swinging to the south-west past Lanarth and Grugwith. This fault is nowhere exposed in section though the brecciated rock occupying it may be seen in old mine shafts less than half-a-mile west of Porthoustock and in the fields at Trenoweth Farm, Tregoning Mill (about a quarter-of-a-mile north-east of St. Keverne), to the south of Mill Mehal, and on the roadside to the south-east of Lesneage. These breccias are sometimes reddened with hæmatite, but in other places are hard and siliceous. From Lanarth to the St. Keverne main road at the west of Trelan Vean the boundary of the gabbro follows a series of marshy depressions which are continued southwards past Trelan and Gwenter, and there are no rock-exposures near the actual junction. Except on the west of Trelan the rocks met with on the south and east side of the flat boundary hollow are always gabbro and greenstone, while on the opposite side are hornblende schist and serpentine. The nature of the junction in this part of its course is very obscure; it may be a fault or a series of faults, but in that case it describes a remarkable curve. This hypothesis is supported to some extent by the very simple and well-defined character of the boundary; it runs for long distances in a nearly straight line; there are no enclosures of serpentine in the gabbro adjoining it, and intrusive dykes of gabbro in the serpentine must be very scarce as remarkably little *débris* of gabbro is found in the serpentine downs on the convex side of the curve.

To the south of Gwenter, however, the boundary is an intrusive edge. It takes a very sinuous course, usually not difficult to map because the soils and *débris* found on the two types of rock are very distinct in appearance. In the serpentine there are innumerable gabbro dykes which increase in number rapidly as we approach the actual margin. Along the shore, for example, from Kennack to Carrick Luz, they may be seen every few yards and often are separated only by a foot or two of serpentine (Plate VIII). They are also very frequent at Coverack. In the downs and fields the exact position of the boundary is sometimes difficult to define on account of the great abundance of gabbro *débris* on the serpentine, showing the presence of large numbers of dykes, and as the ground is very level there is no marked surface feature at the junction. In the gabbro along this edge there are many inclusions of serpentine, similar in character to the coarse bastite serpentine which is the prevailing rock in this quarter of the Lizard, and some of them are of considerable size.

The cliffs from Manacle Point to Coverack give splendid exposures of the gabbro, and the greenstone or epidiorite dykes which penetrate it (Fig. 3, p. 102); and the sections on the shore at Coverack and at Carrick Luz have been described by many geologists. At Coverack the first serpentine is seen at the North Corner and from there to the harbour, a distance of nearly half-a-mile along the shore, the two kinds of rock occur in nearly equal proportions; the serpentine forming a groundwork into which dykes and irregular intrusions of gabbro, varying from a few inches to many feet in thickness, have been injected. In this locality the troctolite also is found as dyke-like masses of no great extent which cut the serpentine and are in turn veined by the gabbro. The best specimens of this rock are to be obtained on the west side of the harbour in the little cove below the post office; they are spotted rocks, green or red, according to whether their iron oxides are magnetite or hæmatite. Professor Bonney[1] was the first to discover the troctolite and ascertain its relations to the serpentine and gabbro.

At Carrick Luz also the intrusive character of the gabbro is perfectly apparent, though the junction in Spernic Cove, on the west side of the headland, may be broken by faults. On the east side of this cove a projecting mass of serpentine is riddled with gabbro veins, and a few yards further south along the shore the junction again is seen, its lower portion having been eroded by the sea into a fine natural arch or cave. On the west side of this there is serpentine, on the east gabbro, and in the crown of the arch many veins of gabbro are visible running out into the serpentine. To the east of the headland, in Lankidden Cove, the same phenomena are repeated and the number of gabbro veins which invade the serpentine is very great.

The inland exposures of the Crousa Downs gabbro are very unsatisfactory; the rock has weathered deeply and the surface of the downs and cultivated fields is strewn with great blocks which are covered with grey lichens (Plate VII., fig. 1). Rock actually *in situ* can be observed in only a few places, as for

[1] T. G. Bonney, 'On the Serpentine and Associated Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 33, 1877, p. 906.

example in old pits at Kestlemerris on Crousa Downs, and at Gwenter, also on the roadside to the west of St. Keverne, and between that village and Porthoustock; and in such places the gabbro often shows concentric or spheroidal weathering. Most of the old pits which are very numerous in the farm-yards are dug in a soft yellow decomposed rock containing large residual blocks or cores of gabbro. As the farmers obtain stone for mending walls and roads by breaking up the blocks on the downs very good specimens of the gabbro may be procured, and though they are not actually in place one may be certain that they have not been transported for any distance; but little information can be gathered relating to the structure, direction of the dykes and strike of the foliation in the solid rock beneath.

The Gabbro Dykes.

The gabbro dykes are quite a feature of the geology of the Lizard; they occur only in the serpentine (Plates VIII. and X.). Though coarse foliated gabbros or hornblendic schists may be seen among the Lizard hornblende schists at Porthoustock[1], in the quarry by the roadside above Mullion Cove, at Porthkerris and elsewhere, and have been described by several observers, they do not form well-defined dykes and it is not certain that they belong to the Crousa Downs gabbro. No veins of gabbro are known in the mica schists or other rocks of the Old Lizard Head Series.

The relative abundance of gabbro veins in different parts of the Lizard depends entirely on the distance from the gabbro bosses. At Coverack they form an injection plexus which is so intricate that they could not be shown on a map (Fig. 2); there are large dykes many feet across which are cut by smaller dykes, and in some places ramifying systems of veins only an inch or two in diameter traverse the serpentine in all directions. At Lankidden Cove and Spernic Cove, on both sides of Carrick Luz, the phenomena are precisely the same; the gabbro veins bulk almost as largely as the serpentine which they penetrate. About Compass Cove also (which is half-a-mile west of Spernic Cove) the number of gabbro dykes is enormous (Plate VIII.); in fact from Poldowrian (Plate X.) westwards to the Green Saddle they are usually only a few feet apart. From Lankidden to the Black Head many gabbro veins may be seen in the cliffs, especially at the Gaider, Downas Cove and Beagles Point, but they become less frequent at Pedn Boar and the Black Head; northwards by the Ebber Rocks they increase in numbers and every little cove contains one or more. On Chynhalls Point and below the Coverack Headlands Hotel there are a great number, and the serpentine on the shore of Perprean Cove contains dozens of them usually ten yards or so from one another.

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[1] T. G. Bonney, 'On the Serpentine, Gneissoid, and Hornblendic Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 52, 1896, p. 19.

Harford J. Lowe, 'The Sequence of the Lizard Rocks (second paper),' *Trans. Roy. Geol. Soc. Cornwall*, vol. 12, 1902, p. 520.

In the north-west corner of Perprean Cove a small boss of troctolite appears among the gravel of the beach and is intersected by several dykes of gabbro.

On the west side of Kennack Bay gabbro dykes cut the serpentine in considerable numbers ; a well-known dyke[1] occurs a few yards south of the gate at the telegraph house, and all the way south to Enys Head gabbro veins may be found. One of these on the northern slope of Little Cove, north of Caerleon Cove, was analysed by Mr. Hudleston,[2] and another which occurs on the south side of Caerleon Cove is well known. The greenish-yellow saussurite dykes on the southern slope of Enys Head have been referred to as cutting the banding of the serpentine (p. 71). On the north side of Kildown Cove a large gabbro dyke is visible in the cliff, and has been mentioned by Professor Bonney.[3]

From Enys Head south to Carn Barrow no gabbro is seen in the hornblende schists, but as soon as we pass the fault which terminates the outcrop of hornblende schist gabbro is found, at first in the talus beneath the grassy slope at the top of the cliff, and immediately thereafter at the sea-level along with serpentine and gneiss. The little cove where stands the ruinous pilchard-fishers' hut is known as Polgwidden and on both sides of it there is gabbro ; from this point southwards to The Chair the coves are best examined with the help of a boat. Gabbro appears in all of them with serpentine and banded gneisses ; the whole forms a complex which can only be described as a *mélange*, in which all the rocks are mixed and welded together in inextricable confusion. The peculiarities of this section will be described in a later part of this Memoir ; it will suffice here to say that though the geologists who have visited the Lizard have differed much in the interpretation of this ground they have agreed that the gabbro is newer than the serpentine and intrusive into it. This is in fact very well seen in the first cove north of The Chair where a large horizontal sill and several vertical dykes of gabbro cut the serpentine.[4]

On the west coast gabbro dykes are few. None, for example is known in the serpentine of Pentreath Beach, but north of this, under Holestrow, gabbro is found among the fallen *débris*. Further to the north along this shore, in the coves east of the Lion Rock, Teall and Fox[5] recorded small dykes of gabbro. In Kynance Cove there is a mere remnant of a dyke, much crushed, in the serpentine reef in the beach at the foot of the path, and from the cove the large cuboidal blocks of pseudophite described by Fox and Teall as formed from a gabbro dyke may be seen lying on a ledge in the face of the cliff at a point 250 yards south-east of the hotel. Although pseudophite occurs at the foot of the cliffs near Gew Graze no gabbro has been recorded on the western cliffs from this point till we reach Pol Cornick, where Teall and Fox described one or more dykes, and at Mullion Cove where the base of the cliffs is often accessible, there are no gabbro dykes and no gabbro boulders in the beach.

At Porthallow there must be a gabbro dyke two or three feet thick, as large blocks of this rock are scattered on the shore at the base of the serpentine but no exposures of gabbro *in situ* are known ; the boulders have apparently come down the cliffs with the large landslip which is a conspicuous feature of this shore.

The largest of the gabbro dykes is that which forms the promontory of Carrick Luz; its breadth is not less than 120

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[1] C. A. McMahon, 'Notes on the Hornblende-schists and Banded Crystalline Rocks of the Lizard,' *Quart. Journ. Geol. Soc.*, vol. 45, 1889, p. 540 and fig. 12.

[2] W. H. Hudleston, 'Notes on the Chemical Composition of some of the Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 33, 1877, p. 926.

[3] T. G. Bonney, 'The Hornblendic and other Schists of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 39, 1883, p. 6.

[4] T. G. Bonney, 'On the Serpentine and Associated Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 33, 1877, p. 897.

[5] Howard Fox and J. J. H. Teall, 'Notes on some Coast-sections at the Lizard,' *Quart. Journ. Geol. Soc.*, vol. 49, 1893, p. 206.

Howard Fox, 'On the Occurrence of an Aluminous Serpentine (Pseudophyte) with flint-like Appearance near Kynance Cove,' *Mineralogical Magazine*, vol. 9, 1891, p. 275.

yards, but as this mass is followed inland it contracts somewhat, and then, at Poldowrian farm, broadens and joins the large rectangular prolongation of the Crousa Downs boss which extends from Poldowrian to Trevenwith and Gwenter. Most of the gabbro dykes are less than twelve feet wide; very commonly they are less than two feet, and thin thread-like veins, not more than an inch in thickness, are very frequent. Instances of one dyke of gabbro cutting another (Fig. 2, p. 94) are by no means scarce, and sometimes the first dyke has been shifted or faulted by the second. Gabbro dykes also cut the troctolite both at Coverack Harbour and at Perprean Cove. On the other hand the gabbro is cut by the fine black dykes of dolerite and epidiorite in every district of the Lizard; instances of this are so numerous that there is no need to cite them.

Many of the gabbro dykes have straight and parallel edges; this type for example prevails about Poldowrian and Compass Cove and is often seen near Carrick Luz; they vary in breadth from three feet to less than an inch and can often be followed for twenty yards. Sometimes the dykes bend sharply at a right angle, taking a line of jointing in the serpentine; at other times they fork and the branches may again unite, forming a plexus. The larger dykes contain many enclosures of serpentine. On the south shore of Chynhalls Point there is a gabbro dyke which splits into a number of thin radiating branches like the ribs of a fan. Occasionally a dyke thins out rapidly and comes to an end; a very fine example of this may be seen in the east corner of Compass Cove, where a dyke about ten feet broad rises out of the gravel of the beach and curves round to the east, tapering to a fine point. The special characteristic of the Lizard gabbro dykes, however, is that none of them can be followed for more than a limited distance; even in the best exposures they usually run for only a few yards and then stop. Sometimes they are cut off by faults, but more commonly they seem to be wrenched off by displacement of the serpentine into which they were injected; at the same time they show many phenomena of metamorphism which can only be explained after their petrographical characters have been considered.

Petrography of the Troctolite and Gabbro.

The Troctolite.—The troctolite of Coverack shore and of Perprean Cove[1] consists essentially of labradorite felspar and olivine. Hand specimens vary somewhat in character but are always distinctly spotted. The Coverack troctolite shows green or reddish clusters of olivine in a grey matrix of felspar; the troctolite of Perprean Cove is a darker rock and richer in olivine, which forms a deep green matrix in which lie compound spots of felspar and olivine. The felspars of this rock have a distinct

[1] First recorded by Harford J. Lowe, 'The Sequence of the Lizard Rocks (second paper),' *Trans. Roy. Corn. Geol. Soc.*, vol. 12, 1901, p. 517.

tendency to idiomorphism, yielding angular sections, but they enclose small dark grains of olivine[1].

The felspar according to its optical properties and the chemical analyses of Houghton (*see* p. 100) is labradorite with about 60 per cent. of anorthite ; it is sometimes fresh but may be much decomposed and replaced by 'saussurite.' Most of the grains show pericline and albite twinning and are of irregular outline ; this mineral is hardly at all schillerised. The olivine is represented by rounded crystals permeated by a meshwork of serpentine and secondary iron oxides. It contains small dark platy or rod-shaped inclusions, and also fluid cavities. In many sections of the troctolite augite is present, of a pale green or yellowish variety, often with the perfect lamination of diallage. It occurs both as small irregular crystals and as narrow rims surrounding clusters of olivine and separating them from the felspar. By increase in the amount of diallage the troctolite passes into olivine gabbro. The rocks contain very little primary iron oxides, and only an occasional grain of apatite may be seen in them.

The characteristic structure of the troctolites (Plate IX., fig. 2) is perfectly shown by many slides from the shore below Coverack ; the olivine occurs as clustered grains, partly serpentinised, and the felspar envelops them ; through the felspar radiating cracks filled with serpentine pass outwards, having developed by the expansion in volume consequent on the hydration of the olivine. The same structure is sometimes observed in the diallage surrounding olivine in the bastite serpentine. All the ingredients have irregular forms and seem to have interfered with the crystallisation of one another. Very commonly radiating rims of a finely fibrous mineral surround the olivine. These are known as 'reaction rims' and will be described more fully in the olivine gabbro where they occur also. A striking peculiarity of the troctolite slides is that they rarely show cataclastic or pressure structures ; this rock, in fact, has always normal igneous characters.

The Gabbro.—The gabbros of the Lizard, as Dr. Teall has shown, may be grouped into three classes (*a*) the normal types, in which the igneous structures are well preserved; (*b*) the flaser gabbros with their structures and their minerals altered by pressure, and (*c*) the gabbro schists, which are well foliated. The augen gabbros hold a sort of middle place between the flaser gabbros and the gabbro schists (Plate IX.).

The normal gabbros all contain olivine, which mineral is absent from all the pressure-modified representatives of this class. These rocks are nearly coal-black in colour when quite fresh, because their felspars are filled with minute black enclosures producing schillerisation, but they do not show a distinct 'play of colours' like the labradorite of Labrador. But when the olivine gabbros are weathered or a little sheared their felspars

[1] Many descriptions of the petrographical characters of the Lizard troctolites and gabbros will be found in Professor Bonney's papers, viz. :—'On the Serpentine and Associated Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 33, 1877, p. 884 ; 'The Hornblendic and other Schists of the Lizard District, with some additional Notes on the Serpentine,' *Quart. Journ. Geol. Soc.*, vol. 39, 1883, p. 7 ; 'On Bastite-Serpentine and Troktolite in Aberdeenshire, with a Note on the Rock of the Black Dog,' *Geol. Mag.*, 1885, p. 439 ; T. G. Bonney and C. A. McMahon, 'Results of an Examination of the Crystalline Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. 47, 1891, p. 464. A full description of these rocks has also been given by Dr. Teall, 'The Metamorphosis of the Lizard Gabbros,' *Geol. Mag.*, 1886, p. 481, and 'British Petrography,' 1888, p. 174, &c. *See also* F. T. S. Houghton, 'Note on an Olivine Gabbro (Forellenstein) from Cornwall,' *Geol. Mag.*, 1879, p. 504 ; A. Harker, 'Petrology,' 1908, p. 83 ; J. J. H. Teall, 'Notes on some Minerals from the Lizard,' *Mineralogical Magazine*, vol. 8, 1888, p. 116 ; G. A. J. Cole, 'Aids in Practical Geology,' 1906, p. 233 ; C. A. McMahon, 'Note on the Foliation of the Lizard Gabbro,' *Geol. Mag.*, 1887, p. 74.

Fields covered with weathered Gabbro Blocks.

Augen structure in the Gabbro at Spernic Cove.

become opaque and grey in colour, passing into saussurite and other secondary products.

The minerals of the olivine gabbros (Plate IX, fig. 1) are felspar, diallage, and olivine with a small proportion of primary hornblende, hypersthene and iron oxides. The felspar is always a variety of labradorite containing about 60 per cent. of anorthite, and is of similar composition to that of the troctolite and the tremolite serpentine. In microscopic sections it has a dark colour and is almost opaque from the abundance of black inclusions, which are sometimes so small that they can hardly be resolved by high microscopic powers. At other times these inclusions are rod-shaped and are arranged in three systems crossing one another, evidently following definite crystallographic directions. Where slight cracks traverse the felspar owing to incipient fracture and crushing, the mineral becomes more transparent and the very minute inclusions seem to disappear. Albite twinning is invariably present but pericline twinning is much less common than in the flaser gabbros. The felspar often shows the cloudy opaque spots which are described as saussurite, even in rocks which have been little crushed.

The augite is colourless or pale brown and has invariably the diallage lamination more or less perfect; often this structure is confined to one part of a crystal. Black or brownish schiller inclusions occur in it though not in great numbers. The olivine is in irregular grains like those of the troctolite, and weathers to serpentine and magnetite, or sometimes to dense aggregates of talc that have a strong double refraction. It has black inclusions which may be rod-shaped or branching, like those which Professor Judd[1] has described in the Tertiary peridotites of the Inner Hebrides. Hypersthene is seen rarely, and only as thin borders to clusters of olivine. It is not fibrous but compact and, unlike the rhombic pyroxene of the serpentines, has distinct though not strong dichroism. Brown primary hornblende is often present though never in great quantity, and either grows around the diallage or forms perthitic intergrowths with it. Its colour in thin slices is pale clove brown and the pleochroism is well-marked. Large irregular plates of black iron oxides occur also, though not frequent. Apatite is a common accessory mineral.

Some of these rocks have typical gabbro structure, that is to say all their minerals are devoid of crystalline outlines, so that it is very hard to determine any sequence of crystallisation; but others are ophitic (Plate IX., fig. 1) with large plates of diallage enclosing felspars which have rather perfect lath-shaped forms. The diallage crystals may be an inch in diameter. In a few slides grains of felspar are also enclosed in olivine but the olivine is never moulded on the felspar so completely as in the gabbros of Ayrshire, described by Teall[2], or in the allivalites of Rum[3].

Around the olivine there are often thin rims of diallage or hypersthene, and between the olivine and the felspar narrow borders of a finely fibrous radiate mineral are common both in the troctolites and in the olivine gabbros. The fibres are so thin that it is very difficult to ascertain their optical properties, but it is clear that they do not belong to one mineral as sometimes they have a moderately strong double refraction while at other times they are nearly isotropic. In the latter case they probably consist of secondary products such as chlorite, bastite or serpentine, and the olivine also is partly serpentinised. Dr. Teall[4] considers it probable that the mineral of the inner zones is anthophyllite, while an external zone consists of actinolite. These structures are of the type known as 'coronas' or 'reaction rims.'

The Flaser Gabbros.—In this group we place those gabbros which exhibit distinct evidence of crushing and re-crystallisation under pressure but have not lost completely their igneous structures or assumed the characters of schists (Plate IX., fig. 3). They have an exceedingly wide distribution in the Lizard.

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[1] *Quart. Journ. Geol. Soc.*, vol. 41, Pl. XII. (1885).

[2] 'The Silurian Rocks of Britain, vol. 1, Scotland,' (*Mem. Geol. Surv.*), 1899, Plate XXIII., fig. 2.

[3] A. Harker, 'The Geology of the Small Isles of Inverness-shire,' (*Mem. Geol. Surv.*), 1908, p. 86.

[4] 'British Petrography,' 1888, p. 176.

Olivine is never found in these rocks, but the fact that it is always present in the normal gabbros makes it, to say the least, extremely probable that most of these rocks formerly contained olivine. In many of the sections rounded pseudomorphs of amphibole are visible which seem not to have been derived from pyroxene as they never show traces of that mineral and sometimes occur in fresh or little altered diallage. From their shapes it is probable that they represent original olivine, but this is only an inference as in no case has a core of olivine been seen in these clusters. They have an outer zone of radiate prisms of green actinolite, spreading through the surrounding felspar, and a central aggregate of colourless tremolite in densely packed acicular needles sometimes mixed with a little chlorite and occasionally full of small black grains of iron oxide. The resemblance of these growths to the well-known pilite pseudomorphs after olivine is obvious.

The diallage of the flaser gabbros is in all cases being transformed into hornblende. Often the change has affected only the peripheral parts of the crystals, and blades of pale green actinolite spread outwards like leaves of grass from the surface of the diallage. They are not in parallel growth with one another or with the pyroxene. In the augen gabbros this appearance is especially characteristic, and tails of actinolite may be found at the pointed ends of the flattened diallage crystals. Actinolite or pale green hornblende is also exceedingly common in the cleavages and fissures of the labradorite, a fact which indicates that aqueous solutions have been operative in their formation. The change to fibrous amphibole spreads to the interior of the crystals, but very often large areas of compact greenish hornblende, having uniform extinction throughout, constitute the interior, and have a fringe of actinolite needles. These homogeneous pseudomorphs may retain the shape of the original pyroxene, with its ophitic relations to the felspar. This indicates that the transformation to hornblende is accelerated by the movement which goes on at the surface of the crystals but will also take place if the pressure lasts sufficiently long without actual crushing or displacement. In some gabbros the diallage has a very well-marked platy structure and prismatic crystals of pale green hornblende may be observed forming in the planes of parting. They are not all in parallel growth with the diallage or with one another though they not unfrequently have that arrangement, as may be seen in cross-sections.

The diallage is seldom granulitised, and then appears as small grains mingled with hornblende; recrystallisation as amphibole apparently takes place more readily than granulitisation when stresses affect the mineral. A notable exception to this rule may be mentioned, however. In most of the good exposures of the gabbro there are pale green rocks, resembling greenish marbles or calc-silicate hornfelses. These 'white gabbros' when sliced prove to consist of crushed felspar (sometimes fresh, but often more or less saussuritised) with a nearly colourless or pale green diopside, also in minute rounded or irregular granules. These rocks have been much crushed, but this variety of augite is perfectly stable under such conditions and the amount of amphibole present is exceedingly small. We are reminded of the pale green augite of the hornblende schists, but Dr. Teall's researches show that this pyroxene is a chrome-diopside, and it is almost certainly a primary mineral.

The secondary hornblende of the flaser gabbros is colourless or pale green; deep green shades are distinctly rare, and often the original brown hornblende of these rocks is not modified but remains even when the diallage which it surrounded is entirely transformed. It vanishes, however, in the last stages of recrystallisation.

The primary labradorite of the Lizard gabbros suffers two kinds of change, namely crushing and saussuritisation. The first symptoms are the appearance of a network of cracks along which the dark schiller inclusions disappear, having apparently been reabsorbed. In polarised light the felspar then breaks up into a mosaic. The twin-planes become irregular, often wedging out rapidly, or are spindle-shaped and discontinuous. At the same time a very fine pericline-lamellation makes its appearance, sometimes only in alternate albite-lamellae, and distinct in character from the coarser pericline twins of the normal gabbros. As granulitisation advances seams of fine crushed felspar appear along the cracks (figures of this stage in the gabbro at Gwenter have been given by Dr. Teall[1]). An aggregate of small, isodiametric grains, rounded or squarish in outline, with very fine twinning, is the ultimate stage of this process, but this is

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[1] 'British Petrography' (1888), figs. 22 and 23, p. 175; *Geol. Mag.*, 1886, p. 483.

not so common as mortar-structure with large grains in a fine crushed interstitial matrix.

The crushed felspar is often not saussuritised, and saussurite occurs in rocks which are not cataclastic ; hence we believe that, like uralitisation, this process is favoured by pressure acting through the solutions which permeate the rock, but is not a necessary consequence of shearing or interstitial movement. Dr. Teall[1] has pointed out that if saussurite be defined with Cathrein as a mixture of albite, epidote and garnet, it is a rare substance in the Lizard gabbros. What we here describe under that name is a white, greenish or pink, secondary material after labradorite felspar, always fine-grained and often indeterminable under the microscope. It is sometimes quite soft, but usually harder than the blade of a knife, shows no cleavage and no constant micro-structure. Where more coarsely crystalline than usual it can be ascertained to contain certain minerals such as prehnite, garnet, zoisite, chlorite and alkali felspar mixed with a variable amount of actinolite.

The first appearance of saussuritisation is marked by the development of small rounded dull spots which in the hand specimens appear white or pale green but in the microscopic slides are so finely granular as to be semi-opaque. This mineral has a high refractive index and moderately strong double refraction, and is harder than steel. Where it is most abundant it almost completely replaces the felspar and occurs in rounded patches which show a granular or sometimes a nearly spherulitic structure ; usually it has a weak reddish or brown colour. Its nature has not been determined. Prehnite also is very frequent, and in some cases occurs in masses and nodules several inches in diameter ; it is white with a dull lustre and much resembles massive felspar in external appearance. In microscopic section this mineral is colourless and has the usual optical properties except that it never shows optical anomalies such as are supposed to be especially characteristic of prehnite. It forms flattened tablets with a bisectrix emerging perpendicular to the lamellae ; vertical sections have often good rectangular form and straight extinctions, but the other sections are irregular. It can often be seen gradually spreading across the felspars, but in some rocks occurs almost alone and then has a strong tendency to radiate groupings. The saussurite dykes on Enys Head contain much prehnite ; the mineral was also separated from blocks of saussurite exceedingly rich in it which were found in a gabbro vein in serpentine at a small pit about 450 yards north-west of Corgerrack (near Kuggar) and was analysed by Mr. Radley in the Survey's laboratory. It proved to have the normal composition of prehnite except that it contained about 4 per cent. of magnesia (*see* p. 90). On the north side of Little Cove (which is the cove north of Caerleon Cove) a few yards above the coast-guards' path there is a rotten dyke of gabbro schist with much white saussurite. Hudleston analysed this saussurite and a comparison of his analysis (II.) with Mr. Radley's shows that this rock also must consist principally of prehnite. With prehnite a pale coloured garnet often occurs (always in small irregular crystals), and another prismatic mineral not determined.

Epidote is very rare in the saussurite of the Lizard gabbro, but zoisite is sometimes seen and has the usual dark-blue polarisation tints. Chlorite often replaces the felspar over considerable areas of a rock slice, and, especially in the dykes, there is frequently a development of pseudophite. This mineral is semi-transparent, grey or bluish, and much resembles chalcedony or chert in appearance, but is quite soft. It was first recorded by Fox who gives an analysis of it by Player (IV.). Pseudophite also occurs replacing alkali felspars (*see* p. 143) ; under the microscope it is nearly isotropic, but is not homogeneous, as many small doubly-refracting scales of other minerals occur in it often as rosettes, spherulites, &c. Part of the white material, enclosing fragments of serpentine, polished and sold as 'steatite' appears to be pseudophite.

In the gabbro dykes much of the felspar has been converted into a soft white glistening aggregate of scales of mica, but this may be due to ordinary weathering. Carbonates such as calcite and dolomite are found in varying amounts but indicate decomposition. In the typical saussurite they are usually absent. Albite or alkali felspars are very rare but appear sometimes in the last stages of alteration. The fresh granulitised felspar is always labradorite. Lastly we may mention the small prisms and grains of actinolite which arise from the reconstruction of the femic minerals and spread outwards into the felspar.

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[1] *Op. cit.*, p. 152.

—	I.	II.	III.	IV.
SiO_2	43·73	45·70	43·82	33·3
TiO_2...	0·09	—	—	—
Al_2O_3	22·84	23·00	24·72	21·8
Fe_2O_3	1·59	0·50	—	0·4
FeO	0·35		—	—
MnO	0·20	—	—	—
BaO	n.f.	—	—	—
CaO	20·05	19·30	27·10	—
MgO...	3·88	4·75	—	29·7
K_2O	0·89	1·95	—	—
Na_2O	0·85		—	—
Li_2O...	tr.	—	—	—
H_2O at 105°	0·29	4·80	—	—
H_2O above 105°	5·58		4·36	14·9
P_2O_5...	0·03	—	—	—
Cl	n.f.	—	—	—
	100·37	100·00	100·00	100·1

I. Prehnite, separated from Saussuritic Gabbro, quarry 450 yards N.W. of Corgerrack, Kuggar, Ruan Minor, Cornwall (Anal. E. G. Radley). Powder separated by borotungstate of cadmium between spec. grav. 2·855 and 2·755.

II. Saussurite of 'newer gabbro,' north of Caerleon Cove, Ruan Minor, Cornwall (Anal. W. H. Hudleston, *Quart. Journ. Geol. Soc.*, vol. 33, 1877, p. 927).

III. Prehnite, theoretical composition (Naumann-Zirkel, 'Mineralogie,' 1907, p. 659).

IV. Pseudophite, east side of Kynance Cove, Lizard, Cornwall (Anal. J. H. Player). Howard Fox, 'On the Occurrence of an Aluminous Serpentine (Pseudophyte) with flint-like appearance near Kynance Cove,' *Mineralogical Magazine*, vol. 9, 1891, p. 275.

The other minerals of the flaser gabbros are few in number. Apatite is seen occasionally in small grains or disjointed prisms which may be full of small dark enclosures. The iron-oxides may be completely altered to sphene, sometimes accompanied by rutile. Sphene arises also in the conversion of the diallage to hornblende, apparently by the partial rejection of the lime; it presumably, obtains its titanium from the small schiller enclosures of the diallage which disappear at the same time.

The structure of the flaser gabbros is so varied that it baffles description; a very large number of them, however, show the original ophitic character very clearly though the pyroxene is partly or completely replaced by hornblende. The rounded outlines of the pilite pseudomorphs still indicate the original forms of olivine. The lath-shapes of the felspars persist till a distinct foliation makes its appearance.

In the augen gabbros (Plate VII., fig. 2), of which figures have been given by Dr. Teall[1], the ophitic structure is completely gone, but rounded or elliptical crystals of diallage remain in a well-foliated matrix of felspar that flows around them. The diallage is bordered with green amphibole, which is well crystallised, but never idiomorphic, and in the smaller augen may replace the pyroxene entirely. The felspar is sometimes granulitised, but is always more or less saussuritic, and frequently entirely converted into secondary products.

[1] *Geol. Mag.*, 1886, Plate XIII. 'British Petrography' (1888), Plate XLIII.

Gabbro Schists.—The gabbro schists may be defined as coarse-grained saussurite hornblende schists. They do not contain diallage and their felspar is usually completely saussuritised; many of them have a thin linear foliation; in others the folia of hornblende are distinctly lenticular (Plate IX., fig. 4), showing a transition to the augen-gabbros. The hornblende is always green in section and sometimes bright green also in the hand specimens.

Distribution of the different types of Gabbro.

The flaser gabbro is the prevailing type; much of it looks nearly massive in the hand specimens, though the replacement of diallage by hornblende, with consequent loss of the metallic lustre and assumption of green in place of brown colours in the darker parts of the rock, indicates the progress of amphibolisation. A special characteristic of the Lizard gabbros, well shown by all the best exposures, is the great variation in the size of their component crystals. Most of the rock is rather coarse grained, having crystals a quarter of an inch or more in diameter, but there is also much pegmatite, often forming distinct veins or vein-like patches. Some of these pegmatitic varieties have crystals of diallage four or five inches across. At Carrick Luz, Pen Voose, and Coverack these coarse gabbros can be found in many places and frequently their diallage is in excellent preservation. Some of them show very good ophitic structure, but the felspars are never so large as the pyroxenes. In good exposures, seen from a distance of a few yards, the speckled or patchy character of the rock, owing to the coarse areas mixed with finer-grained types is exceedingly striking. Where shearing has affected the gabbro it sometimes assumes almost a brecciated character owing to the alternation of coarse and fine types in a very irregular manner; this can be seen, for example on the north side of Godrevy Cove, near St. Keverne.

The normal olivine gabbros are restricted to the neighbourhood of Coverack, where they occur in the fore-shore below the village and as far west as Penhallick. Specimens may also be seen at the North Corner and around Cowisack and Polcoverack. They may be easily recognised by their coal-black appearance.

Fluxion banding is usually not very obvious, and is never so pronounced as veining by pegmatites. There are no dark streaks which would correspond in composition with pyroxenites or ultrabasic rocks, but often we may observe white or pale green bands which consist only of felspar and bright green augite. Pale gabbros, free from olivine (Dr. Teall[1] has called them eucrites), occur also in some plenty near Gwenter, where they seem to form the major part of the rock; they are highly granulitic. The banding, however, is never very persistent, and in regularity does not approach the fluxion structure in the serpentine.

In the dykes all the varieties above mentioned may be found. Many of them are very coarse pegmatites and a dyke no more than a foot in width may have diallage crystals two inches in

[1] 'British Petrography,' (1888), p. 174.

diameter. Unsheared olivine gabbro is not frequent, but may be found in a rather fine-grained dyke, a foot wide, which cuts the serpentine on Dolor Point, at Coverack, and runs in a east-north-east direction from the Paris Hotel. Most of the veins in the serpentine show more or less crushing and belong to the flaser gabbros; they are also in nearly all cases much decomposed and saussuritized. Some of the best specimens of augen gabbro (Plate VII., fig. 2) have been obtained from the Carrick Luz dyke on its western side in Spernic Cove.

At Coverack there is a perfect transition between the gabbro and the troctolite, so that the two rocks belong evidently to the same series though the troctolite is the earlier. There is nowhere, however, a clear passage between the serpentine and the troctolite, though the latter is often more rich in olivine than any of the gabbros; the junctions between troctolite and serpentine are sharp and well defined and there must have been a pause between the close of the injection of the serpentine and the first introduction of the troctolite. That the pause was not of long duration and the serpentine was still hot is sufficiently proved by the coarse crystallisation of even the thinnest dykes of gabbro in the serpentine (Plate VIII.).

Metamorphism of the Gabbro.

The metamorphism of the Lizard gabbro is one of the vexed questions of the geology of this region and has given rise to much discussion. It has been regarded as a cataclastic effect, produced by earth movements acting on the rock after it had consolidated, and as a fluxion foliation which is ascribed to the movements of a half-crystallised mass through fissures during injection. It is impossible to recapitulate the evidence used on either side, but the main facts of the case will be presented, and the conclusions which we have arrived at from a study of the rocks both in the field and with the microscope.

It is certain from the microscopic characters of the rocks that at any rate the greater part of the crushing was done after consolidation. All the elements are involved in it, though not always to the same extent; and there is never a trace of any mineral having been fractured and subsequently healed up by a renewed deposit, such as occurs in some brecciated volcanic rocks. An examination of the augen gabbro (Plate VIII., fig. 2) is quite conclusive on this point for its diallage is broken, twisted, and worn to elliptical grains by the movement of the felspar past it; yet in all the normal gabbros and all the rocks which retain traces of igneous structure it is certain, from the ophitic structure, that the diallage finished crystallising after the felspar.

At the same time it is obvious that the crushing took place at a very early period in the history of the gabbro; for that rock is cut by a large number of black dykes, some of which are olivine dolerites while others are epidiorites and hornblende schists, and these never share in the foliation of the gabbro. The massive dolerite dykes may be seen at the west end of Coverack (Fig. 2,

p. 94), in the beach, cutting perfect gabbro schists, yet are themselves the least metamorphic rocks in the Lizard complex. But these dykes have fine-grained chilled edges where they are in contact with the gabbro, a fact which proves that the country rock had cooled down before they were injected. They belong, however, to the same set of intrusions as the gabbro and often approach closely to it in petrographic character, so that we are not at liberty to suppose that the interval was a long one.

If we endeavour to apply to the Lizard gabbro those theories of dynamometamorphism which are in current use for the basic igneous rocks or 'greenstones' of North Cornwall we find many features which it is impossible to explain. The greenstones, around Penzance and Camborne, for example, are in very much the same state of metamorphism or vary only slightly in this respect; but, in the Lizard, part of the gabbro is an absolutely normal igneous rock while other parts are schists and augen gabbros. It is not sufficient to postulate that accidentally a limited area has escaped from the effects of the movements by which the foliation was produced, because the most normal gabbros and troctolites, around Coverack, for instance, are sometimes cut by gabbro schists, and in the same district we find dykes of gabbro, some of which are unmodified rocks, while others, immediately adjacent, are in an advanced condition of metamorphism. This can be seen most clearly at Coverack (Fig. 2, p. 94), but at Carrick Luz, Kennack, Pen Voose, and all places in the Lizard where there are good sections of the gabbro dykes it can be proved that adjacent dykes show very different stages of metamorphism, some being highly schistose while others, though sheared, differ little in appearance from normal igneous rocks.

There are localities where nearly normal gabbro passes in a distance of a few feet (or even inches) into a well-foliated gabbro-schist; one of these occurs a few yards north of the northern point of Pen Voose[1]; here the change takes place where the gabbro is faulted against the serpentine and might conceivably have been produced by movement along the line of fault. But this can explain only a very little part of the metamorphism in the gabbro of the Lizard for, both in the dykes and in the bosses, there are many localities where pronounced foliation rapidly makes its appearance, and it is certain that there is nothing of the nature of ordinary faulting. Moreover many undoubted faults, including the great fault which forms the northern boundary of the gabbro, are accompanied by no increase in the metamorphism. The general distribution of flaser gabbros through Crousa Downs and around St. Keverne proves that the pressures by which the igneous structures of the rocks were modified were general and affected the whole region.

If we investigate the shore-sections from Coverack north to Porthoustock we shall find that it is very difficult to attain a clear conception as to the processes by which foliation and flaser structure were produced. It is evident that the gabbro boss is

[1] J. J. H. Teall, 'The Metamorphosis of the Lizard Gabbros,' *Geol. Mag.*, 1886, p. 487.

not a simple intrusion. It was originally somewhat heterogeneous, consisting of troctolite and several varieties of gabbro, and shows occasionally an imperfect fluxion structure; moreover it is a compound injection as bands and veins of slightly different composition can clearly be traced, showing that, like the Tertiary laccolites of Skye[1], it was filled by successive inflows of magma and the earlier were solid before the later arrived. The pegmatite dykes (or segregations) ramify through the whole complex; and all these structures have been broken and deformed by a series of movements, usually of small magnitude but very numerous and complicated.

The gabbro dykes, however, furnish evidence much simpler and more easily interpreted; we shall consider this in somewhat greater detail as it throws much light on an obscure and difficult problem.

As already stated only one dyke has been met with which is a normal gabbro in a fresh condition. Many of them look like normal igneous rocks in the hand specimens, but in microscopic sections prove to be in a state of great decomposition. The majority probably are flaser gabbros, showing a greater or less amount of crushing and often much weathered. Augen gabbros appear frequently and gabbro schists are still more numerous, occurring in abundance at Carrick Luz, Compass Cove and Lankidden Cove.

The foliation in the dykes is in nearly all cases parallel to the margins of the dyke, whatever be its course; it is equally

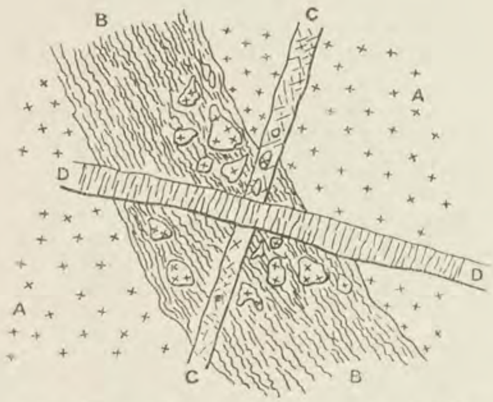

Figure 2. *Plan of dykes in shore at west end of Coverack.*

The country rock is serpentine (A) which has a weak fluxion foliation almost due north; this is cut by a dyke of gabbro schist (B) running in a north-west direction, perfectly foliated and in places highly schistose. It contains many blocks of serpentine but both these inclusions and the walls of the dyke are almost quite massive. The gabbro-schist is cut in turn by a straight dyke of coarse gabbro pegmatite (C) with crystals of felspar and diallage up to two inches in diameter; it runs north-north-east and shows very little foliation. This dyke also contains inclusions of serpentine. The whole series is crossed in a west-north-west direction by a dyke of olivine dolerite (D) which is in a perfectly massive condition.

[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 77.

well-marked in the horizontal, vertical and inclined dykes, and when one foliated dyke cuts another each has its own direction of foliation. Consequently the schistosity at once suggests fluxion movement. Where a dyke bends the schistosity bends with it, and if a dyke forks each branch is foliated parallel to its length.

The thin dykes are quite as frequently massive as the thicker ones; but when a dyke of moderate thickness (a foot or so) is schistose it generally has a fairly uniform appearance throughout (Plate VIII.), though often the margin is finer grained and more perfectly schistose than the centre. The thick dykes are less uniform; sometimes they are foliated at their margins and nearly massive towards the centre, but some of them are more foliated in certain bands than elsewhere without there being any apparent reason for this. As a rule, however, if a dyke is foliated it has this character throughout.

In 1891 Professor Bonney and Major-General McMahon[1] brought forward a theory ascribing this foliation to fluxion movements in a partly consolidated magma. "Suppose that the mass at the time of intrusion was not at a very high temperature, that mineral separation had already commenced, and that it consisted of crystals of felspar and pyroxene, or—which is perhaps more probable—of completed pyroxenes and inchoate felspars, floating in a magma (having in the latter case the composition of felspar) which was already not very liquid. When the temperature was slightly lowered, as for instance near the faces of a fissure, the magma might become sufficiently viscous to exercise considerable strain upon the included crystals; they would be occasionally cracked, deformed, torn up, and aggregated in streaks; the mass would also become ill mixed; in short it would exhibit on a large scale the phenomena of a fluxion-structure, which would be more conspicuous towards the surface, but might set in here and there in any part or might occur like a foreign fragment owing to the rupture and entanglement of portions of an outer 'crust.' As consolidation proceeded, the magma would sometimes continue to augment the crystals already formed, and the coarser varieties be produced; sometimes it would independently crystallize and thus a fine-grained variety be produced or a quasi-porphyritic condition be retained." A similar theory had been previously formulated by McMahon[2] to explain the gneissose structures of some Himalayan granites, and was subsequently applied by Mr. Barrow[3] to explain the structure of certain gneisses and pegmatites in the Scottish Highlands.

This remarkably ingenious and original theory is of the highest value; undoubtedly it goes a long way to solve the problem of the foliation in the Lizard gabbro, and it is even more successful when applied, as its authors suggested, to the banded gneisses of the Kennack series in the Lizard. We may suppose that the

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[1] *Quart. Journ. Geol. Soc.*, vol. 47, 1891, p. 489.
[2] *Geol. Mag.*, 1887, p. 76. [3] *Geol. Mag.*, 1892, p. 64

massive dykes were injected in a molten state and cooled as normal igneous rocks; the flaser-gabbros and gabbro-schists were partly liquid and partly crystalline when intruded and as the mass solidified the injection pressures continued to force it onward. If we may imagine that as the magma crystallised it passed from a viscous liquid to a highly plastic solid[1] while motion still continued, the foliation, the augen structure and the orientation of the schistosity parallel to the walls of the dyke would all find a satisfactory explanation.

There are, however, certain features which this theory does not adequately explain; there is, in fact, much evidence to show that the gabbro dykes of the Lizard have been involved in crushing as a consequence of earth-movement, and that a large part of the foliation is due to this[2].

The serpentine which is in contact with many of the dykes of gabbro-schist is crushed for a distance of several inches from the margin of the dykes, and shows a new or super-induced foliation parallel to the junction. Excellent examples of this are to be seen in Compass Cove (Plate VIII.) half-way between Spernic Cove and the Green Saddle. Gabbro dykes are very numerous there, and very few of them are in a massive condition, the great majority being augen gabbros and gabbro schists. On each side of them the serpentine walls have an augen or schistose structure for two or three inches from the junction. This foliation is nearly at right angles to the fluxion banding and augen structure which were developed in the serpentine before the injection of the gabbro; it is always parallel to the foliation of the dyke and very similar to it in character. This new foliation obliterates the primary foliation of the serpentine, but it becomes gradually lost as we pass outwards from the edge of the dyke. The gabbro veins are so numerous that often they are separated by only a few inches of serpentine, and in that case the foliated structure is identical in the dykes and in the rock between them.

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[1] That minerals and rocks are much more plastic at high temperatures than at low temperatures is proved by theoretical and by experimental investigations. For information on this subject see :—G. Tammann, 'Krystallisiren und Schmelzen,' p 163 and p. 180 (1903); C. Doelter, 'Physikalisch-chemische Mineralogie,' p. 158 (1905); F. D. Adams and J. T. Nicolson, 'An experimental Investigation into the Flow of Marble,' *Phil. Trans.* vol. 195A, p. 377 (1901); L. Milch, 'Ueber Zunahme der Plasticität bei Krystallen durch Erhöhung der Temperatur.' *Neues Jahrbuch für Mineralogie*, 1909 (1), p. 60. L. Milch, 'Ueber Plastizitat der Mineralien und Gesteine,' *Geol. Rundschau*, vol. ii, 1911, p. 145.

[2] McMahon, in a note on the foliation of the Lizard gabbro, that appeared in the Geological Magazine in 1887 (p. 74), apparently before he had visited the Lizard or was acquainted with its rocks in the field, advanced a hypothesis that bears the closest resemblance to that which we have adopted as the most satisfactory explanation of the metamorphism of these rocks. He considers it likely that they had been injected through fissures in a plastic or partly consolidated state, and that shearing movements had acted, "frequently at intervals of sufficient duration to allow the marginal portions of the gabbro to cool and consolidate." Professor Bonney and he, in their subsequent paper (1891), on the crystalline rocks of the Lizard district apparently did not consider that earth-movements were to any extent the cause of the foliation in the gabbro for they state that "earth-movements have produced marked effects only at the extreme north and the extreme south of the district" (*loc. cit.* p. 498).

Foliated Gabbro Dykes in Serpentine at Compass Cove.

This shows that in these dykes the foliation was produced when the gabbro and the serpentine adjoining it were in the same state; both must have been quite solid; probably they were not entirely cold because the persistency with which the foliation follows the dykes and the absence of similar foliated belts in the serpentine elsewhere shows that there must have been some predisposing cause. We may reasonably suppose that the dykes and their walls were still hotter and hence more readily crushed than the main mass of the serpentine (which at that time was still a peridotite[1].

In many other places dykes of gabbro can be seen which lie in marked shear-belts or crush-zones in the serpentine. For a distance of several inches on each side of the dyke the serpentine is reduced to the state of a fine greenish schist, very soft and much decomposed, but often rich in tremolite and talc. Examples of this which can be easily visited are to be seen around Caerleon Cove. On the south of the Cove, a few yards south of the beginning of the cliff there is an inclined gabbro vein in the serpentine; the gabbro has been torn apart and appears only as a succession of lenticles in a line of greenish serpentine-schist. Another good example is the dyke of saussurite gabbro already alluded to as seen on the north side of Little Cove above the coast-guard's path. In both of these cases the gabbro is saussuritized, probably by decomposition after shearing. At Little Cove the dyke is bordered by several inches of a green schist so soft and rotten that it crumbles in the hand. Other examples of the same phenomenon may be found along the cliffs from this point northwards to Kennack. In these cases the serpentine is quite as much or more altered than the gabbro. These phenomena remind us strongly of the zones of secondary shearing which have been described by Mr. Clough† from the augen gneiss of Carn Chuinneag in Ross-shire.

[1] In this chapter we have assumed that the serpentine of the Lizard was still in an undecomposed state at the time when the pegmatitic veins of gabbro were injected. It is true that Professor Weinschenk[1] describes certain Alpine serpentines as consisting of primary intergrowths of antigorite and olivine (stubachite); he believes that these originated by crystallisation under pressure (piezocrystallization). Sir Thomas Holland[2] has advanced the hypothesis that the water and other vapours included in the magma are in certain cases very potent agents of rock decomposition and the olivine of ultrabasic rocks has often been converted into serpentine by a process of pneumatolysis that went on during cooling. In the Lizard district there is little evidence that has a direct bearing on this question, but one point is of some interest in this connection. Many of the fine dunite serpentines, at Porthallow for instance, are intersected by numerous veins of chrysotile (Plate VI., fig. 2), and these veins are posterior to the folding of the banded rocks as they are not in general dragged out or crushed by movement. It has been pointed out by Professor Sollas[3] that the cause of this veining is presumably the expansion that takes place during the conversion of olivine into serpentine by the assumption of water into the mineral molecule. We think this explanation is highly probable and it seems to lead to the conclusion that the serpentinisation of the Lizard peridotites took place at a comparatively late period in their history.

[1] 'Spezielle Gesteinskunde,' 2nd Edit., 1907, p. 184.
[2] *Geol. Mag.*, 1899, p. 30 and p. 540.
[3] *Geol. Mag.*, 1895, p. 259.

† 'Summary of Progress of the Geological Survey for 1902,' (1903), p. 150.
'The Geology of Ben Wyvis, Carn Chuinneag, etc.' (*Mem. Geol. Surv.*), 1912.

Many other dykes of gabbro schist, however, have walls of serpentine in an absolutely normal state. This type occurs in great plenty around Carrick Luz; many branches and small offshoots from the main dyke can be seen in Spernic Cove and Lankidden Cove, and though the gabbro may be highly foliated the serpentine shows no alteration at the junction of the two rocks. In this case there is no escape from the conclusion that, as the gabbro must have been crystallised before the peculiar augen structure developed, the rock must have passed through a period in which it was solid but extremely plastic. Hence we infer that these dykes were caught by movements of the walls immediately after crystallising and while they were still very hot.

Exactly similar phenomena are seen in the inclusions of serpentine in dykes of gabbro schist. In Spernic Cove though the gabbros are schistose, the serpentine inclusions are massive or only slightly foliated; at Compass Cove there are many inclusions of serpentine which have been reduced to thin lenticles having a perfectly schistose structure.

There is also abundant evidence that the gabbro dykes were involved in numerous movements and displacements during the period which immediately followed their intrusion. They were succeeded, probably at no great interval, by the black dykes of dolerite and epidiorite; and in many sections it is clear that the gabbro dykes were faulted and sheared before the black dykes were injected (Plate X.). In some cases the movement was of the nature of faulting along clean-cut lines of displacement, and though both serpentine and gabbro may be brecciated they are not rendered schistose by the faults. Instances of this are exceedingly common, but one of the best and most accessible is found a few yards south of the gate on the west side of Kennack. On the south side of the second little cove a gabbro vein about nine inches thick is four times shifted by small faults, and along one of these a black dyke has risen, but is not itself affected by the faulting, which is clearly older than the dyke (Fig. 6, p. 127). In these cases the gabbro is coarse-grained and not schistose, though microscopic sections show that it has undergone a limited amount of crushing.

Still more commonly the gabbro dykes are wrenched off by irregular planes of movement along which the serpentine also becomes more or less schistose. This is the reason why so few of the dykes of augen gabbro or flaser gabbro can be followed for more than a few yards. They are often bent and dragged out to tapering ends at which the foliation converges to a point, so that they look like pieces of soft metal which have been wrenched asunder; and the foliation is most perfect at the sharp curves and at the ends of the dyke. The impression produced on the observer is that these veins have been caught in powerful but irregular movements; they have been softer and more plastic than the peridotite which surrounded them and have yielded to the stresses; there has also been an internal shearing which has crushed the minerals and set up a rough foliation.

Among instances of this we may note the two dykes at Caerleon Cove and Little Cove above alluded to; the dyke below Polbream Point, to be more fully considered in a subsequent chapter; the thick dyke on the north wall of Kildown Cove; the southern dyke in the east side of the cove west of Poldowrian; the dyke in serpentine in the middle of Kynance Cove; and the thick curved dyke which occurs in the north-east corner of Compass Cove. At Poldowrian (Plate X.) and Polbream Point it is clear that the crushing of the gabbro dyke took place before the injection of the adjacent black dykes which cut the gabbros there.

From these facts we seem justified in inferring that the consolidation and cooling of the gabbro were attended by stresses and earth-movements to which a large part of the metamorphism is to be ascribed. We hardly need point out that this was also found to be true of the serpentine. Its margin was folded with the hornblende schists, and foliation was induced in many parts of its mass before the gabbro dykes were injected. The structures of the gabbro are quite analogous to those of the serpentine and were produced by the same agencies in nearly the same way. There are distinctions, however, which are worth noticing. The serpentine at its margins is folded, but in no part of the gabbro has folding been proved; all the movement seems to have taken the form of internal shearing in a large unwieldy complex which would not fold; this was already noted in the large intrusion of lherzolite. In the serpentine and the gabbro the foliation is always parallel to the margin of the mass, but the foliation of the gabbro cuts or traverses that of the serpentine. At the edge of the serpentine the foliation of the hornblende schist and of the serpentine both conform to the junction line.

Chemical Composition of the Gabbro.

Mr. Radley has made an analysis of the olivine gabbro of Polcoverack, which is very fresh and almost entirely unaffected by pressure metamorphism. For comparison we quote an old analysis of the troctolite of Coverack by Houghton (II.) and two analyses of allied rocks of Tertiary age from the Inner Hebrides. The troctolite (II.) as compared with the Lizard gabbro shows distinctly less lime and more magnesia and alumina. The smaller percentage of lime while the magnesia is present in greater amount enables us to understand why olivine is more abundant in the troctolite while pyroxene is less frequent.

As compared with the Skye gabbro the Lizard rock (I.) is much poorer in lime and alumina; hence its felspar is labradorite while that of the Hebridean rocks is bytownite or anorthite. Mr. Harker has directed attention to this peculiarity of the basic and ultra-basic plutonic rocks of Skye and Rum. The allivalite contains so much magnesia that it is evidently much richer in olivine than the troctolite of Coverack.

Analyses of Gabbros, Troctolite, etc.

—	I.	II.	III.	IV.
SiO_2	50·69	45·73	46·39	42·20
TiO_2	0·42	—	0·26	0·09
Al_2O_3	20·56	22·10	26·34	17·56
Fe_2O_3	1·55	0·71	2·02	1·20
Cr_2O_3	0·08	—	tr.	0·06
V_2O_3	0·02	—	—	—
FeO	3·10	3·51	3·15	6·33
MnO	0·16	—	0·14	0·18
(CoNi)O	n.f.	—	—	0·13
BaO	n.f.	—	—	—
CaO	11·99	9·26	15·29	9·61
MgO...	6·84	11·46	4·82	20·38
K_2O	n.f.	0·34	0·20	0·11
Na_2O	3·36	2·54	1·63	1·11
Li_2O	tr.	—	—	—
H_2O at 105° C.	0·18	4·38 (both)	0·10	0·06
H_2O above 105° C. ...	0·94		0·48	1·13
P_2O_5	0·05	—	tr.	—
FeS_2	0·11	—	—	0·02 S
CO_2	n.f.	—	—	tr.
	—	—	—	0·04CuO
Total	100·05	100·03	100·82	100·21

I. Fresh olivine gabbro, from blocks at roadside about 400 yards west of Polcoverack, near Coverack [E. 6709]. (Anal. E. G. Radley.)

II. Troctolite of Coverack (Anal. F. T. S. Houghton), *Geol. Mag.*, 1879, p. 505.

III. Olivine gabbro, Cuillin Hills, Skye [8093] (Anal. W. Pollard), cited from A. Harker, 'Tertiary Igneous Rocks of Skye' (*Mem. Geol. Surv.*), 1904, p. 103.

IV. Allivalite (anorthite-olivine rock), Allival, Rum [10461] (Anal. W. Pollard), cited from A. Harker, 'Geology of the Small Isles' (*Mem. Geol. Surv.*), 1908, p. 80.

—	I.	II.	III.	IV.	V.
SiO_2	49·65	49·9	49·4	48·8	52·8
TiO_2	—	—	—	—	—
Al_2O_3	29·35	6·2	29·8	10·6	2·8
Fe_2O_3	0·59 (both)	1·7	1·2	1·7	1·8
FeO		3·9	—	4·7	—
MnO	—	0·4	—	—	—
MgO	0·46	16·1	1·7	18·6	16·6
CaO	12·18	20·4	12·6	12·2	25·2
Na_2O	3·61	—	3·3	—	—
K_2O	0·48	—	0·4	—	—
H_2O	3·19	0·9	1·7	1·8	0·5
Cr_2O_3	—	0·6	—	tr.	—
Total ...	99·51	100·1	100·1	98·4	99·7

I. Felspar from the troctolite of Coverack (Anal. F. T. S. Houghton), *Geol. Mag.*, 1879, p. 505.

II. Chrome-diopside from gabbro of Coverack (Anal. J. H. Player), quoted from J. J. H. Teall, 'Notes on Some Minerals from the Lizard,' *Min. Mag.*, vol. 8, 1888, p. 116.

III. Labradorite from the same rock as II. (Anal. J. H. Player), *ibid.*

IV. Hornblende from gabbro schist, Pen Voose (Anal. J. H. Player), *ibid.*

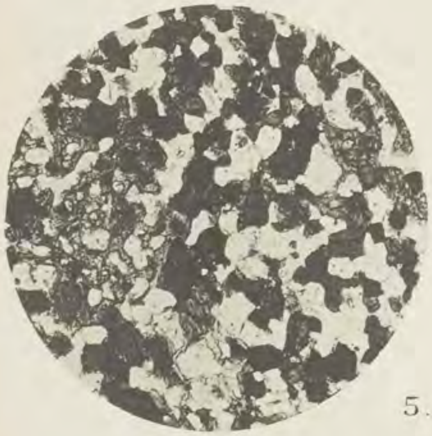
V. Malacolite from gabbro, Carrick Luz (Anal. J. H. Player), *ibid.*

1.

2.

3.

4.



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PHOTOMICROGRAPHS OF ROCK-SECTIONS.

PLATE IX.

PHOTOMICROGRAPHS OF LIZARD GABBROS AND DOLERITE.

Fig. 1.—*Olivine gabbro* (6368), half-a-mile north-west of Coverack, magnified 12 diameters. One of the normal Lizard gabbros in which foliation is completely absent. The photograph shows that the rock has well-developed ophitic structure and consists of olivine, diallage and plagioclase felspar.

,, 2.—*Troctolite* (7617), Coverack, magnified 8 diameters. Clusters of olivine, weathering to serpentine, are surrounded by clear felspar. Radiate systems of cracks spread outwards from the olivine.

,, 3.—*Flaser gabbro* (6734), North Corner, Coverack, magnified 10 diameters. In this specimen the felspar is crushed and fissured, and its schillerisation is disappearing. One pyroxene crystal is completely, another partly, replaced by fibrous actinolite. The original igneous structure, though still visible, is partly destroyed.

,, 4.—*Gabbro schist* (6365), Compass Cove, east of the Green Saddle, magnified 9 diameters. The igneous structure is obliterated and the rock is coarsely schistose. The pyroxene has been replaced by lenticular aggregates of actinolite. The clear matrix is altered felspar.

,, 5.—*Hornblende beerbachite* (6249), south side of Porthoustock Cove, magnified 35 diameters. This is a granular rock consisting of brown hornblende, pale green augite and clear labradorite. It forms a dyke in the gabbro.

,, 6.—*Olivine dolerite* (6852), west end of Coverack, magnified 24 diameters. The view shows a large grain of olivine rendered dark and semi-opaque by abundant minute black inclusions. The matrix is ophitic and consists of augite and plagioclase felspar.

CHAPTER VIII.

THE DOLERITE AND EPIDIORITE DYKES.

After the gabbro had consolidated and cooled down a large number of basic dykes were injected into all the older members of the complex. Their existence was known to all the geologists who have visited the Lizard, but for detailed accounts of them we are indebted principally to Professor Bonney, Dr. Teall, and Mr. Howard Fox[1]. Many important particulars have also been given by Mr. Harford Lowe[2].

Distribution of the Dykes.

Along the cliffs from Porthoustock to Godrevy Cove the abundance of black dykes in the gabbro is extraordinary. In some places it is possible to step from one dyke to another, as they are separated only by thin partitions of gabbro. On Porthoustock Point, for example (Fig. 3), eleven of them are seen in a breadth of about seventy feet. They vary from ten feet to a few inches

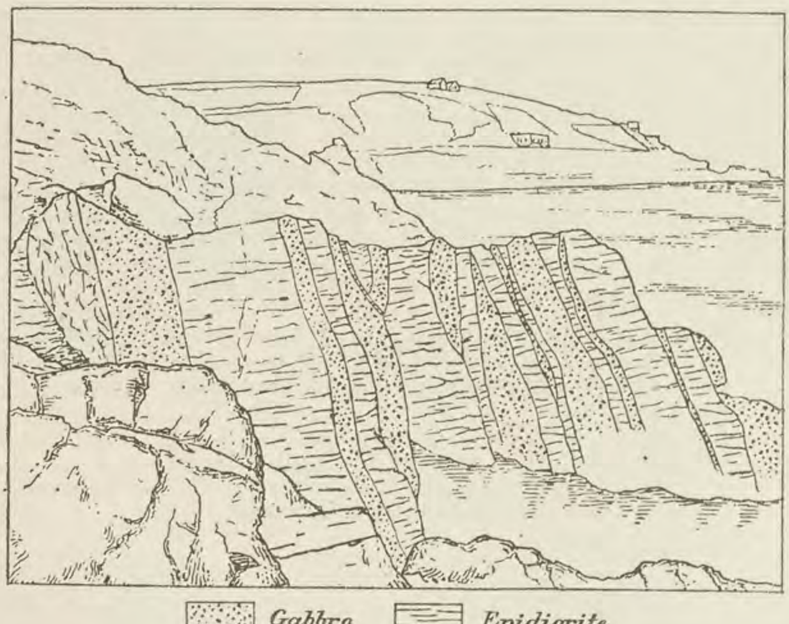

Figure 3. *Epidiorite Dykes cutting Gabbro at Porthoustock Point.*

[1] Reference may be made to the papers by those authors cited on p. 61, also to J. J. H. Teall, 'On the Basic Igneous Rocks of Cornwall,' Geologists Association, Excursion to Cornwall, 1887, p. 34, also *Proc. Geol. Ass.*, vol. 10, 1887, p. 58. Howard Fox, 'On the Gneissic Rocks off the Lizard,' *Quart. Jour. Geol. Soc.*, vol. 44, 1888, p 309. Howard Fox and A. Somervail, 'On the Occurrence of Porphyritic Structure in some Rocks of the Lizard District,' *Geol. Mag.*, 1888, p. 74. A. Somervail, 'The Origin and Relations of the Lizard Rocks,' *Trans. Roy. Geol. Soc. Cornwall*, vol. 11, 1893, p. 536.

[2] Harford J. Lowe, 'The Sequence of the Lizard Rocks,' *Trans. Roy. Geol. Soc. Cornwall*, vol. 12, 1901, p. 438, and 1902, p. 537.

in breadth and the gabbro between them may be only six inches wide; in fact sometimes two dykes have entered the same fissure and the later has chilled edges against the earlier, or two dykes may be separated by a thin wall of gabbro which dies out so that they come together along part of their extent. These dykes have usually vertical and parallel walls, so straight and well-defined that they resemble closely the Tertiary dolerites of some parts of the west coast of Scotland; in other cases they may be seen to branch, or a narrow dyke may run irregularly for some distance till it finds a clean-cut fissure when it proceeds along a straight course. The thickest dyke is one a little north of Manacle Point which is about forty feet broad, but it may really be produced by the coalescence of several thinner dykes.

On the south side of Porthoustock Cove the rock-exposures are partly covered by the *débris* from the quarries, but to judge from the sections visible and from the nature of the rock, which is crushed for road-metal, there is quite as much greenstone as gabbro. The thin vertical partitions of gabbro so much resemble dykes that De la Beche and other geologists have imagined that the gabbro was really intrusive into the 'greenstone,' and probably for that reason this district was coloured as 'greenstone' on the early maps of the Geological Survey, but the fact that the black dykes have always fine-grained chilled edges where they are in contact with the gabbro shows the true order of the succession*.

From Manacle Point south to Godrevy Cove there are many black dykes in every little cove, and this is also a feature of the Dulgevean, Shark's Fin, and other reefs off the shore. After passing the Cove, however, we meet fewer of them, and near Dean Point they become comparatively scarce. From Lowland Point to Coverack not many are seen, but there is a small group about three hundred yards north of the North Corner. in the foreshore below Coverack they occur in great numbers, cutting both serpentine and gabbro (Fig. 2, p. 94). Some of them are four or five feet in thickness, but the majority are not over a foot. Below the raised beach sands they are weathered in spheroidal fashion, but those laid bare in the shore below are exceedingly hard and fresh. Along the shores of Perprean Cove black dykes are numerous and usually rather decomposed, and from Chynhalls to the Black Head they occur every few yards and are often eroded by the sea into long narrow gullies running west-north-west or north-north-west. They vary greatly in freshness, some being soft and rotten while others are hard and splintery. As at Manacle Point they have usually straight vertical walls but inclined dykes are not uncommon, and they occasionally fork and give off branches. Sometimes a black dyke breaks up into two or three parallel ones which may again unite.

From the Black Head to Carrick Luz the dykes are not so frequent but a number may be seen in the cliffs on each side of the mouth of the stream at Downas Cove and at Beagles Point, mostly in a rotten state; in the coves on each side of Carrick Luz several examples occur, and fine black threads which cut the

* J. J. H. Teall, *Geol. Mag.*, 1886, p. 482.

gabbro on the west side probably belong to this series. Further west they occur in considerable numbers and have a marked tendency to take the form of sloping sills dipping to east and east-north-east at angles of 45 degrees and less (Fig. 4 and Plate X.). Excellent examples of this type may be seen in the cove west of Poldowrian where a pathway leads down over a slanting face of serpentine to the beach; others occur further west among the rocks below the Green Saddle, and there is a good and fresh example below a little quarry on the top of the cliff before the path descends to Kennack. On the east side of Kennack Cove others are seen, one being five or six feet thick and enclosing a large slab of serpentine. In Carn Kennack, the hillock of serpentine in the centre of the cove, a branching rotten black dyke outcrops on the west side and may also be traced in the first little cove on the south.

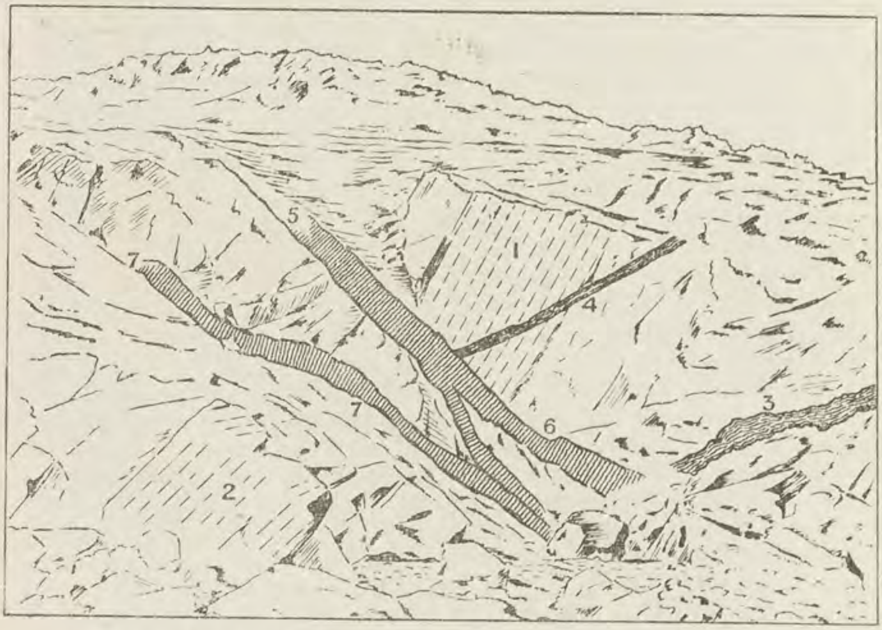

Figure 4. *Dykes of epidiorite and gabbro cutting the serpentine, cove west of Poldowrian.*

A photograph of this locality is given in Plate X (*q.v.*).

The cliffs consist principally of serpentine of the coarse variety full of large bastite crystals. These have a well marked orientation giving rise to a fluxion banding, seen in the photograph at two places (1 and 2). This banding is cut by many gabbro dykes of which two are shown (3 and 4). The lower of these (3) is much crushed and foliated and its course is sinuous; the upper (4) has straight well-defined margins and is more massive in structure. Both of them are cut sharply across by a set of epidiorite dykes (5, 6, 7) and these must have been injected along planes of faulting as the gabbro veins are not seen on the west side of the cove in the serpentine. The epidiorite dykes may be described as inclined sheets dipping to the east; they branch and enclose masses of serpentine in several places. The weathering of the lower dyke has given rise to a sloping surface down which there is a rough foot-path. The lower dyke (7) has often a schistose appearance while the upper (5) is massive. At the point marked 6 the upper dyke contains veins of red biotite gneiss and hence exhibits some of the characters of the Kennack Gneisses. The height of the cliff is eighty to a hundred feet.

Epidiorite Dykes cutting Gabbro Dykes in the Serpentine, Poldowrian.

Where the serpentine reappears on the west side of the bay black dykes are found in it in plenty; there are about a dozen in the first 150 yards south of the gate. One of these is especially well known; it cuts a gabbro dyke (Fig. 5) about seventy yards south of the gate. The gabbro dips to the west at a low angle while the black dyke is vertical though slightly tortuous, and runs nearly north and south. The gabbro has been faulted before the dolerite was injected. Rounding the corner into the gravelly cove beyond we meet with several fine-grained black dykes in the serpentine, presenting features of interest which will be described in a later part of this chapter. From this point for several hundred yards the cliffs are mostly composed of banded gneisses; then we pass the mouth of a little streamlet and a projecting headland of gneiss which can be rounded only at low water; in the coves between this headland and Polbream Point there are many black dykes. At Polbream Point black dykes can be seen emerging from a mass of banded gneiss, and below the headland there is a well-defined straight and nearly vertical dyke.

From Caerleon Cove south to Enys Head the dykes are not so frequent, but on the headland several are seen cutting the serpentine. Two occur at the south side near the cave and there are others on the north side; they cut the gabbro but not the banded gneisses. From Kildown southwards past Cadgwith to Polbarrow the cliffs are mainly hornblende schist and no black dykes are known, but they appear again in the coast sections between this and Pen Voose though usually not as dykes with parallel walls but as irregular streaks and threads permeating a *mélange* of serpentine and gabbro, and mixed up with granite and banded gneisses.

About the Lizard Head black dykes are known only at the life-boat station at Polpeor (Plate V., fig. 2) and in the adjacent cliffs and reefs. There they assume a remarkable facies since they occur as pillow-shaped masses lying in the mica schists and green schists of the Old Lizard Head Series. In the old quarry on Venton Hill Point there is a whale-backed mass rising among the andalusite mica schists which proves to be an ophitic epidiorite and is undoubtedly one of the basic dykes, but it cannot be traced beyond the quarry. Further north, in the serpentine of Pentreath Beach, several dykes may be seen much decomposed, and in the cliffs from there to the Lion Rock a few have been observed. In the cove north of the Lion Rock and on the east side of Kynance Cove (Fig. 4), where the pseudophite occurs, there are dykes of this group, but one of the most interesting is seen in the downs to the east of Kynance where the carriage road makes a sharp bend before it descends into the valley; to the east of the bend there is a cutting in the rock and on the north side of this, in the serpentine, there is a long thread-like dyke of fine hornblende schist, very rotten and crumbling. Traced westwards it thickens slightly and seems to arise from a nearly massive intrusion of fine black rock which can be seen on the south side of the road where the cutting ends.

The western cliffs of the Lizard contain few dykes of dolerite or epidiorite. On Pengersick (the south part of Vellan Head) there are several, along with dykes of aplite. One occurs also on the north side of George's Cove (half-way between Vellan Head and Pol Cornick), and at the latter locality there are several which were described by Teall and Fox. They run in a west-north-west direction through the junction of the serpentine and the schists. After passing Ugo Dour Cove we find a dyke in the serpentine of one of the small infolds where the high cliff gives place to a low slanting face of rock covered with grass. North of this no black dykes are known in the coast sections though fragments of them may be found on the serpentine downs. Through the whole area of schists on the north of the serpentine dykes must be very scarce as no instance of them has been noted, and between Porthallow and Porthoustock, although the cliff exposures are excellent, no black dykes are known.

Field Relations of the Epidiorite Dykes.

These dykes cut all the rocks of the Lizard complex except the banded gneisses and the granites or granite gneisses. In their distribution, however, they are exceedingly capricious. Occurring in great numbers on the east coast from Porthoustock to Kildown Point and in the cliffs below Polbarrow, they are comparatively scarce on the west and south coasts. In particular they seem to avoid the mica schists and hornblende schists, for some reason which has not been solved. In this respect the country north of Porthoustock, which consists of hornblende schists without any black dykes, offers a very strong contrast to the district south of that village where the gabbro is filled with dykes of this group. Their abundance in the gabbro may be due to the fact that that rock had only recently solidified and was in a state of tension owing to contraction on cooling.

Their principal areas of distribution are in or about the larger intrusions of the gabbro, and on the margins and outskirts of the Kennack gneisses. The reasons for this appear to be that these dykes are the successors of the gabbro, with which they have the closest relations both in structure and composition; they are the final part of the gabbro magma which was injected after the main mass had assumed its present position. The two series bear the same relations to one another as the Cornish granites and the elvan dykes. At the same time they were the precursors of the banded gneisses which followed them without any pause, and with which they are connected by transitional stages.

That all the black dykes of the Lizard belong to one series it would be impossible rigidly to demonstrate; we can only say that in their field relationships and their microscopic characters they present so much uniformity that there is no reason to doubt their intimate connection with one another. The only exceptions to this are the black dykes which cut the Man of War gneisses in the outlying skerries off the Lizard; these differ in some respects from all the dykes on the mainland, and there is room for doubt whether they are to be assigned to the same group.

The strike of the dykes is not always the same; many of the smaller ones, about Kennack, for example, seem to trend in all directions ; but it is safe to say that north to north-west strikes are the most common, and dykes having this direction far exceed in numbers all those having other strikes. From Porthoustock to Kennack the immense majority of the black dykes run north or north-west, and in other parts of the Lizard the same tendency is very strong, as, for example, in the porphyritic dykes described by Fox and Teall at Pol Cornick[1]. It is a well known fact that after a great period of folding systems of dykes are often injected into the folded rocks having a general direction along the axes of the folds. The Cornish elvans are instances of this, and the dykes of porphyry, porphyrite, and lamprophyre of the southern Highlands of Scotland; the black dykes of the Lizard seem to bear this relationship to the axes of folding in which the mica schists, hornblende schists, and early parts of the serpentine had been involved.

In their relations to the older rocks the dolerite and epidorite dykes behave usually as normal igneous intrusions. So much is this the case that the possibility that some of those which occur near Coverack might be of Tertiary age[2] has been entertained by more than one writer. In the mica schists, however, they take the form of pillow-shaped masses (Plate V., fig. 2), with tapering ends, dragged out and rounded by the flow of the more plastic schists around them during some period of movement. Elsewhere we occasionally find black dykes partly or completely converted into green schists and hornblende schists[3], but the consideration of the causes of this metamorphism may be deferred till we have described the petrographical characters of the rocks.

Classification of the Epidiorite Dykes.

The black dykes of the Lizard may be divided into groups the members of which have many characters in common. Some of these groups have a well-defined geographical distribution, as certain types of black dykes are found only in one district. Where many dykes occur together they are usually of the same petrographical variety, and this undoubtedly points to the conclusion that they have originated at the same time, and if they could be followed downwards might prove to arise from a common source.

The classification we propose to use is a petrographical one, based on the microscopic characters of the rocks, but regard has also been had to their mode of occurrence and their distribution. All the black dykes are of thoroughly basic composition, corresponding to dolerites and olivine dolerites. Where they are least altered they may contain fresh olivine or pseudomorphs after that mineral, and augite of brownish colour is frequently preserved in the more massive examples. Plagioclase felspar and iron oxides are the other essential minerals. The massive or unfoliated rocks are very frequently ophitic, and this is invariably the case where the augite is still present; very often, however, the pyroxene has been replaced by hornblende (uralite), but if the rocks have not been

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[1] *Quart. Jour. Geol. Soc.*, vol. 49, 1893, p. 204.
[2] T. G. Bonney, *Quart. Jour. Geol. Soc.*, vol. 33, 1877, p. 924.
[3] Howard Fox and J. J. H. Teall, *loc. cit.*

sheared the ophitic structure can still be ascertained without the slightest difficulty. A few of the dykes are porphyritic with large phenocrysts of plagioclase felspar, or, more rarely, of augite.

Other dykes are granular and non-ophitic, consisting of augite and plagioclase felspar in small anhedral crystals. They have a close resemblance in structure and composition to some varieties of the gabbro, and belong to the class of fine-grained gabbros or beerbachites. In none of these rocks has olivine been detected, though they may contain hornblendic pseudomorphs which probably represent that mineral.

In all parts of the Lizard district it is possible to find examples of black dykes converted into hornblendic schists, as has been described by Dr. Teall[1] in certain dykes at Pol Cornick on the west coast, but this is of little value as a means of classification, as many dykes are massive in one place and quite schistose in another, and the passage from a massive dyke-rock to a schistose one may often be observed to take place within a few inches.

The Coverack Dykes.

At Coverack, on the shore betwen the Post Office and a point about four hundred yards north of the North Corner, a group of black dykes is exposed which are less altered than any other members of this class within the Lizard area. Their special features have been pointed out both by Professor Bonney and by Dr. Teall. They are little modified, and their igneous structures are in excellent preservation. Even in these rocks, however, evidence of metamorphism may sometimes be observed, and there seems no reason why they should be considered of distinct origin from the other black dykes of the district; the occurrence, in fact, of purely massive types, that are normal igneous rocks, along with others that are highly metamorphic, has already been indicated as characteristic of both the gabbro and the serpentine in the Lizard.

Good examples of these dykes are seen in the foreshore about three hundred yards west of the pier at Coverack. They vary in width from six inches up to six feet, and are vertical, cutting across the serpentine, the troctolite, and many veins of gabbro (Fig. 2, p. 94). The trend of the black dykes is about north-west, and they vary little in this respect; they have fine-grained chilled edges against all the older rocks. Those that are exposed in the gravel of the beach are very fresh and have a dark grey colour from their abundance of plagioclase felspar, but in the low cliff where the black dykes are seen beneath the deposits of the raised beach they often exhibit marked spheroidal weathering.

A microscopic section of one of these dykes (6849), (Plate IX., fig. 6) shows that the rock is an ophitic olivine dolerite. There are small porphyritic crystals of olivine, quite fresh at their centres though weathered at their margins to dark brown limonite and serpentine. A striking peculiarity of these crystals is their grey colour which proves, when high magnifications are employed, to be the result of the presence of great numbers of minute black inclusions (probably magnetite). These opaque specks have rounded shapes and are arranged in

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[1] *Loc. cit.*

curved lines that ramify through the substance of the olivine. The augite is of pale brown colour and nowhere yields traces of crystal outlines; it occurs only as ophitic plates in which lath-shaped crystals of plagioclase are embedded. The felspar is fresh and clear, and with polarised light shows the usual complicated twinning; optical tests established that it is a basic labradorite (with 30 per cent. of albite). The outer borders are somewhat more rich in alkalies but the crystals are not conspicuously zoned.

The thin sections show little evidence that the rock had been crushed but the augite is to some extent uralitised as borders of pale green amphibole often surround the pyroxene crystals. For the most part this secondary hornblende is fibrous or matted, but compact growths are sometimes seen.

Some of the adjacent dykes show a more advanced stage of uralitisation, as in them the pyroxene has been completely replaced by green and brownish amphibole but the ophitic structure is perfectly retained and there are still large olivine crystals filled with minute black specks (6852). About a hundred yards north of the North Corner there are ophitic dolerite dykes which contain much fresh augite but no olivine (6848). In most of the dykes, however, the felspar is the only original mineral which is preserved; the augite is replaced by fibrous amphibole and there are also clusters of pale tremolitic needles that are presumably pseudomorphs of 'pilitic' character after the original phenocrysts of olivine. These facts indicate that the Coverack dykes cannot be separated from the others that occur on the east coast of the Lizard, as all exhibit the same changes, though to a varying degree.

The Manacle Point Dykes.

Over the whole area occupied by the gabbro, and especially along its northern edge, dykes of 'greenstone' occur in immense numbers. By far the finest section in which they are exposed is that afforded by the eastern cliffs from Porthoustock Point to Godrevy Cove. About Manacle Point the individual dykes are often separated only by a few feet of gabbro (Fig. 3). South of Godrevy Cove they become notably less frequent, though several may be seen on the north side of Dean Point, and others at the quarries there. On the north side of Coverack Bay black dykes are few.

In the inland country the exposures are very bad, as even where the soil is not cultivated the rocks are covered with a thick accumulation of rotted *débris*. Fragments of fine dark epidorite occur, however, in the soil in sufficient quantity to prove that many dykes must be present; and in the pits where rotted gabbro has been extracted for agricultural purposes, dark vertical bands of decomposed greenstone often intersect the more coarsely crystalline and paler coloured gabbro. Rotted greenstone dykes *in situ* may be seen in the 'marl-pits' at Lanarth, Trevean, Treleague, and around Rosenithon. Apparently they break up into small pieces under the action of the atmosphere, probably on account of their numerous joints, as large blocks of greenstone do not occur on the downs, though huge lumps of gabbro are strewn about in great numbers.

Among these dark dykes which cut the gabbro two petrological types can be identified; one having the ophitic texture of a dolerite while the other has the granular texture of a gabbro.

The first of these—the *ophitic epidiorites* or *uralitised dolerites*—is probably the more common, for fully one-half of the dykes sliced belong to this class. The felspar of these rocks is idiomorphic, in elongated rectangular or lath-shaped prisms, and is surrounded by masses of hornblende that have no definite shape but fill up the spaces between the felspar crystals. The plagioclase ranges in composition from medium labradorite to bytownite and is often very fresh, but many rocks also contain rectangular porphyritic crystals of felspar that may be half an inch long and these are generally saussuritised or changed to secondary aggregates in which epidote, prehnite and white mica may often be recognized. Augite has not been seen in any of the members of this group but is invariably replaced by hornblende. Occasionally we may remark the presence of radiate pseudomorphs of white amphibole that resemble pilite after olivine, and sometimes these aggregates have the outlines of olivine crystals, as in a dyke that occurs 300 yards south of Dean Point (6704). From the scarcity of these pseudomorphs, however, though the original igneous structures are well preserved, it is safe to infer that few of these dykes contained porphyritic crystals of augite or of olivine. The hornblende is sometimes pale green, fibrous and matted ; at other times it occurs as small grains of rounded or anhedral form, closely packed between the felspars ; and in other rocks a large part of the amphibole, though undoubtedly secondary, makes large irregular ophitic plates that are penetrated by many lath-shaped crystals of felspar. The hornblende, fibrous or compact, is usually green of varying shades but seldom very dark in colour ; a little brown hornblende is also not infrequent, and may in some cases be primary.

Ophitic epidiorites of this type are found throughout the whole of the gabbro area ; they are seldom so fine-grained as the Coverack dykes previously described, and never so fresh (as olivine and augite are not found in them), but in other respects the similarity between these two groups is very great.

The second type of dyke that occurs at Manacle Point and throughout a large part of the gabbro area may be described as fine-grained gabbro or *beerbachite* (Plate IX., fig. 5). In these the felspar occurs in small crystals that are squarish or rounded, but not lath-shaped, and the augite forms similar rounded or anhedral grains that are not moulded upon the surfaces of the felspars. For the most part the augite has been replaced by fibrous uralitic pale-green hornblende ; occasionally, however, fresh pyroxene of brownish colour may be remarked in the slides (6342). Pilite pseudomorphs after olivine also are not wanting, though scarce. Some of the rocks have much dark brown hornblende, presumably primary. The green hornblende often contains minute black inclusions that indicate the schiller structure of the original augite ; the felspar also is sometimes schillerised but this is less frequent. In fact most of the structural and mineralogical features of the coarse gabbro are repeated in these rocks on a smaller scale. These beerbachite dykes have not a restricted distribution but occur among those of the ophitic type along the shore from Porthoustock to Lowland Point, and are found in many places inland.

The West Coast Dykes.

Only a very small number of dykes is known to occur on the west side of the Lizard peninsula. In 1883 Messrs. Fox and Teall described a group of ' porphyritic epidiorite ' dykes which they had discovered in the coast sections between Ugo Dour Cove and Pol Cornick. They have a general north-west trend, and range from a few inches up to five feet in thickness. The banded complex of hornblende schist and serpentine at Pol Cornick is cut sharply by these dykes, and they show chilled edges against it, but they are not proved to intersect the gabbro veins that occur in the serpentine there. Two epidiorite dykes are well seen in the bare rocks on the top of the cliff at Pol Cornick; the others are visible at the base of the cliffs at low tide. Many of the dykes contain phenocrysts of plagioclase felspar, and those that are least sheared have a matrix of ophitic augite (more or less completely transformed into hornblende) enveloping lath-shaped crystals of felspar. In places these dykes have been converted into hornblende schists, but this subject will be discussed in a later part of this chapter.

A very good example of a black dyke traversing hornblende schist and serpentine may be seen on the west side of the second little cove west of Ugo Dour (Parc Bean), at the locality where the crystallized datolite was obtained, that was described by Mr. McLintock in 1910[1]. This dyke is about two feet thick, has a north-west trend and is nearly vertical. In places it is slightly schistose. It contains no augite, but is a porphyritic epidiorite with phenocrysts of plagioclase in an ophitic groundmass. The felspar of the rock is nearly entirely converted into saussurite or pseudophite, and the pyroxene has been replaced by ophitic plates of pale brown hornblende (5183).

Three hundred yards south of Pol Cornick there is a small projecting headland on the north side of George's Cove, where one (or perhaps two) porphyritic epidiorite dykes may be seen on the top of the cliff. At the base of the cliff another dyke of similar character occurs near the north end of the cove and is accessible only with a boat. These dykes have a close resemblance to those of Pol Cornick. They have ophitic structure, and, in microscopic sections, though the rocks are much decomposed, a good deal of fresh brown augite may still be seen.

There seems little reason to doubt that these dykes belong to the same period of igneous injection as the epidiorite dykes of the east coast that have been previously described. They have the same composition and the same structure; they exhibit the same metamorphic changes, though original augite is more frequently preserved in the west coast dykes. They cut the serpentine and the hornblende schist and are later than the folding of these rocks; moreover they have the north-west trend that is so characteristic of the dykes around Coverack and Manacle Point.

Between George's Cove and Pentreath Beach black dykes have been found at a few places cutting the serpentine. There are two small dykes on the west side of Vellan Head, narrow and branching, with a general north-west direction, but they are schistose and belong to a class that will be discussed subsequently. Several dykes occur also on the east side of Kynance Cove (Fig. 5), at the locality for pseudophite that was described by Messrs. Fox and Teall. There is another at the inner end of the cove north of the Lion Rock and several may be seen in the footpath along the top of the cliffs from Kynance to the Lizard near the large landslip which is known as Holestrow. Several small black dykes are exposed in the serpentine that forms the north wall of Pentreath Beach, and another may be traced for a few yards in the cliff about the middle of Pentreath Beach, but apparently soon dies out. None of these dykes is porphyritic and all of them are very much decomposed. So far as is known they are not ophitic and some of them belong to the same group as those of Kennack Bay.

In the hornblende schist of the Lizard district black dykes are exceedingly rare, being known to occur only at George's Cove and Ugo Dour. But in the mica schists there is one ophitic epidiorite that probably belongs to the set of basic dykes which followed the intrusion of the gabbro. This occurs as a boat-shaped mass in the andalusite schist of the small quarry on the tope of Venton Hill Point. The whole mass is not more than eight feet long and appears to be a phacoid that has been pinched off by movements in the schist, as the dyke cannot be followed down the cliff, and no similar mass is known in the vicinity. That it is an intrusive dyke is shown by its coarse ophitic structure, which is remarkably well

[1] W. F. P. McLintock, 'On Datolite from the Lizard District, Cornwall,' *Mineralogical Magazine*, vol. XV., 1910, p. 407.

preserved though the augite has been replaced by hornblende and the rock is full of prehnite and other secondary products. The dyke also has produced a slight contact alteration on the mica schist, which is distinctly harder and more compact at the junction of the two rocks.

The Dykes in the Lizard Reefs.

In his paper on 'The Gneissic Rocks off the Lizard,' Mr. Howard Fox[1] described for the first time the interesting group of dykes that occur on almost all the outlying skerries, traversing the gneisses, granulites and basic schists of the Man of War Series. He showed that many of these dykes had well-defined parallel walls, but others had been displaced and torn apart by movements. The trend of the dykes varies a good deal, some having a north-west direction while others run east and west or even north-east and south-west. The dykes are so numerous that several occur on each of the more important reefs, there being two dykes on the Quadrant and two on the Man of War Rock. Basic dykes are known on the Wiltshire Rock and the reefs close under Old Lizard Head, but no well-defined dykes have been observed on any part of the Lizard cliffs or on the Labham Reefs which are exposed at low water to the south of Polpeor. Many of the dykes of this series are vertical, but others are inclined at comparatively low angles; they sometimes branch and enclose pieces of the gneissic rocks through which they rose.

Dr. Teall[2] has described the microscopic characters of some of the dykes from which specimens were collected by Mr. Fox, and from his descriptions and a study of the rocks and slides in the Survey's collection it seems clear that there is much uniformity in their petrographical characters. The dyke-rocks may be classified as porphyritic hornblende schists. Nearly all of them show white felspar phenocrysts in the hand specimens, and the matrix is dark-green, rather fine-grained and distinctly schistose. In the microscopic sections it becomes evident that the porphyritic character is all that remains of the original igneous structures of the rock. The large felspars are sometimes idiomorphic and rectangular in section, the soft matrix having apparently flowed round them without breaking or deforming them. At other times they are dragged out into spindle-shaped lenticles tapering at both ends. When fresh they have the optical characters of basic labradorite, but they are very often turbid and saussuritised. The matrix consists of hornblende and felspar, together with epidote, chlorite and other products of their decomposition. It is never ophitic, as in the dykes we have previously described, but has been thoroughly recrystallised. The minute felspar grains are rounded or anhedral ; the rocks are, in fact, thoroughly metamorphic ; very often they are excellent schists as the long needles of bright green hornblende are disposed with their long axes parallel to the foliation. In other specimens, however, the foliation is rudimentary and the rocks are not distinctly fissile.

The relation of these dykes of the Lizard reefs to the other basic dykes of the Lizard peninsula is a problem of some difficulty. They have some peculiar characters which might justify us in regarding them as belonging to a distinct period of intrusion and of much greater age than the epidiorite dykes that followed the injection of the Crousa Downs gabbro. They have not consistently the north-west strike that characterises the later dykes, and they are more uniformly and more highly metamorphic. In both these respects, however, there are undoubted members of the other series that agree with them, for in the great abundance of

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[1] *Quart. Journ. Geol. Soc.*, vol. 44, 1888, p. 309. [2] *Loc. cit.*

basic dykes on the mainland there are many irregularities of trend and much variation in metamorphism. The question is an open one, but, on the whole, it seems safest to regard the dykes of the Lizard reefs as a distinct series.

The Polpeor Dykes.

In the brown mica schist that forms the cliff at the Lizard lifeboat station at Polpeor Cove (Plate V., fig. 2), there are curious lenticular masses of dark porphyritic hornblende schist. These have attracted a good deal of attention from geologists[1] because they furnish very striking examples of the dragging apart of masses of hard igneous rocks enclosed in soft and plastic sediments. The lenticles of greenstone are bolster-shaped, but pointed at the ends, from four to eight feet long and one or two feet broad; several may be seen in the mica schist at the foot of the road that leads down past the lifeboat house and others are visible in the rocks of the shore to the south of this. They tend to occur in rows and often lie along the bedding and foliation of the mica schist; the separated masses are very like one another in appearance and have probably been derived from not more than one or two intrusions. We assume that they are not interbedded igneous rocks, though they conform to the foliation of the schists, because they are of a distinct type from the green schists and hornblende schists that belong to the Old Lizard Head Series, and they occur with varying associations of green schist and mica schist in such a way as to indicate that they are not arranged along definite planes of bedding.

In microscopic section they show an excellent foliation and contain much green hornblende in fine acicular prisms. The remains of phenocrysts of felspar are present as drawn out lenticular pale spots, full of decomposition products. Darker spots, consisting essentially of chlorite, may be the persistent traces of pyroxene crystals. The rocks are highly schistose and are full of secondary minerals such as white mica and carbonates.

These Polpeor dykes have rather close affinities with the porphyritic epidiorite dykes that cut the gneisses of the Lizard reefs. It is possible to argue, however, that they belong really to the series of post-gabbro intrusions, and that they have been excessively metamorphosed and drawn out because they occur in the mica schist which is one of the most plastic and easily deformed of the rocks that occur in the Lizard district.

The Kennack Dykes.

Around the shores of Kennack Bay from Carrick Luz to Kildown Point fine-grained dark basic dykes occur in great abundance (Fig. 6). Although presenting considerable variety in mode of occurrence and in petrographical characters they clearly belong to one series. They are of the same age as the dykes of the Coverack shore, as in many sections they can be shown to cut the serpentine and gabbro, while they are older than the banded gneisses and acid rocks, which often truncate their outcrops. For several reasons it is desirable to treat them as a separate group; they

[1] T. G. Bonney, *Quart. Journ. Geol. Soc.*, vol. 39, 1883, p. 4; J. J. H. Teall 'On the Basic Igneous Rocks of Cornwall,' *Proc. Geol. Assoc.*, 1887, p. 34.

have a rather well-defined area of distribution, present many petrographical peculiarities, and have very close relations to the banded gneisses that immediately followed them.

These dykes are so numerous that it would be impossible to give an account of them individually. Wherever the serpentine appears in the cliffs around Kennack, black dykes may be found, often in groups of three or four, side by side. In their field characters they display a great variety. Some are vertical, like the dyke that has often been described[1] cutting a thin gabbro vein in the serpentine cliffs about seventy yards south of the gate at the west corner of Kennack Sands. Others are inclined like the large dyke at the east side of the sands, which has a dip of 35 degrees to the east. Many of them have an irregular course and give off branches; an example of this may be seen on the west side of the knoll of serpentine that rises from the sands in the middle of Kennack Bay (Carn Kennack); this dyke also is schistose in several places. Some of the smaller dykes are quite tortuous; instances of this occur in a group of small dykes cutting the serpentine in a cove below the Thorny Cliff, four hundred yards north of Polbream Point. In many places veins of gabbro are as common or more common than the dark fine dykes, and sometimes the latter have insinuated themselves into the fissure occupied by a gabbro vein, so that the gabbro appears only on one side of the complex dyke or as inclusions caught up by a black dyke; there are several dykes of this type at the base of the cliffs within two hundred yards north of Polbream Point. Occasionally a black dyke ends by splitting up into many thin veins that form a plexus ramifying through the serpentine in all directions; there is an example of this a few yards south-east of the gate at the west side of Kennack Sands (Fig. 6).

Some of the largest dykes occur at the east side of Kennack, where they often take the form of inclined sheets dipping at angles of about forty degrees to the east. These dykes may be five or six feet thick, and often enclose large blocks of serpentine. Three good and easily accessible instances of this class may be mentioned; one is at the west edge of the sands, another is in the high cliff, 600 yards south-south-east of Trevenwith, and may be reached by a bad path from the top of the cliff. Another very fine example may be seen in the cove to the west of Poldowrian (Plate X.), where it is easy to descend along the dip slope of the dyke to the shore; there are really two black dykes in this cove, separated by a few feet of serpentine, and dipping in the same direction; both of them cut many veins of gabbro pegmatite. Vertical dykes and irregular dykes also occur along these cliffs, but they are smaller and less conspicuous than the inclined sills.

The majority of the dykes are two or three feet thick, with well-defined walls and fine-grained margins that are sometimes schistose. Very frequently they have a north to north-west trend, but this is most marked in the larger dykes which are also the most persistent. The smaller dykes may run east and west, and often change their direction in a few yards. Some of the larger dykes can be followed in the shore for a hundred yards or more, but

[1] C. A. McMahon, 'Hornblende-Schists and Basic Crystalline Rocks of the Lizard,' *Quart. Journ. Geol. Soc.*, vol. 45, 1889, p. 540.

none of them can be traced inland, as they crumble much more rapidly than the serpentine around them, and are covered over with soil and grass.

Dykes of the type now under discussion are not entirely confined to the shores of Kennack Bay. They occur, for example, on the west coast, especially in the neighbourhood of Pentreath Beach and to the south-east of Kynance. There also the country rock is the coarse bastite serpentine. A feature of their distribution which is of considerable importance is that they never occur at any great distance from intrusions of the banded Kennack gneisses or 'Granulitic Series.' In the gabbro of Crousa Downs they are practically absent, though a few of the dykes of the Manacle Point group approach fairly close to them in petrographical characters. Rocks of this class, however, occur in Lankidden Cove on the east of the gabbro of Carrick Luz (where their relations are not clearly exposed) and in association with the gabbro mass below the cliffs at The Chair.

In the serpentine of the downs and on the flat top of the old Pliocene platform fragments of rocks of this type may be picked up in the soil at not a few places, but their manner of origin can be established only when the dykes are exposed in section in small pits, quarries, and other artificial openings.

Petrographically the rocks of this set of dykes have certain very unusual characters, for though they are distinctly igneous rocks they are always metamorphic, yet they are seldom well foliated. A microscopic section of one of the Kennack dykes (Plate XII., Fig. 2) typically shows many small prisms of green hornblende that have little trace of crystalline form and are not specially elongated in any definite direction. Between these lie small anhedral grains of felspar. The hornblende is sometimes brownish, but is never of deep colour in the slides. The felspar is not often fresh, but has then the refraction and optical characters of andesine and labradorite, though many of its grains are simply twinned or untwinned. Very frequently the felspar is entirely replaced by secondary products, among which sericite, prehnite, carbonates, quartz, and saussurite are the most common; epidote is scarce in these rocks. The generally decomposed state of these dykes is undoubtedly to be ascribed to the action of solutions that have percolated through the serpentine, for these strongly attack the silicates of rocks, especially the felspars, and all rocks that occur in the serpentine are apt to be much altered.

All the rocks contain small grains of iron oxides, and usually also pyrites; granular sphene is remarkably scarce when we consider that the rocks are really metamorphic, and occasionally we find a few brown prisms of rutile. Biotite, alkali felspars and quartz make their appearance only where there is good reason to suspect permeation by the acid gneisses which followed the injection of the black dykes.

If we examine a sufficiently large number of sections of these rocks we find that they present variations in two different directions. Some of them, where the alteration is least, exhibit residual igneous structures, not entirely obliterated. Many, for example, are distinctly porphyritic, with large dull-looking crystals of plagioclase; in section these are usually represented by aggregates of sericite, saussurite and prehnite (6,726), but their crystalline forms are often well preserved. Other dykes are distinctly ophitic, as the felspar occurs in lath-shaped crystals which are embedded in ophitic plates of green hornblende. The first large inclined sheet on the east side of Kennack sands is not only ophitic in structure, but also contains a little of the original augite in the interior of the irregular plates of green hornblende (6,692); in other parts of the same dyke all the augite has vanished, and the ophitic structure also is lost. In only two other Kennack dykes have remains of the primary augite been detected.

The other structural variation exhibited by the Kennack dykes depends on the development of foliation. In other words they become schistose, but as this is not confined to them but appears also in all the basic dykes of the Lizard, the circumstances that give rise to it may be discussed in reference to the whole series.

METAMORPHISM OF THE DOLERITE DYKES.

It was pointed out by Messrs. Fox and Teall[1], in 1893, that certain porphyritic epidiorite dykes at Potstone Point (Pol Cornick) developed foliation in places, and massive and schistose varieties of these epidiorites might be observed in the same dyke. By microscopic investigation they showed that the appearance of foliation was attended by the crushing of the felspars of both the first and second generation, and that at the same time the ophitic augite disappeared and was replaced by aggregates of fibrous pale green hornblende that have a parallel orientation in accordance with the foliation of the rock. From this they inferred that in its origin the foliation was connected with pressures or stresses that acted on the dykes at a period subsequent to their consolidation; that is to say the dykes were ophitic dolerites before they were converted into schists.

Phenomena of this kind are, of course, not restricted to the black dykes but are found in nearly all the intrusive rocks of the Lizard. The Man of War gneisses and the black dykes that intersect them have never been observed to show normal igneous characters but the serpentine, the Crousa Downs gabbro and the later gneisses all appear in massive forms in some part of the Lizard districts. The black dykes, in fact, are of all the Lizard rocks those that most frequently retain the structures of ordinary igneous intrusions; they develop foliation only locally and seldom in great perfection. The schistose black dykes, however, present several features of interest that merit a brief description.

In all the classes of black dykes enumerated above, and in all the districts where they occur, foliated types make their appearance and the circumstances under which they occur appear to be of three kinds.

(1.) Many dykes, which are in the main of massive character, show foliation at their margins or in thin belts that appear irregularly and are not persistent. This is perhaps most common in the thickest dykes. The inclined sheets, for example, in the cliffs on the east side of Kennack, between the sands and Carrick Luz, have often a weak marginal foliation which is clearly visible in hand specimens. At first glance this looks like a fluxion structure and suggests that the first material injected was forced in under great pressure as the dyke fissure was gradually opened up; it might also have been comparatively cold while the later portions of the same intrusion were hotter, more thoroughly liquid and found an easier passage. This explanation, however, is not entirely satisfactory for several reasons. In the first place, all dykes, of whatever age and composition are subject to these conditions, yet foliation very rarely characterises their margins. There is also good reason to believe that these dykes consolidated as normal dolerites and have subsequently undergone a profound metamorphism with the development of new minerals and the more or less complete obliteration of the original structures. Replacement of augite and olivine by hornblende is a change that can often be proved to have arisen through the action of pressure

[1] *Quart. Jour. Geol. Soc.*, vol. 49, 1893, p. 204.

on igneous rocks in the solid condition; the granular or ' granoblastic ' structure of these dykes is also of the type that indicates re-crystallisation in the solid. At the time when the metamorphism took place the rocks were probably not quite cold, though much below their fusion point and as the pressures were high irregular movements may have been produced, especially at the margins where the dyke rocks were in contact with the rigid walls.

(2.) Foliated structure often makes its appearance suddenly where the black dykes are bent or change their course. Many instances of this might be cited but we will mention only a few of the most accessible. The dyke that cuts across a gabbro vein in the serpentine seventy yards south of the gate at the west side of Kennack shows this well, as also do several dykes in the coves to the north of Polbream Point. Another very good example is the black dyke at the base of the grassy slope at Parc Bean, about six hundred yards south-south-west of Predannack Wollas. In this case again two explanations offer themselves. We may suppose that the foliation is due to the obstruction to the flow of the dyke material round a corner. This hypothesis is met by the same difficulties as in the previous case; moreover, it happens sometimes that the ends of the dyke do not meet but are separated by an interval; consequently there can have been no passage and no flow. Other dykes become schistose at a bend where their thickness is reduced perhaps from two feet to one foot, and it is hard to believe that a fissure one foot wide was so narrow that the crystals of a fine grained rock were dragged out as they passed through it. Here again the theory of deformation after consolidation seems to present the fewest difficulties. The schistose parts of the dykes look as if they had been squeezed by movements of the wall-rock, and the foliation is often irregular and sinuous as if a tough but yielding rock had been twisted by external pressures. At the same time we must remember that many of the black dykes are cut clean across by faults, and their ends shifted for several feet or yards, and yet foliation does not make its appearance; in such cases the rock was cold and solid before the displacement. Where foliation develops through dislocation of the dykes the dyke-rock must have been hot and plastic at the time of the movement; we note also that the wall-rocks, which were at a low temperature, do not show foliation at the places where the black dykes become schistose. All the evidence, in fact, points to pressures that occasioned movements of the walls of the dykes, and through them of the dyke-rock itself, at a time when the dyke was crystalline and solid but not yet cold.

(3.) Lastly there are certain black dykes that are completely schistose. In the field these rocks have a perfect resemblance to certain decomposed hornblende schists of the Landewednack group. Unfortunately they are always so rotten that it has proved impossible to study their microscopic characters satisfactorily. The black dykes of this type are distinguished by the freedom with which they give off branches; while other black dykes seldom branch these ones often form a perfect network of veins ramifying in all directions through the country rock.

Among instances we may mention a small dyke in serpentine about six yards south-east of the gate at the west corner of Kennack sands; there are many small veins that seem to arise from a six-inch dyke that is fairly massive. On the west side of the serpentine headland below Carn Kennack there is a dyke that runs irregularly and splits up into many thin branches that are often schistose. On the west coast schistose dykes are seen a little below the top of the cliff at Pengersick, three hundred yards south of Vellan Head. Far the best example of this type, however, is visible on the side of the road 150 yards north-east of Kynance Hotel (Fig. 5). The road, before beginning to descend into the Kynance valley passes through a narrow cutting in the serpentine; carriages are usually left on the top of the down a short distance to the east of this point. On the north side of this cutting thin streaks of hornblende schist may be found in the serpentine; if carefully traced they may be followed for about twenty yards. They are nowhere more than nine inches thick. The shape of the mass precludes us from regarding it as an inclusion of schist in the serpentine, for a long thin inclusion of this type would have been broken by movement of the magma. Moreover, the long axis of the schist lies across the direction of flow in the serpentine, which is readily ascertained at this point by examining weathered surfaces of the rock. That the schist-mass is really a vein is further proved by the fact that it gives off branches. On the south side of the rock-cutting the schistose dyke may be again seen, at the western end, and a mass of dark fine compact rock occurs there resembling the basic portions of the Kennack gneisses; this mass may be in reality the source from which the black dyke came.

The serpentine that forms the walls of these schistose dykes is often rotten and soft but is never a good schist. Apparently the dyke was transformed into a schist while it was still soft and hot. The foliation nearly always closely follows the length of the injection though sometimes oblique, especially where the dykes fork; even the thinnest branches are foliated lengthwise and adjacent veins may have different directions of foliation. There is no sign of displacement or faulting; clearly the development of the schistosity was connected with the intrusion of the dyke. These facts seem to require a special explanation, somewhat of the following nature. As the temperature fell the rock consolidated, but before it was cold and while it was still plastic there was a sudden increase of pressure. The dyke material was driven into a series of narrow branching cracks in the country rock. Increase of pressure would promote crystallisation and this would be assisted by the low temperature of the fissures. Pressure and movement combined would transform the dolerite at once into a schist.

CHAPTER IX.

THE KENNACK GNEISSES AND THE GRANITE GNEISS.

The long succession of intrusive igneous rocks in the Lizard peninsula was brought to a close by the injection of a group of remarkable banded gneisses, followed without a pause by red granite gneiss and granite. To these rocks, or to an important part of them, the name 'Granulitic Group' was given in 1883 by Professor Bonney, but this name is by no means unexceptionable. There are many granulitic rocks in the Lizard, and some of these are sedimentary while others are igneous; the igneous granulites belong to two series of widely different ages. Dr. Teall has called the basic part of this complex the 'banded gneisses,' and this is an excellent designation, but not applicable to all the rocks in question, as many of them have a veined rather than a banded structure. We propose to use the name 'Kennack Gneiss' for the mixed rocks which are typically represented by striped, flecked, and veined gneisses in which a darker basic element alternates with a pale grey or pinkish acid portion. The best sections of these rocks are afforded by the cliffs on the west side of Kennack from Polbream Point northwards.

The Kennack Gneisses.

It has long been recognised by those who have studied the geology of this district that the nature, origin, and history of the Kennack gneisses is the crux of the Lizard problem, and during the last fifty years a voluminous literature has been devoted to controversies on this subject. As usual in such cases there has been much truth on both sides of the discussion, and an adequate solution of the difficulties can be arrived at only by recognising that the phenomena are of a very complex description.

Although these gneisses did not escape the notice of the earlier geologists such as Majendie, Sedgwick, and De la Beche, little that is of positive value can be gleaned from their descriptions. Professor Bonney was the first to recognise the importance of these rocks and to enunciate a coherent explanation of their origin. In his first paper on the Lizard rocks he regarded this group as a sedimentary series which had been invaded by the serpentine. It was subsequently pointed out by Dr. Teall, Mr. Fox, and Mr. Somervail that many of their characters indicated that they were of igneous origin. This view was ultimately adopted by Professor Bonney and General McMahon, so that there is now a consensus of opinion that these gneisses are igneous rocks.

On the other hand Professor Bonney, supported by General McMahon, has always maintained that the 'Granulitic Group' consists of rocks that are older than the serpentine, and where these two come in contact the serpentine is always intrusive into the other. Dr. Teall was the first to question this interpretation, followed by Mr. Somervail; to Mr. Harford J. Lowe, however, is due the credit of establishing that the only possible interpretation of the relations of these two groups is to regard the gneisses as a series of intrusions that penetrate the serpentine. He showed, in fact, that the gneisses and granites of the Kennack district are the latest members of the Lizard complex.

That the Kennack gneisses are an intrusive group can be established by many lines of evidence. They have the form of bosses, dykes, sills, and interlacing veins; they cut the serpentine and all its structures; they have an excellent fluxion banding and an injection foliation parallel to their margins. They contain very many inclusions of the serpentine of all sizes from several hundred yards to a few inches in diameter; they cut through the gabbro and the black dykes. It is true that their relations to the serpentine are often obscured by faults and lines of crushing; they also, so far as their appearances goes, have a more metamorphic character than the serpentine which they invade, for the gneisses are banded rocks with striking foliation (recalling the Lewisian gneisses) while the serpentine is often nearly massive. That a group of highly foliated rocks should be injected into a nearly normal serpentine, is a phenomenon which in the Lizard is equally well exhibited by the augen gabbro and the gabbro schist. It remains only to point out that the basic part of the Kennack gneisses is the same magma as filled the black dykes; the acid part is the earliest injection of the red granites which were subsequently to play an important *rôle.*

Distribution of the Kennack Gneisses.

The banded Kennack gneisses occupy only a very restricted area in the Lizard, occurring mainly as small intrusions, and for that reason it has not been possible to designate them on the one-inch map with a special colour. The red granite gneiss, however, appears as large intrusions covering three or four square miles. Of these the principal are the Goonhilly Downs Gneiss, the Erisey Gneiss, and the Kuggar Gneiss. Smaller areas occur at Clahar and Clahar Cairn, and there is a considerable mass around Ruan Minor, and in the valley leading down to Cadgwith.

These gneisses decompose and weather down so much more readily than the serpentine that they make very little show on the surface. They form smoothly rounded country covered with a light, dry and rather friable soil. There is little bare rock and the granite appears only as small fragments in the fields, with an occasional larger block two feet or more in diameter built into the hedge-walls or stiles. Where pits have been opened in the granite gneiss no sound rock is obtained, but only a soft ' marl ' that can be dug out with a shovel, though harder lumps are found in it; pits of this kind may be seen at Erisey, Gwendreath, and St. Ruan. Sometimes, however, on the sides of a valley a small quarry may be found where the pink gneiss is in a fresh condition, but as the stone is not used for any purpose except repairing the roads, it is never quarried on an extensive scale. Fresh gneiss is visible occasionally in places inland, as, for example, in a small quarry on the east side of the Lizard Road near the sixth milestone from Helston, beside the road leading to Cadgwith on the south side of the valley (two hundred yards west of the Coast-guards' houses), and on the roadside halfway between Kuggar and Kennack Sands.

The banded Kennack gneisses have their typical development on the margins of the granite gneiss intrusions, where they form a fringe of sills and veins (Fig. 6). The best example of this is found on the south-west side of the Kuggar Gneiss, where, in a triangular space bounded on the north by a line drawn from Kuggar to Kennack Sands, the banded gneisses are injected into the serpentine in a bewildering variety of protrusions. This is the series of 'Granulitic' rocks that is so well exposed in section in the Thorny Cliff and Polbream Point; their inland extension may be mapped by the character of the fragments in the soil, but, as rock exposures are few, no definite boundaries can be laid down for the individual sills of which the mass consists. The margin, however, if we judge by the character of the coast sections, must be of highly irregular form.

In the same way the margin of the Ruan Gneiss, where it comes to the shore at the Devil's Frying Pan, consists of a typical banded complex; its central part is red gneiss, but banded rocks appear again on its edges at Brugan and to the north-east of Ruan Minor. A great fringe of intrusions of banded gneiss extends southwards from the Erisey gneiss, and is seen about Trerise and in the valley to the south of this; but the northern and western sides of this gneiss are of pure acid types, with which dark rocks are inter-mingled only in a few places. The country between Ruan Minor and Kuggar lies between the outcrops of the three masses of gneiss that we have mentioned, and is filled with injections of the banded gneiss. Most of these cannot be mapped out because the ground is all cultivated and there is no evidence except the fragments in the soil, but these indicate that the serpentine is riddled with in-jections of banded gneiss, and these are well exposed in several pits on the sides of the Poltesco Valley. From Caerleon Cove to Kildown Point the cliffs are mainly serpentine, but they contain great masses of banded gneiss. It is indeed probable that Kennack Bay is a depression formed by the weathering of a large granitic mass, from which some of these veins of banded gneiss may have been emitted.

The Goonhilly Downs Gneiss seems to consist almost entirely of a fine red gneiss that passes at times into massive granite. This is true also of the gneisses at Clahar and Clahar Cairn, where banded rocks are in evidence in two places. On the west side of the Lizard road banded gneisses are few, though there is a considerable number of intrusions of pure pink granite, *e.g.*, at Laden Ceyn, Vellan Head, Jollytown, Gew Graze, and Kynance. But typical Kennack gneisses are found in the side of the valley east of the Soap Rock, in the cliff below the Yellow Carn and at Pentreath Beach. On the path from the Lizard Village to Kynance there are large blocks of beautiful banded gneisses at the edge of the downs about half-a-mile from Hill's Hotel.

In the cliffs between Polbarrow and Pen Voose (by which name the cove north of Church Cove has generally been referred to in the literature of Lizard geology) there is a most remarkable series of sections of banded gneisses intruded into a complex of gabbro and serpentine. This can be examined most easily at Polbarrow and at Pen Voose, where there are good paths down the cliff. The sections are of extraordinary complexity and show that gabbro, sometimes massive and sometimes foliated, has invaded a nearly normal serpentine as great sills and irregular intrusions. Into this complex the banded gneisses have forced their way and a perfect *mélange* of igneous rocks has been produced that baffles description. To add to the confusion a good deal of movement has gone on, either during the intrusions or at a subsequent period, so that in places the natural sequence of the rocks seems fairly clear, but often it is too involved to be decipherable. These sections have been appealed to by those who have engaged in the controversies regarding the Lizard succession. The relations of the rocks, however, are seldom clear enough to justify positive conclusions, and these sections cannot compare with those on the west side of Kennack Bay. In another respect they are exceptional, for they show the gneisses penetrating the gabbro; this occurs again on the north side of the arch in Spernic Cove (on the west side of Carrick Luz), but nowhere else in the Lizard can the banded gneisses be found intruded into the gabbro. In the excellent coast sections from Coverack to Porthoustock no dykes or veins of the acid rocks have been discovered.

Relations of the Kennack Gneisses to the Older Rocks.

The banded gneisses also very seldom invade the hornblende schists. The red granites do so, as has been mentioned already, in more than one locality but only in one section can the Kennack gneisses be demonstrated to occur in the Lizard schists. On the north side of the entrance to the Devil's Frying Pan, at Cadgwith, the base of the cliff consists of hornblende schist with a few veins of red granite. The top of the cliff is composed of banded gneisses with much red granitic material. Among the gneisses there is a small outcrop of the fine flinty-looking serpentine which indicates that this is the position of the original margin of the serpentine and that the gneisses have followed the junction of the two older rocks. The dark hornblende schist, veined with granite, has so much resemblance to the banded gneisses that they can hardly be distinguished in the field, but the microscopic characters of the rocks leave no doubt that we have here two different types of basic rock. There is much faulting visible in the section on the north side of the Frying Pan, but the cliff facing the sea does not appear to be cut by faults; as the banded gneisses have followed the foliation planes of the hornblende schists the two sets of rocks might readily be supposed to belong to one series.

The rock into which the gneisses intrude is in the vast majority of cases the coarse bastite serpentine; that is to say the gneisses are found principally in the heart of the serpentine stock and not at its margins. In a few places, however, the banded gneisses occur in tremolite serpentine, as in the valley above the Soap Rock and at the base of Kildown Point. Now, as has been described in an earlier part of this Memoir, the bastite serpentine generally shows a well-developed fluxion structure. The banded gneisses invariably cut this fluxion structure quite sharply, often at right angles. This evidence is perfectly conclusive as regards the sequence of the rocks for the serpentine shows no tendency to flow around the Granulitic Group, whereas the latter has practically always a good fluxion banding parallel to its margins indicating that it flowed in a molten or viscous state into the positions it now occupies. Evidence of this sort can be got in any of the coast sections from Enys Head to Kennack, and is beautifully clear in some of the sills exposed in the cliffs at Polbream Point and to the north of it.

Great numbers of inclusions of serpentine occur in the gneisses; some of those in the fields of Gwendreath and Kuggar farms are an acre or more in area. On the west side of Kennack Sands, immediately south of the gate, a mass of serpentine three hundred yards long appears in the cliffs; the gneisses can be traced all round it both on the seaward and the landward sides, and many dykes both of epidiorite and of banded gneiss penetrate it (Fig. 6). Small lumps of serpentine enclosed in gneiss are a feature of all the best sections of the Kennack gneisses from Church Cove north to Kennack; they vary from ten feet down to an inch or two in diameter. Only a few places need be mentioned where they can be well seen. In the middle of Pen Voose (not the north end of the cove but only a few yards north of the bottom of the steps) there is a cliff of banded gneiss and on the face of this cliff about a dozen inclusions of serpentine can be seen in the gneiss. On Enys Head (at the base of the grassy slope) and in the serpentine quarry on the top of Kildown Point serpentine occurs in gneiss; a gneiss sill forms the north side of Polbream Point and is crowded with serpentine inclusions, and in the little coves a few yards to the north of this the same phenomenon is frequently repeated. Immediately south of the gate at the west side of Kennack sands there are ridges of banded gneiss in the shore between tide-marks, and if these be carefully searched many lumps of serpentine will be found in them, but they are not conspicuous as the soft serpentine is eaten out and forms hollows under the scouring action of the sand and gravel of the beach.

Those who regard the serpentine as intrusive into the gneisses have described these serpentine masses as tongue-shaped intrusions, but as Mr. Harford Lowe[1] has pointed out no such intrusion can be demonstrated in the field. Moreover, the serpentine is always the coarsely crystalline variety and often shows its banding and augen structure cut sharply across by the gneiss; in fact the serpentine was a metamorphic rock before it was caught up in the gneiss. An interesting parallel can be drawn between the augen gabbro and the banded gneiss in their relations to the serpentine. A minor gabbro intrusion such as that of Carrick Luz has the same injection foliation as the gneisses; the foliation is in the main parallel to the bounding walls of serpentine. They both contain serpentine inclusions round which the foliation has a tendency to flow; the serpentine blocks are coarsely crystalline and fluxion banded. But the gabbro was a nearly homogeneous

[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. xii., 1901, p. 464.

magma at the time when it was intruded while the gneisses were heterogeneous, consisting of two portions imperfectly blended, and hence the gneisses show a strongly marked fluxion banding that is nearly absent from the gabbro.

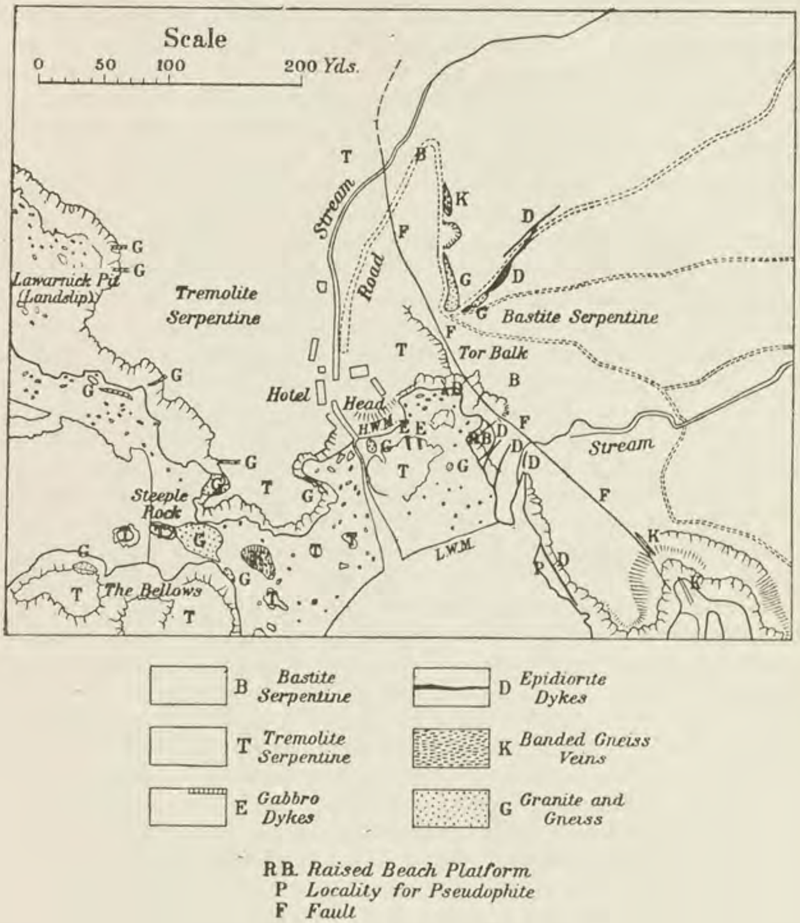

Figure 5. *Map of Kynance Cove.*

The country rock is serpentine which is of two varieties, the bastite serpentine (B) on the east and the tremolite serpentine (T) on the west. These are separated by a fault (F) which passes in a north-north-west direction from the south-east corner of the map and is attended by brecciation of the rocks on each side. In the serpentine there are two small dykes of crushed gabbro (E) visible in the reefs in the shore a little east of the Hotel. Many black dykes (D) cut the serpentine especially near the mouth of the stream in the south-east corner of the map; some of these are distinctly schistose, and the one which occurs near the centre of the map on the side of the road leading to Kynance from the east has been referred to on p. 118. This dyke is attended by intrusions of granite (G) and banded gneiss (K) which cannot be traced into it though there can be little doubt that they are intimately connected. There are many other intrusions of red granite and gneiss especially north and east of the Steeple Rock. In all probability these are offshoots from a larger mass that once occupied the cove in which the Steeple Rock stands but has been removed by the eroding action of the sea. At the south-east corner of Lawarnick Pit there are bands of hornblendic rock to which Professor Bonney has directed attention on several occasions.

Types of Gneiss Intrusions.

The variety of shapes that the gneiss intrusions assume is almost endless; still it is possible to recognise a number of types that are repeated more or less frequently. The boundaries of the inland masses can never be defined owing to the absence of exposures, but in the cliffs and on the shore platform many opportunities are provided of examining gneiss intrusions both in section and in plan. We may classify them as bosses or domes, sills, veins, dykes, and networks.

Bosses and Domes.—In the flat rocky shore small rounded outcrops of gneiss are often seen, usually less than a hundred yards in diameter. Their edges are banded gneiss while their central parts are granite gneiss of bright red colour. Thus on a small scale they repeat a phenomenon that characterises the larger granite masses of the Lizard peninsula. The foliation, at least near the margins, is well marked and follows the boundary; in all cases observed it dips outward, or has a dome-like arrangement. The mass, in consequence, resembles a boss that has been forced up in a pasty condition from below. In the centre of some domes there is only granite, but others show the serpentine rising in that position and the gneiss forming a ring around it. In such cases we are dealing with a thin arched sill of banded gneiss having anticlinal dips. In the south end of Pen Voose Cove a very small arched sill is exposed in section. It is only a few feet thick and the serpentine above and below it are clearly seen. Other examples are visible below high water mark at the south side of Caerleon Cove, on the east edge of Kennack Sands, and a quarter of a mile west of Spernic Cove (Carrick Luz). Sometimes these bosses give off veins or processes irregularly penetrating the serpentine.

Sills.—A very characteristic form of gneiss intrusion is the sill, which is a large mass with nearly parallel sides and having a more or less steep dip in one direction. Some sills are forty or fifty feet thick, others are only two or three. Occasionally they are nearly horizontal, like the sill above the cave on Enys Head; more frequently they have a considerable inclination. A feature of the sections in the cliffs from Polbream Point to Kennack is the large number of sills dipping to the north and north-east at angles from 25° to 50°. The well-known rocks on the west side of Kennack Sands, near the gate, belong to a thick sill that dips east at 30°; further south there is a great sill in the Thorny Cliff at the south side of the streamlet. The north side of Polbream Point is a sill of banded gneiss eight feet thick. These sills can be traced from base to top of the cliffs and though they are not everywhere of the same thickness their sides are generally parallel. The fluxion banding follows their length with remarkable consistency. At their margins not a few of the sills give off veins that spread outwards through the serpentine; a very good example of this is furnished by the sill on the south side of the streamlet at the north end of Thorny Cliff. This sill forms a headland that can be passed only at low water; it rises in a bold escarpment facing the cove to the south and dips north at a moderately high angle. At the base of the sill the serpentine is filled with a plexus of gneissic veins; between this place and Polbream Point several sills give off veins in the same manner.

Veins.—Veins of banded gneiss (Plate XI.) are probably more common than any other form of intrusion. They may arise from the bosses or the sills but often appear in the coast sections as disconnected masses. Their thickness is subject to much variation and they cannot usually be followed for any considerable distance. A characteristic form assumed by the veins is wedge-shaped or tongue-shaped, tapering to a point; a very fine example of this form was figured by Mr. Fox and Dr. Teall[1] from the cove east of the Lion Rock. The first and second veins in the serpentine cliffs south of the gate at Kennack (Plate XI. and Fig 6) are somewhat of this shape and there are several examples below the Thorny Cliff. This peculiar form appears to be a consequence of the highly viscous condition of the magma at the time when it was intruded, but it is occasionally assumed by the gabbro veins as in one instance in Compass Cove, west of Poldowrian.

Networks.—Fine networks of gneiss in serpentine are by no means very common though found, as has been described, at the edges of many sills. The veins are always very rotten, and hence the cliff tends to crumble down and the section becomes obscured; anastomosing veinlets of the acid series are perhaps most common in the larger serpentine inclusions, and many may be seen in the large serpentine mass on the west of Kennack sands.

Dykes.—Thin dykes of banded gneiss, with straight and parallel sides, and vertical or nearly vertical in position, are somewhat rare. For this there must be some reason since the gabbro and the epidiorite very commonly assume this form. We believe that the scarcity of thin straight dykes of gneiss is a consequence of the high viscosity of the magma and of its having been injected as a pasty mass under great pressures attended by earth movements. But dykes of the mixed rock do occur, and they throw a very clear light on the genesis of the whole banded complex. They have been found only on the shores of Kennack Bay.

Occasionally in a typical black dyke thin threads of red granite may be seen. The best example is the upper dyke in the cove west of Poldowrian (Plate X. and Fig. 4); the red granite threads may be followed for several yards yet apparently are not chilled against the epidiorite; in fact in microscopic section they prove to contain biotite and hornblende in addition to plagioclase, orthoclase, and quartz, that is to say they are of the mixed type that has been described as mica diorite by Dr. Teall and others (7473).

A most interesting mixed dyke occurs in the serpentine cliff about one hundred yards south-west of the gate at the west side of Kennack Sands (Fig. 7). Mr. Harford J. Lowe[2] first noticed this dyke and pointed out its significance.

It rises nearly vertically from the gravel of the beach to a height of twelve feet in the serpentine cliff and terminates upwards against a thread or vein of banded gneiss which probably occupies a horizontal line of dislocation. The dyke is about

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[1] *Quart. Jour. Geol. Soc.*, vol. 49, 1893, p. 209.
[2] *Trans. Roy. Geol. Soc. Cornwall*, vol. xii., 1901, p. 456.

eighteen inches wide and looks at first glance very like the black dykes which occur in such numbers in the adjacent cliffs, but on closer inspection proves to consist of mingled red granitic and black epidioritic material. It is not well banded as the red and black materials are not in parallel streaks, and in its upper part the red granite fills the whole centre of the dyke with the black rock at the edges. This dyke might be regarded as a black dyke into which the red granite had forced its way. In that case

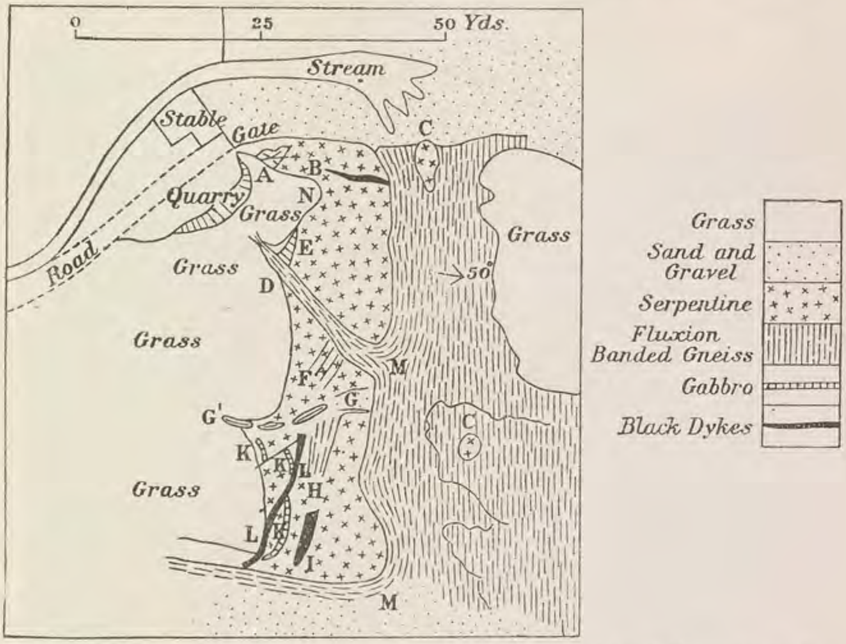

Figure 6. *Map to show rocks exposed in Beach at west side of Kennack Sands.*

This map shows a small area immediately south of the stable at the end of the road that leads from Kuggar to Kennack. The cliffs consist mainly of serpentine but this is merely part of a large inclusion in the banded gneisses which can be traced all round it.

At A the serpentine is cut by a plexus of small black dykes which are schistose in places; east of this there is a black dyke B which cannot be traced into the plexus, though probably connected with it. Several inclusions of serpentine occur in the banded gneisses and two of them are indicated at CC. A large dyke of banded gneiss is emitted from the main mass at M and cuts the serpentine. It is seen in vertical section in the cliff at D, where it cuts across a dyke of very coarse gabbro E. This dyke is not found on the other side of the gneiss, and hence the latter may have risen along a fault line. This gneiss dyke is represented on Plate XI. At F the fluxion-banding of the serpentine is well seen, and it may be observed that the gneiss intrusion crosses it almost at right angles. Another vein of banded gneiss is visible in the cliff and shore at G^1 and probably is given off from the main mass at G though the boulders on the beach cover the junction. This vein of gneiss is connected with another that runs southwards at H and in the continuation of this there is a well-marked black dyke I. A small nearly horizontal dyke of gabbro K is displaced by two faults and along one of these a black dyke has risen L; this dyke is referred to on pp. 98, 117.

The banded gneiss shows a good fluxion banding which is parallel to its margins, and where it gives off branches as at MM the fluxion bands are diverted to follow the course of the veins.

the basic material must have been hot and at least semi-liquid for there is no sharp demarcation between the two rocks that occupy the fissure. Alternatively we might suppose that a mixed magma was injected into the fissure in a liquid state and the two components were not thoroughly blended together before the mass consolidated.

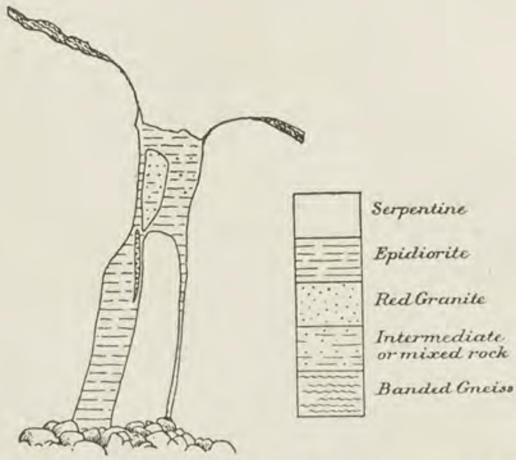

Figure 7. *Composite Dyke in Serpentine at the west side of Kennack.*

In any case the conclusion seems unavoidable that before the doleritic magma of the black dykes had ceased to invade the serpentine a red granitic magma was making its appearance and was flowing in the same channels as the basic liquid, though for some reason the two materials did not dissolve completely in one another and a viscous, streaky, heterogeneous fluid was the result.

A still better example of this type of dyke occurs beneath the Thorny Cliff at a place three hundred yards north of Polbream Point, or one hundred and fifty yards north of the Cavouga Rocks. On the north side of a little cove a steeply inclined dyke of banded gneiss is visible in the serpentine; it is four feet thick, with parallel walls, and dips west at sixty degrees. At the base of this sill there is what seems to be a black dyke, with the usual jointing and all the external characters of these intrusions, but the banded gneiss which fills the upper part of the fissure is welded firmly to the black dyke so that the two appear to belong to the same injection. In this case the banded gneiss has a good longitudinal flow structure and the typical appearance and composition of that series of rocks.

We shall describe only one more section of this kind, but the section in question is the most instructive regarding the origin of the banded rocks that has been found in the Lizard. There is a little chine on the north side of Polbream Point where a rather steep grassy path descends to the shore. On the north side of this chine a mass of serpentine rises from the beach. It is coarsely crystalline and shows a slight fluxion banding. In the serpentine are two dykes of gabbro, one of them exceedingly

Vein of Banded Gneiss cutting Gabbro Dyke in Serpentine, Kennack Sands.

coarse with crystals of diallage more than an inch in diameter, massive in places but twisted off at one end where it follows a narrow fissure in an upward direction and soon wedges out and disappears. A black dyke, in turn, has forced its way into the same fissure as was occupied by the gabbro vein but does not follow it for any distance as it soon turns aside and disappears behind the gravel of the beach. Traced westwards the black dyke is seen to rise from an irregular mass of similar material that has intruded into the serpentine. If now we inspect this material carefully we find it threaded with thin red veins of pegmatite, and in its upper parts it coalesces with a typical banded gneiss intrusion at a height of about twelve feet from the beach. This section proves very clearly that the last of the black dykes were the first of the banded gneiss intrusions.

Origin of the Kennack Gneisses.

We are now in a position to understand the genesis of the Kennack gneisses. When the doleritic or black dyke intrusions were coming to an end a red granitic magma began to force its way upwards. It found the channels in which the basic magma was flowing and drove the doleritic material in front of it. The first injections belonging to this period were purely basic (typical black dykes) but this was soon exhausted and the mixed magma succeeded. For a time this contained little granite, but the proportion of acid material increased rapidly as the last of the basic magma was swept out, and the typical banded rocks soon predominated. The section at Polbream Point shows these phenomena with diagrammatic clearness.

Undoubtedly the acid and the basic magma had originated by segregation from one source, but under the conditions in which they were now placed they exhibited great reluctance to fuse together and produce a homogeneous mass. The basic rock, where only an infinitesimal amount of granite had been added to it, did not absorb the acid liquid, but in crystallisation the two remained distinct, and the granite appears as red strings of quartz and felspar in a basic mass that seems almost unmodified in composition. The liquids did merge, however, to some extent, owing partly to mechanical stirring as they passed through narrow fissures, and partly to diffusion; in this way the 'mica diorite,' which we have mentioned in the Poldowrian dyke, originated. In the subsequent flows of mixed rock that form the banded gneiss there has often been partial interfusion between the basic and the acid types; in fact it is difficult to obtain the typical epidiorite or the true red granite in many parts of the banded gneiss. Still what strikes the field geologist in looking at the sections is the remarkable manner in which each ingredient has preserved its identity.

Characters of the Kennack Gneisses.

We pass now by a natural transition to consider the relations between the acid and the basic material in the heterogeneous complex that we have called the Kennack gneiss, and the various types of banding and veining that they exhibit, together with the origin of these structures.

I. *Veined Gneisses.*—Often the dark basic portion of the Kennack gneisses is veined by the acid substance; on the other hand the basic has never been observed to vein the acid rocks, and it is an invariable rule that the darker the colour of the mass the older it is. The veins often form a ramifying series cutting the dark rock in all directions; several types may be recognised.

Dr. Teall[1] (and also General McMahon[2]) have described and figured a very striking instance of a black ' diorite ' veined with red granite that may be seen at the rocky cape at the north end of Pen Voose Cove. The granite of the veins is flesh coloured and very pure; the veins are thin and exceedingly numerous, and on the whole they are fine-grained.

Another well-known example is on the shore at the west side of Kennack not many yards from the gate. Here a mass of dark coloured and nearly massive rock is cut by many veins of coarse pegmatite that contain large flesh coloured crystals of felspar in their thicker parts but are nearly pure quartz at their terminations.

Figure 8. *Kennack Gneiss; veined type. Kennack.* × $\frac{1}{20}$.
(*From a photograph.*)

Again we find basic masses that are intersected by thin threads of red pegmatite sometimes having a rather drusy structure (Fig. 8); we have described instances of this from Polbream Point and Poldowrian. These threads are sometimes not connected with any visible mass of granite and may perhaps have been injected at the same time as the dark including mass. In other cases they can be traced into thick granite veins. In the example figured above the basic rock must have been solid before the acid material was injected into its cracks.

[1] *Geol. Mag.*, 1887, Plate XIV., fig. 1.
[2] *Quart. Journ. Geol. Soc.*, vol. 45, 1889, p. 538.

In many places the banded gneisses are cut by thin white or pinkish quartzo-felspathic veins that cross the banding nearly at right angles, these represent the last part of the magma to consolidate. The fissures which they occupy are often small faults for the banding is displaced by them (Fig. 10).

II. *Blocky Gneisses.*—Many exposures of the Kennack gneisses show dark blocks of various sizes and shapes embedded in a matrix of banded gneiss or red granite gneiss. Two excellent examples of this type occur in the west wall of Pen Voose about the centre of the cove; one shows a round block of black ' diorite ' about two feet in diameter and was figured and described by Dr. Teall in 1887[1]. Close to this there is a elongated block about five feet long with pointed ends; its long axis lies parallel to the fluxion banding of the enclosing gneiss which in both cases is of the ' streaky ' type. Other examples can be seen in any of the coast sections where Kennack gneisses are exposed, but we may mention one in a low cliff about fifty yards north of the mouth of the streamlet at the north end of Thorny Cliff; the blocks there are more numerous and the mass looks like a dark breccia injected with many granitic veins.

Where lumps of gabbro or serpentine have been caught up in the gneisses they show little evidence of rounding by solution and do not dissolve or mix with the gneiss. The reason for this is presumably that these rocks were cold; they may also have been enclosed by the gneiss only a short time before it reached its present position and therefore when it was in a highly viscous state. The ' diorite ' blocks behave in a different way and probably were at a higher temperature when they were involved in the gneiss. Those blocks which preserve their identity well, and are sharply marked off from the surrounding gneiss have a deep black colour, and in microscopic section differ in no essential respect from the black dykes of Kennack type. They consist of hornblende and plagioclase felspar with iron oxides, sphene and other accessories; sometimes they are porphyritic and not unfrequently they preserve remains of ophitic structure. These are the characteristics of the Kennack dykes and appear in no other rocks of the Lizard complex, a fact which in itself is sufficient to establish the origin of the banded or mixed gneisses. But the black blocks are very seldom angular; they are generally rounded or lenticular, like the inclusions we have referred to in the cliff at Pen Voose, and this shows that they were being dissolved by the acid magma around them.

At the same time another process goes on for the deep black colour passes into a dark grey, and it is evident that the acid magma is diffusing into the interior of the inclusions; the red felspathic matrix shows the converse change for it becomes darker by absorption of the basic material. The phenomena present a very complete analogy to the changes that have been described by Mr. Harker[2] where the acid rocks of Skye and Rum gradually incorporate basic xenoliths into their mass. The dark included blocks are softened for they lose their angular shapes and appear

[1] *Loc. cit.* [2] 'Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 183.

to be drawn out; they were not melted for the fluxion banding of the surrounding gneiss curves round them in such a way as to indicate that they were more rigid than the matrix. The explanation of the origin of the Kennack gneisses that was advocated in 1891 by Professor Bonney and General McMahon[1] applies perfectly to the rocks of this type; the basic material has been softened, partly melted, and imperfectly absorbed by the acid magma, and at the same time the whole mass has been drawn out by fluxion movements.

III. *Blotched or Streaky Gneisses.*—The second type passes imperceptibly into the third as the dark material becomes softer, forming elongated streaks lying parallel to the flow and less sharply distinct from the acid substance in which they lie. The appearance of these gneisses often recalls a section of streaky bacon (Fig. 9). The acid material is generally more abundant than in the previous types but there are great variations in this respect and in the patterns shown on the surface. The general character depends, however, on the basic substance appearing as streaks while the acid substance forms continuous bands that flow around the basic; the latter must have been to a considerable extent more fluid than the former; nevertheless, it is evident that the whole complex was thoroughly plastic and adapted itself readily to the irregularities and deflections of the channel into which it was being propelled. The streaky gneisses often show fluxion curving around hard inclusions of serpentine and other rocks.

Figure 9. *Kennack Gneiss; streaky type. Kennack.* × $\frac{1}{12}$.
(*From a photograph.*)

As the difference in colour and composition between the dark streaks and the pale matrix gets less and less, and at the same time the boundaries of the basic patches become more indefinite the

[1] *Quart. Journ. Geol. Soc.*, vol. 47, 1891, p. 477.

appearances often suggest that the two rocks are not of distinct origin, but that we have here a liquid which was in process of segregation at the time when it was injected. This hypothesis has been applied to the Kennack gneisses by Somervail[1]. It is exceedingly attractive, and we know of no reason why it may not apply to the gneisses of the streaky type; on the other hand we are not aware of any evidence that is sufficient to prove it. In view of the fact that basic epidiorite blocks like the material of the black dykes can be shown to occur in the Kennack gneisses, and are gradually absorbed by them, it seems simpler to make use of one hypothesis than of two unless we find that one hypothesis is insufficient. It is true also of the Lizard rocks as a whole that though many of them have arisen by differentiation from a common magma, the separation into ultrabasic, basic, and acid portions was virtually complete before the rocks were intruded into their present situations.

Figure 10. *Kennack Gneiss; fluxion banded type. Kennack.* $\times \frac{1}{10}$.
(*From a photograph.*)

IV. *The Flow-banded Gneisses.*—In this group we place those gneisses which show a good parallel banding[2] such as indicates that the dark and light components were both quite liquid and flowed along side by side (Fig. 9). This type also is very common, though not so common as the others. The acid material may have been at a temperature somewhat above its fusion point as the sections indicate that the basic rock is the first to become viscous on cooling down. The relative breadth of the dark and light bands varies in different specimens. The fluxion banding is seldom straight; it winds around inclusions and other obstacles to the flow. Where the intrusion follows a curved or zig-zag path the banding often is deflected and maintains a close parallelism with the irregularities of the walls of the fissure. Where an

[1] *Geol. Mag.*, 1890, p. 511.
[2] For figures of this type, *see* McMahon, *loc. cit.*

intrusion suddenly widens the fluxion banding may become involved and almost spiral as if material had poured in from all sides into the central space. When intrusions taper to a point the banding often converges.

It is to be remembered, however, that though on a large scale the sills and veins of banded gneiss have an excellent fluxion banding parallel to their length it is always possible to find cases, especially in the streaky gneiss, where for short distances the banding is not strictly conformable to the junction. Professor Bonney has pointed out several instances of this[1]. There seems no difficulty in explaining this as a consequence of the imperfect plasticity of the rocks, especially when they belong to the two first types that we have enumerated; it is perfectly certain that the Kennack gneisses were in a very viscous state before they came to rest in the positions where we now find them. Often also the discordance may be only apparent, as the actual junctions are displaced by small faults such as occur in great numbers in every section of the Lizard coasts.

Petrography of the Kennack Gneisses.

For convenience of description these rocks may be divided into basic, intermediate and acid types. In each group many varieties may be recognised, an essential feature of the whole series being its excessive variability both in structure and in composition.

(*a*) The *basic* rocks are dark hornblende schists, and epidiorites; as a rule they are not very coarse-grained. These rocks consist essentially of plagioclase felspar and green hornblende in approximately equal proportions. The hornblende in microscopic sections is green, sometimes of pale shades but never of the dark-coloured varieties that are often seen in the Landewednack Schists. The mineral is rarely bounded by crystalline faces though sometimes the prism zone is fairly well defined in cross sections; usually there is a little elongation parallel to the prism axis but the crystals are rarely acicular. The plagioclase felspar, for reasons that will be subsequently discussed, is seldom in good preservation but the evidence supports the conclusion that it must have been for the most part a variety of labradorite. Acid plagioclase and alkali felspars are typically absent from the basic rocks. Of the accessory minerals the most important are biotite, apatite and titaniferous iron oxides, the latter often surrounded by granular sphene. Among secondary components are to be reckoned chlorite (after biotite or hornblende); prehnite, sericite and calcite after plagioclase felspar.

The commonest type of basic rock in the Kennack Gneiss is a dark hornblende schist (Plate XII., fig. 1) composed of small grains of felspar and hornblende, neither of which possess crystalline form. These rocks are often rather massive in appearance and hence the name diorite has generally been given to them by writers on the geology of the Lizard, but when carefully examined both in the field and in microscopic specimens they usually show a distinct foliation, and this may in some cases become quite pronounced. They are always fine-grained and present a very close resemblance to the more schistose specimens of the black dykes that occur in Kennack Bay, and in other parts of the Lizard district.

Two other types, less common though not by any means rare, are of some interest because they preserve to a certain extent their original igneous structures. They may be described as ophitic and porphyritic epidiorites. In the ophitic epidiorites the plagioclase felspar occurs as lath-shaped crystals with rectangular outlines and is enclosed by aggregates of green hornblende that clearly show by their relations to the felspar that they are the remains of ophitic masses of augite. The pyroxene of these rocks has always been converted into secondary

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[1] *Quart. Journ. Geol. Soc.*, vol. 52, 1896, p. 29.

aggregates of hornblende. Good examples of this type were found in the centre of Little Cove (on the north side of Caerleon Cove) and on the west side of Kennack Sands. In many specimens the traces of ophitic structure are rather indistinct, though recognisable to those who have made a special study of the stages by which basic igneous rocks pass into schists.

The porphyritic epidiorites are much more abundant and their presence in the 'Granulitic Series' has been described by Mr. Howard Fox and Mr. Somervail.[1] The most notable occurrence is on the shore below the Thorny Cliff where, in the cove north of the Cavouga Rock there are dark epidiorites with crystals of weathered, dull-looking plagioclase that may be three inches long. The reefs that rise through the sands and gravel on the west side of Kennack also furnish good examples of this type of rock, as has been described by Mr. Howard Fox.[2] In many other places porphyritic structure makes its appearance in a more or less sporadic fashion.

The phenocrysts are always plagioclase felspar and are mostly in a state of advanced decomposition ; the secondary products are usually prehnite, sericite and calcite. The matrix is fine-grained, non-ophitic and often slightly schistose. A noteworthy feature is the retention of sharply idimorphic outlines by the felspar phenocrysts though the groundmass is a fairly well-developed schist ; in such rocks the felspar and hornblende of the matrix can be seen to flow around the corners of the porphyritic crystals.

Many peculiarities of the basic part of the Kennack Gneisses indicate clearly their affinity with the black dykes. The ophitic types and the porphyritic types occur in both of these groups of rocks : schistose rocks are more common in the dark portion of the gneisses, but equally perfect schists may be obtained in the black dykes. The minerals of both sets of rocks are identical and have the same characters.

On the other hand there are many features that distinguish these rocks from the Lizard hornblende schists. Ophitic structure and porphyritic structure are absent or are very exceptional in the hornblende schists ; in no case have we found these rocks ophitic and we have never seen porphyritic felspar in them though sometimes a porphyritic crystal of augite may occur. Augite and epidote, so common in the Landewednack Schists, are absent from the basic parts of the gneiss, where sphene on the other hand is very common.

(*b*) The *intermediate* portion of the Kennack Gneisses comprises these rocks in which there has been a mingling of the acid with the basic magma. They consist of hornblende, biotite, felspars and quartz, and hence when they are foliated they may be described as hornblende gneisses and biotite hornblende gneisses. The more massive specimens are not unlike mica diorites and hornblende granites. Among their felspars orthoclase and albite occur, with oligoclase and other soda-lime felspars, and are often in good preservation. Sphene, apatite and iron-oxides are the usual accessories.

The hornblende of these rocks is of the rather pale green kind usually found in hornblende granites ; the biotite is dark-brown and strongly dichroic. Traces of idiomorphism are seldom met with in either of these minerals. There is sometimes a tendency for the felspar to appear in porphyritic crystals with centres of labradorite or andesine and borders of oligoclase, but these crystals are never so distinct or large as those that occur in the porphyritic epidiorites. In rocks of this type from the north part of Pen Voose the large felspars have zoned inclusions of small hornblende and biotite crystals in their outer portions.

These rocks are distinguished from the basic portion of the banded gneisses by their paler colour and greater richness in felspar. They are also characterised by the presence of certain minerals that are normally absent from the basic rocks ; among these we may enumerate biotite, acid plagioclase, alkali felspar and quartz. The alkali felspars include both orthoclase and albite and are often very abundant ; sphene also is almost constantly present, and often occurs in such a manner that it does not seem to have formed after ilmenite. The amount of quartz is very variable.

The great variety of rocks that occur in this series makes it difficult to give a general account of them, and this is increased by their banded character, for

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[1] *Geol. Mag.*, 1887, p. 518. C. A. McMahon, *Quart. Journ. Geol. Soc.*, vol. 45, 1889, p. 537.

[2] *Trans. Roy. Geol. Soc., Cornwall*, vol. 1, 1891, p. .

often in the same slide two distinct types may be seen alternating with one another in narrow strips not more than a quarter of an inch wide. Some rocks are nearly massive and have fairly good igneous structure; a good example of these has been described and figured by Dr. Teall in his 'British Petrography' (Plate XXXII, fig. 1). It occurs as a small mass at the north point of Pen Voose cove. The dark femic minerals are deep brown biotite and bright green hornblende; the rock contains also much felspar partly as larger crystals which though not very idiomorphic may be regarded as phenocrysts, and partly in smaller irregular grains. The larger felspars have centres of labradorite and andesine, often turbid through decomposition, and clear fresh margins of oligoclase passing into albite. The composition of the small fresh felspar grains in the groundmass corresponds to the outer zones of the phenocrysts, and oligoclase is evidently the dominant felspar of the rock. A small amount of quartz is also present and this is the only mineral that shows cataclastic structures; we note also the presence of apatite, sphene, iron oxides and occasional crystals of orthite (5963). The rock has been described as a mica-diorite by Dr. Teall, but he remarks that the micas show a parallel orientation which is well brought out in his coloured illustration. Similar "mica diorites" may be found among the Kennack Gneisses at the north end of Pentreath Beach (5976).

The foliated types, however, are more common than the massive and are well-banded. Hornblende is very common and much resembles that of the foliated basic rocks; biotite though often abundant is not always present. Basic felspar occurs in most of the rocks though usually too much decomposed to be identified; the acid plagioclase and alkali felspar on the other hand are often in very good preservation. Some of these gneisses consist of hornblende with much alkali felspar (orthoclase and albite) and very little quartz; though they have the structure of gneisses their composition resembles that of syenites (5018, 5044). Alkali felspar, in fact, is often very abundant in the intermediate portion of the Kennack Gneisses.

(*c*) The *acid* portion of the Kennack Gneisses, as already stated, forms pale-coloured bands alternating with the intermediate and basic or occurs as veins that penetrate the older members of the complex. Two types may be recognized, one containing biotite and generally pinkish-grey in colour, while the other is almost devoid of femic minerals and has usually a bright red colour. From the intermediate gneisses they are distinguished by their greater richness in quartz and alkali felspars and the general absence of hornblende and lime-bearing varieties of plagioclase. Most of the types of acid gneiss that occur as integral parts of the banded gneisses can be paralleled among the rocks that form the interior of the large masses of granite gneiss that have risen through the serpentine.

The pinkish biotite gneisses that occur as the acid component of the banded gneisses along the shore from Kennack Sands to Pen Voose, and on the west coast near Pentreath, are fairly uniform in macroscopic appearance. They are seldom rich in biotite, but the scales of black mica have a parallel arrangement that gives the rocks a distinctly gneissose character. As a rule they are fine grained and often they contain small phenocrysts of felspar that appear as lenticular or elliptical grains in a finer matrix. These large felspars have imperfect crystalline form; their outer zones are clear and fresh alkali felspar and their interior has been more basic but is generally turbid by decomposition. In a vein of gneiss about seventy yards south of the mouth of the stream at Poltesco there are large irregular phenocrysts of perthite felspar, with coarse veins of albite.

The biotite of these rocks when fresh is deep brown but is often weathered to chlorite and rutile; it is not uncommonly twisted and deformed by mechanical movements during injection. Oligoclase is common in the biotite gneisses and is often untwinned; consequently it is most easily distinguished from orthoclase by its refractive indices. Albite and orthoclase occur also in great quantity, and with quartz form the greater part of the rocks.

The red gneisses are very rich in alkali felspar (Plate XII., fig. 3) which is albite (with oligoclase-albite) and orthoclase. Microcline is very rare in these rocks. Owing to the absence of parallel scales of biotite they have often a massive appearance and as they tend to be fine grained they have a close resemblance to aplites. Wherever their relations to the other gneisses can be clearly established they are of younger age, and with the exception of certain pegmatite veins they are the latest injections of the Kennack Gneiss group. The pure red gneiss is not often interbanded in thin seams with the intermediate and basic types ; it occurs rather as thick sills or as narrow and sharply defined veins cutting the older parts of the complex. Many of the small bosses or domes of gneiss have centres of this type of rock though at their margins they may consist of banded gneiss ; examples of this are seen to the east of Poldowrian and at the east side of Kennack Sands.

The intermediate rocks and the biotite gneiss are essentially of metamorphic character and have the microscopic structure of typical gneisses ; the red gneiss on the other hand often differs in no important respect from a fine grained, highly acid granite. The plagioclase felspar occurs frequently in perfect crystals which impinge on shapeless areas of quartz, exactly as in a normal granite. A characteristic feature of these rocks also is the abundance of micropegmatite of vermicular structure (myrmekite) embedded in felspar ; it forms rounded clumps and consists of acid plagioclase (mostly oligoclase albite) with curved threads of quartz. From these facts we may infer that towards the close of the injection of the Kennack Gneisses the earth-stresses became relaxed and the magma consolidated under diminished pressures. Many specimens of the red gneiss, however, show cataclastic structure, and the quartz, which was the last mineral to crystallise, appears as granulitic mosaics the individuals of which are often strained though the felspar crystals have been little affected and still retain much of their idiomorphism.

On the west coast from Pentreath Beach all the way north to Mullion Cove the red gneiss is found in dykes and irregular tongues cutting the serpentine. Narrow dykes occur for example in Holestrow and Lawarnick Pit, while near Kynance there are many lumpy masses of gneiss in the serpentine ; they are seen in the beach at Kynance in several places and in the face of the cliff above the western entrance of the caves, and though their appearance might suggest that they are included blocks there can be little doubt that they are intrusions. Similar masses of red or pink gneiss occur to the south of Vellan Head (at Pengersick) and on the south side of Mullion Cove. Some of these masses contain biotite, others do not ; and, while some are nearly massive, many of them have a distinctly gneissose foliation. The basic portion of the Kennack Gneiss occasionally accompanies these intrusions, as at the north end of Pentreath Beach, the bend of the road above Kynance, and on Pengersick ; more usually it does not, and even when present it rarely forms a banded complex. The types of rock found among these gneisses in no way differ from those that occur elsewhere with the banded gneiss and the granite gneiss, so there seems no reason to regard them as belonging to a separate series. The prevalence of pure acid rocks on the western coasts shows that the banded type of Kennack Gneiss clings to the margins of the larger gneiss intrusions and was injected as a highly viscous liquid, while the pure acid material that rose at a later period had more fluidity and penetrated to greater distances.

The Granite Gneiss.

The wide extent of granite gneiss within the Lizard area was not suspected till the revision of the geological maps, as these rocks occur mostly in inland areas where they are covered by *débris*, and make but little show in the coast sections. Six areas of gneiss occur, all of them intrusive into the bastite serpentine; at Pen Voose and Cadgwith they touch the edges of the serpentine stock and send protrusions, in the form of thin red veins, into the hornblende schists, but nowhere are they found within the boundaries of the gabbro. Although these gneiss areas are distinct from one another, they contain very much the same types of rock, which may be described as biotite gneisses and red quartzo-felspathic gneisses (often with some muscovite) resembling those above described as constituting the acid portion of the Kennack Gneiss.

1. The Clahar Gneiss occurs in two masses, at Clahar Cairn and Clahar Garden, the latter being truncated on the north by the

Lizard boundary fault. The outlines of this gneiss cannot be clearly defined, but the rock is seen *in situ* in small pits in the fields, in the farmyard of Clahar Garden, and in the roadside to the north of that. A specimen (5360) collected in the fields 300 yards east of Clahar Garden, is a reddish biotite gneiss, well foliated, rich in myrmekite, and showing a good deal of cataclastic structure in the microscopic slide. Banded dark gneisses, veined with red granite, are seen on the west and south-west sides of this mass in small pits near the farm buildings.

2. The Goonhilly Gneiss has a large outcrop on the highest portion of Goonhilly Downs; it is of very irregular form and can easily be traced by the *débris* on the surface. Several small outlying intrusions occur in the serpentine near it. The rock is exposed *in situ* only in two small quarries on the east side of the Lizard road, half a mile north of Penhale. A specimen from one of these quarries (5338) is a pinkish-grey muscovite biotite granite, a perfectly normal igneous rock without foliation or cataclastic structure. It is rich in primary muscovite and in myrmekite. The joint planes in the quarry are coated with silvery scales of white mica. Nowhere around this granite are basic marginal rocks exposed, though from the evidence of the fragments on the downs they may be inferred to be present in several places.

3. The Erisey Gneiss is the largest of all the Lizard gneisses, its area being not much less than a square mile. It corresponds to the farms of Erisey and Trenoon, and practically the whole of its surface is cultivated; the boundaries are not hard to define in its northern half because the granite weathers down and the serpentine around it stands out in prominent masses. Large pits are opened in decomposed earthy red granite at Erisey, Trenoon, and several other localities. The freshest specimens are to be obtained near an old farm three furlongs east of Erissey, where there are blocks of reddish-grey gneiss showing little foliation. Margins of dark banded gneiss are seen at Trenoon, but are rather conspicuous by their absence around most of this mass; on the south edge, however, they attain a great development and are exposed in many pits and roadside cuttings from the junction of the streams south-east of Erisey by Trerise and Kingey to the bridge on the road from Kuggar to Ruan.

4. The Kuggar Gneiss has a somewhat triangular shape and reaches the seashore for a distance of nearly a mile in the cliffs of Kennack; in all probability it has a considerable extension in a south-easterly direction beneath the sea. The northern boundary is well-defined though very irregular; the position of the western and southern edges is impossible to lay down with any accuracy. The difficulty arises from the fact that this margin is highly irregular, and runs through cultivated fields; moreover, in all the farmyards there are pits in banded gneiss from which ' marl ' or rotten rock has been carted for generations and spread upon the fields. There has also been an extensive employment of sand from Kennack which contains fragments of the banded gneisses. Consequently it is not possible to rely on the indications afforded by the *débris* that is mingled with the soil.

This gneiss is mostly a pinkish-grey, well foliated, and moderately coarse rock, and though it is often much decomposed there are a fair number of exposures of fresh gneiss in the fields, roadsides, and banks of the streams. It has two well marked peculiarities, one being the number and large size of its inclusions of serpentine, the other the great profusion of banded gneisses along its south-western boundary. These are much less common on the north side, though they are well seen in the road cuttings at Gwendreath.

5. The Ruan Gneiss covers a considerable area around the village of St. Ruan and the deep fertile valley leading down to Cadgwith. Its margins are fairly well defined except at its northern end. The only place where it reaches the sea is on the south side of Cadgwith and in the Devil's Frying Pan. The edges of this intrusion are in large measure of the Kennack Gneiss type, with dark and light fluxion-banding, and these rocks occur not only at Cadgwith, but also at Brugan, and to the north of St. Ruan, but the centre of the outcrop is composed of reddish gneisses of pure acid type. Fresh pink gneiss, well foliated, is seen in the roadside about 200 yards west of the coastguards' houses on the south side of the Cadgwith Valley (5033), but at St. Ruan and in the stream below that village the rock is soft and deeply decomposed.

6. From Polbarrow southwards along the cliffs to The Balk much banded gneiss is seen, and in the adjacent fields there are many exposures of the rocks of this group. The geology of this area is very complicated, and the lack of evidence makes it impossible to define the outcrops of the different rocks with any precision. The country rock is bastite serpentine with a considerable admixture of gabbro. The gneiss is mostly of the banded or mixed type, which renders it probable that the rocks visible at the surface are either the upper part of an underlying mass of gneiss or the western edge of a considerable intrusion that has weathered down more rapidly than the serpentine and is now mostly covered by the sea. These gneisses nowhere reach the southern boundary fault that intervenes between the serpentine and the hornblende schists.

The Metamorphism of the Gneisses.

The Kennack Gneisses and the Granite Gneiss are in the main of typical metamorphic facies, for their minerals occur in grains devoid of crystalline form and have a parallel orientation and elongation in a definite direction. The foliated structure is best exhibited by those rocks that contain much biotite and hornblende, but is shown also by the forms assumed by the quartz and felspar in rocks which have few or no femic minerals. In field exposures the fluxion-banding gives the rocks an appearance closely resembling certain varieties of the Lewisian Gneisses of Scotland and accentuates their metamorphic character, but the foliation is to be regarded as distinct from the banding. Thus, for example, many of the biotite gneisses are not fluxion-banded but have a perfect foliation. Although the whole series is of igneous origin the only members of it that show the structures of igneous rocks in good preservation are some of the ophitic epidiorites that occur as blocks in the banded gneisses, and the massive granites of the interior of some of the larger intrusions; these are respectively the oldest and the newest parts of the complex.

In describing the field characters of these gneisses and their structural relations to the other rocks of the Lizard we have attributed certain of their features to the injection of crystalline masses in a heated condition and still in some measure plastic into the older rocks under the action of great pressures. We shall now proceed to describe the field evidence that can be adduced in support of this hypothesis.

The foliation, by which we mean the elongation and orientation of the component minerals, is in general parallel to the fluxion-banding and consequently follows the long axes of the intrusions or the direction in which they flowed. Hence in adjacent veins or sills of gneiss the foliation is often in different directions, and when one of the larger masses gives off a lateral vein the foliation in the vein is often at right angles to that of the parent mass. A slight divergence between the direction of the fluxion-bands and the foliation may occasionally be noted, especially when the banding is irregular or tortuous, but this does not invalidate the general rule; in such cases the foliation usually maintains its direction more persistently than the banding.

These facts are sufficient to show that the origin of the foliation is closely connected with the injection of the gneisses into the fissures which they now occupy. It is an 'injection foliation.'

There is also evidence to prove that the foliation of these gneisses was completely developed prior to the cooling of the rocks. A short distance to the south of the west gate at Kennack the banded gneisses contain many interlacing veins of pegmatite; these pegmatites are built up of large crystals of quartz and flesh-coloured felspar, and at their terminations tend to pass into pure quartz veins. The rock in which they lie is the dark portion of the banded gneiss and is distinctly foliated but the pegmatite veins show neither crushing nor distortion. They can be traced to a rather thick sill of reddish gneiss, also well foliated, which alternates with the dark hornblendic gneiss. The very coarse crystallisation of the pegmatites indicates that the rocks were still hot at the time when the veins were filled; but no foliation was produced in the pegmatites, presumably because the movements had ceased, while the gneisses of which the pegmatites were merely the last portion to solidify, were already perfectly foliated.

Confirmatory evidence can be obtained by studying the junctions of the gneiss with the serpentine. The ultra-basic rock is often rotten and altered where it touches the gneiss, but it is very seldom schistose. In describing the injection foliation of the gabbro veins we noted that at the margins of certain veins the serpentine showed a secondary or superinduced foliation parellel to that of the vein, which indicates that the gabbro was in a fairly rigid state when it was compressed between the walls of serpentine. The absence of similar phenomena at the edges of the gneiss instrusions proves that the latter rocks were essentially plastic;

this leads to the assumption that they were hot though it does not necessarily mean that they were liquid when the foliation was impressed on them, for the acid rocks consolidate at a lower temperature than the gabbros, and the walls of serpentine in contact with the gneiss may have been relatively cold and hence less readily sheared.

An examination of the inclusions of serpentine that occur in great numbers in some of the sills of gneiss reveals some facts that have an interesting bearing on the problem of the origin of the foliation in the gneisses. Many of the serpentine blocks, though much altered in other respects, show little foliation; this is generally true of all the larger serpentine inclusions that have a diameter of two feet or more. The smaller inclusions, on the other hand, have often a schistose surface or are transformed throughout into well foliated schists. In this condition they consist of talc, tremolite, and pale green chlorite, and are exceedingly soft and fissile; the change is to some extent a pneumatolytic one but the development of schistose structure in a rock that must have been solid is clear proof that the enveloping gneiss was already crystallised and in the condition of a plastic solid mass at the time when it finally came to rest.

The difference in the behaviour of the larger serpentine blocks probably implies that they were involved in the gneiss not long before movement ceased and at great distance from the place where they now lie.

The appearance of normal igneous types among the latest injections of the granite may be explained by supposing that the epoch of high pressure during which the gneisses were injected had come to an end and the rocks were not affected by movement as they consolidated and cooled down. We are thus again led to the conclusion that in the history of the Lizard intrusions there were periods of high pressure during which foliated rock-types were produced, and epochs of low pressure during which the injections from the magma crystallised as normal igneous rocks. The development of foliation in the vast majority of cases took place during the cooling of the intrusions; when they were hot they readily foliated, but once they were cold they proved more resistant. In all the Lizard intrusions there are crush zones where structures of a cataclastic type have been produced by movements attended by brecciation and displacement of the solid rocks at a time long subsequent to their cooling. But in the serpentine, the gabbro, and the gneisses the dominant foliation is an injection foliation which was produced in each rock at an early period in its history.

Pneumatolytic Changes in and around the Gneisses.

It has been noted by more than one writer on the geology of the Lizard that in the vicinity of the gneisses the older rocks are often altered in a peculiar way. This is most evident in the serpentine, which often has been converted for a distance of a few inches into a soft greenish rock that consists mainly of talc and tremolite with sometimes anthophyllite and chlorite. Mr. Harford Lowe, in particular, has directed attention to the constancy with which a film of this material makes its appearance at the junctions of the serpentine and the acid rocks. It is found in very many places on the east coast from Kennack to Pen Voose, and on the west coast at Pentreath, Holestrow, and Kynance. These tremolitic rocks are sometimes schistose, when movement has taken place along the junction plane, and it cannot always be shown that the development of foliation is connected with the injection of the viscid gneiss for tremolitic schists are also produced by shearing of the serpentine where no gneiss is present. In other cases the tremolite rock is massive or has a radiate structure, as is well seen in an included block of serpentine in the banded gneisses near the west gate at Kennack; it has been described and figured by Mr. Lowe[1].

It is not likely that this alteration is due to the simple contact action of the gneisses, for the minerals are such as are formed at comparatively low temperatures, and the change can often be observed to spread out from the gneiss along the joints and cracks of the serpentine. It is evidently produced by the action of liquids or gases that diffused outwards from the acid rocks. Now the serpentine has few fissures and carries little water, but the thin injections of gneiss in the serpentine are very permeable and often act as channels for moisture percolating downwards from the surface. Solutions of this kind, however, cannot be the main agents in producing this type of alteration in the serpentine for the gabbro veins also act as water conductors yet tremolitic rocks are rarely seen at their margins. We are reduced to the conclusion that hot vapours or liquids given off by the gneisses on cooling were usually the operating causes and that consequently the changes are of a 'pneumatolytic' type.

The principal mineral of these aggregates is sometimes tremolite and sometimes anthophyllite; the tremolite in section is colourless or very pale green, the anthophyllite colourless, and the two minerals are to be distinguished from one another only by the straight extinction of the anthophyllite in all prismatic cleavage fragments. The amount of talc and chlorite varies, but is usually small. Around Kennack, however, pockets of pale green or silvery white talc, crystallised in small flat scales, are not uncommon near the gneiss and the black dykes on both sides of the bay. Dr. Teall was the first to record the occurrence of anthophyllite at the Lizard. His specimen was obtained at a junction of gabbro and serpentine a few yards north of the north point of Pen Voose; it is to be noted that the gneisses occur in great strength at this locality and intrusions of them can be found along the actual junction of the gabbro and serpentine where the anthophyllite occurs. The analysis by Mr. Player shows 50 per cent. of silica, which is considerably greater than is found in the unmodified serpentine, and hence there is reason to believe that there has been an introduction of this substance from the acid rock; this must in fact have been general at the contacts of gneiss

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[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. xii., 1901, p. 445.

with serpentine in the Lizard, and, we need hardly point out, is a very frequent feature of the pneumatolytic changes around granites.

SiO_2	... ...	50·8
Al_2O_3	... ...	3·6
Cr_2O_3	... ...	tr.
Fe_2O_3	... ...	3·7
FeO	... ...	6·8
CaO	... ...	1·2
MgO	... ...	26·1
Na_2O / K_2O	... ...	0·2
Loss on Ignition	...	5·8
Total ...	...	98·2

Anthophyllite, from junction of gabbro and serpentine at Pen Voose, the Lizard, (Anal., J. H. Player) quoted from J. J. H. Teall, 'Notes on Some Minerals from the Lizard,' *Mineralogical Magazine*, vol. viii., 1888, p. 120.

As has been remarked already, the smaller inclusions of serpentine in the gneisses are often converted into silvery greenish talc tremolite chlorite schists. In this process we have probably two agencies at work, pneumatolytic impregnation modifying the composition and mechanical shearing affecting the structure of the included masses.

A converse or reciprocal action of the solutions that have percolated through the serpentine on the silicates of the veins and dykes must also be postulated to explain the invariably decomposed state of all the rocks that occur in or near the acid dykes. Dr. Teall has remarked that the dykes in the serpentine are usually very rotten[1]. The felspar is most susceptible to change and in the gabbros is often replaced by prehnite and a micaceous substance that seems to be sericite; carbonates are scarce. The alkali felspars are more resistant, but they also undergo profound alteration, and are often converted into sericite and pseudophite. The dykes that occur in the gabbro on the other hand are often very fresh and have their felspars in excellent preservation.

That this change is due to the action of magnesian solutions is proved by the formation of pseudophite after alkali felspar. Mr. Fox first described pseudophite from a dyke near Kynance[2]; he concluded that it was derived from plagioclase, but it seems in every way probable that alkali felspar was often the original substance; at any rate the alteration of alkali felspar to pseudophite can be very well seen at that locality. The pseudophite has much of the appearance of flint and is transparent on thin edges, but quite soft and easily cut. Many localities for this mineral might be cited in the Lizard; one of the best is at the east side of Kennack about a hundred yards east of the eastern gate. There also it can be seen to arise from the alteration of alkali felspar. The best known, however, is the 'soap rock' on the west coast at Gew Graze. A dyke of red granite cuts the serpentine at that locality, and is in part extremely fresh, but elsewhere decomposed into a waxy substance, pale pink and so soft that it resembles white soap. The analysis given below shows the composition of the

[1] *Quart. Jour. Geol. Soc.*, vol. 49, 1893, p. 206.
[2] *Mineralogical Magazine*, vol. ix., 1891, p. 275.

fresh granite and of the secondary product; the latter is evidently pseudophite, as may be seen by comparing it with Player's analysis of the substance from Kynance (*see* p. 145). The changes are apparently a removal of the alkalies and most of the silica, and the introduction of a large amount of magnesia. The pseudophite has, in fact, the composition of a serpentine to which about 14 per cent. of alumina has been added; yet in microscopic sections the original structure of the granite can still be clearly perceived though its substance is converted into an aggregate of scales of a mineral with a moderately strong action on polarised light (5124-5125). An old analysis of the 'soap rock' by Houghton shows that the material varies somewhat in composition, but is always more aluminous than serpentine or steatite.

We quote also an analysis of a white substance from a quarry on the roadside 400 yards west of Trezise (near St. Martin's Bridge) which is evidently also, from its composition, a variety of pseudophite.

These facts explain the much altered state of the felspars of the black dykes and of most of the basic part of the Kennack gneisses. At the north end of Pentreath Beach, on Enys Head, Vellan Head, and Beagles Point there are epidiorite dykes that are so soft that they can easily be carved with a knife; the basic part of the Kennack gneisses has very rarely the felspar sufficiently well preserved to be exactly determined. This is much to be regretted since it makes it impossible to discuss adequately the interfusion that has taken place between the basic and the acid portion of these gneisses, for chemical analyses of these altered rocks would not lead to any certainty on this subject.

—	I.	II.	III.
SiO_2	75·96	37·94	42·28
TiO_2	0·07	0·10	—
Al_2O_3	12·86	14·25	7·21
Fe_2O_3	0·57	1·00	—
FeO	0·10	0·10	—
MnO	0·19	0·12	—
(CoNi)O	nt. fd.	nt. fd.	—
BaO	nt. fd.	0·01	—
CaO	0·46	0·18	—
MgO	0·38	31·08	29·70
K_2O	4·54	tr.	—
Na_2O	4·35	0·47	—
Li_2O	tr.	tr.	—
H_2O at 105°C	0·27	4·49	} 18·92
H_2O above 105°C	0·39	10·34	
P_2O_5	0·04	0·07	—
FeS_2	nt. fd.	nt. fd.	—
CO_2	nt. fd.	nt. fd.	—
Total	100·18	100·15	98·11

I. Granite vein in serpentine, Gew Graze, Cornwall (E. 5125); (Anal., E. G. Radley).

II. The Soap Rock, at same locality; altered state of granite vein (E. 5124): (Anal., E. G. Radley).

III. The Soap Rock; analysis by F. T. S. Houghton (J. H. Collins, 'Mineralogy of Cornwall and Devon,' 1871, p. 97).

—	I.	II.	III.
SiO_2	35·02	33·3	33·51
TiO_2	0·33	—	—
Al_2O_3	14·02	21·8	15·42
Fe_2O_3	0·85	0·4	—
Cr_2O_3	nt. fd.	—	—
FeO	2·59	—	2·58
MnO	0·22	—	—
(CoNi)O	0·15	—	—
BaO	nt. fd.	—	—
CaO	1·77	—	—
MgO	35·17	29·7	34·41
K_2O	0·06	—	—
Na_2O	0·24	—	—
Li_2O	tr.	—	—
H_2O at 105° C...	0·66	} 14·9	0·46
H_2O above 105° C	8·86		12·75
P_2O_5	0·41	—	—
FeS_2	nt. fd.	—	—
CO_2	nt. fd.	—	—
Total	100·35	100·1	99·13

I. Pseudophite, vein in serpentine, quarry 400 yards W. of Trezise, St. Martin's, Cornwall (E. 5959); (Anal., E. G. Radley).

II. Pseudophite, vein in serpentine, east side of Kynance Cove, Cornwall, (Anal., J. H. Player), cited from Howard Fox, 'On the Occurrence of an Aluminous Serpentine near Kynance Cove,' *Mineralogical Magazine*, vol. ix., 1891, p. 275.

III. Pseudophite, Zdjar Mountain, Moravia (Aanal., Hauer). Cited from A. Kenngott, 'Mineralogische Notizen,' *Sitzb. Akad. Wien*, B. xvi. (1855), p. 170.

What seems to be the same type of mineral alteration has been noted by Lacroix in the Pyrenees. 'D'une façon presque générale, au contact du talc, le granite et les granulites subissent des transformations profondes, ils se transforment en une matière jaune ou vert olive claire, onctueuse au toucher, dépourvues d'alcalis et riche en magnésie. Elle est identique à la *pseudophite*, c'est-à-dire constitue une variété cryprocrystalline et pauvre en fer de pennine.' A. Lacroix, 'Le Granite des Pyrénées, et ses Phénomènes de Contact,' *Bulletin des Services, Carte Géol. de la France*, vol. xi., No. 71 (1900), p. 15.

PLATE XII.

PHOTOMICROGRAPHS OF LIZARD GNEISSES AND VERYAN IGNEOUS ROCKS.

Fig. 1.—*Hornblende schist* (6727), basic portion of Kennack Gneiss, Thorny Cliff, Kennack Sands, magnified 12 diameters. A foliated rock consisting of green hornblende, a little biotite and plagioclase felspar

„ 2.—*Hornblende schist* (5176), black dyke cutting serpentine and gabbro, 70 yards south of the gate at the west side of Kennack Sands, magnified 32 diameters. The dark mineral is green hornblende ; the clear spaces are weathered felspar. This represents the schistose type of the Kennack dykes.

„ 3.—*Biotite gneiss* (6358), Gwendreath, magnified 28 diameters. The principal components are biotite, clear quartz and somewhat weathered felspar. In the centre of the figure there is a dark prism of orthite.

„ 4.—*Spilite* (3421), Mullion Island, magnified 38 diameters. The long clear prisms are felspar, and by their radiate arrangement they give a variolitic character to the rock ; the dark matrix is brown augite and weathered glass.

„ 5.—*Granophyre* (6302), in lane 300 yards south of Manaccan Church, magnified 23 diameters, nicols crossed. This rock consists almost wholly of a micropegmatitic intergrowth of quartz and alkali felspar.

„ 6.—*Soda Granite Porphyry* (5322), north-east corner of Porthallow Cove, magnified 30 diameters, nicols crossed. There is much albite, both in small phenocrysts and mixed with orthoclase and quartz to form the groundmass. The rock is crushed but not schistose. Ferromagnesian minerals are almost absent.

1.

2.

3.

4.

5.

6.

Huth, coll.

PHOTOMICROGRAPHS OF ROCK-SECTIONS.

CHAPTER X.

LOWER PALÆOZOIC.

MYLOR SERIES.

The general features of the killas having been described in Chapter II. a brief sketch will now be presented of the distribution and field relations of the various stratigraphical divisions, with such local points of interest as they exhibit. Of the Lower Palæozoic divisions the Mylor group, for reasons already given, is supposed to be the lowest. It occupies a large area in the northern portion of the Sheet, its junction with the overlying Falmouth group forming an irregular line extending obliquely across the map from Mawnan Smith to the Loe Bar. The base of the series is not represented on the map, but its trend so far as can be obtained from its upward passage into the overlying Falmouth division has an average strike of east-north-east and west-south-west (E. 20° N. and W. 20° S.). Owing to the folded nature of the margin, however, this strike is not uniform along the band, thus from Mawnan Smith to Polwheveral Creek it is W. 25° S., thence to Gweek it follows an east and west course, and from Gweek to the west coast at Loe Bar the average strike is W. 29° S.

As the northern edge of the map cuts obliquely across the Mylor band it is represented as a rude triangular tract with a breadth of over three miles in the western districts of Helston and Porthleven and contracting gradually to a point at Mawnan Smith. The bottom of this series has not been reached in Cornwall, and it is probable that the slates seen in the neighbourhood of Breage represent the lowest portion of the Mylor Series that is visible at the surface, and at the same time the deepest Palæozoic strata known in the south-west of England[1]. As regards their age, while they have yielded no fossils except radiolaria, they are linked on with known Ordovician strata—the Veryan Series which will be described later—and in all probability are the basal members of that formation.

This series is penetrated by a well-marked belt of intrusive greenstones that appear to occupy an horizon somewhere about the middle of the group. These intrusions were injected into the Mylor beds in the form of basalts and andesitic basalts at an early stage in their history, and have shared in the subsequent deformation which has prevailed over the region. That greenstone belt extending from Porthleven to Helston and Trevennack is truncated by the Carnmenellis granite, the southern margin of which cuts across the Mylor Series gradually creeping along higher horizons until at Driff it occurs within a thousand yards of the outcrops of the Falmouth Series. The Godolphin granite, on the other hand, that enters this area at Breage, has apparently burst through the lowest portion of the Mylor division, as the

[1] With the possible exception of the Dodman Series.

greenstone belt lies midway between it and the base of the Falmouth Series. A still later set of intrusions that represent the dyke phase of the granite is marked by elvans, a few of which occur between Sithney and Breage, while one or two more are seen on the shores of Polwheveral and Porthnavas Creeks.

As the granites have effected contact metamorphism over a wide belt of killas situated on their borders, the Mylor group presents marked variations in its mineralogical features; not only is this distinction brought out by the differences in character of the metamorphic belt and the killas that lies beyond it, but the metamorphic aureole itself exhibits a variation equally well marked by the different effects of the thermal alteration depending on the proximity of the particular zones to the granite margin. As these phenomena will be discussed in a subsequent chapter it will be sufficient to point out here that while the development of 'knotting' or spotting is the principal characteristic of the contact belt, in the zones more closely approaching the granite biotite and muscovite have been developed on such a large scale as to completely transform the character of the rock, and, instead of the normal killas, phyllites and even mica schists have been evolved; moreover in the inner zone these schists are extensively charged with andalusite.

As the granite from west to east is gradually occupying higher horizons in the Mylor sequence the metamorphic belt embraces in the eastern area almost the whole of the Mylor Series, while in the neighbourhood of Gweek it actually reaches the top of the group and extends for a short distance into the Falmouth beds above. From Gweek Downs, however, to the Cober Valley at Helston, the stratigraphical horizon of the metamorphic zone is again descending in conformity with the granite margin and finally curves round to the north-west and enters the map to the north (352) about half a mile to the east of Sithney. Between Helston, therefore, and Porthleven there is an extensive tract of Mylor beds, divided by the Loe Pool, beyond the metamorphic aureole. This belt, however, does not reach the coast as the latter is fringed between Loe Bar and Porthleven by a narrow tract of altered rock, the continuation of which passes to the east of Breage.

A few of the more important sections in the Mylor group will now be described, commencing with the eastern portion of the belt. At the head of Porthnavas Creek between Penpoll Mill[1] and Porthnavas we see the marginal area between the unaltered Mylor slate and the spotted zone. The Mylor beds here where they succeed the Falmouth Series are dark slates in which there is usually a very fine closely laminated structure that marks the bedding. These slates are full of disturbances chiefly of the nature of small but irregular thrusts. In a quarry between Roskillen and Penpoll Mill situated within the 'knotted' zone the interlaminations are more pronounced and the rock more massive, and in addition to the close array of fine shearing planes, the movements in this mass have been carried so far as

[1] ¼ mile S.S.W. of Roskillen.

to produce in some parts a fine type of brecciation representing the earlier stages of a crush conglomerate. Farther to the west the entire breadth of the Mylor band from the Falmouth group to the granite has been dissected, and is exposed on the shores of Polwheveral Creek. These beds where they succeed the Falmouth group at the southern entrance of the small branch creek leading to Polpenwith are blue slates with fine sandy beds in which the characteristic Mylor interlamination is absent. They soon, however, assume their normal banded habit and are seen in their typical condition on the shore north of Scotts' Quay[1]. The fine sandy beds are not so massive as those of the Portscatho Series and are nearly always well cleaved. These sandy seams are often very thin and closely interlaminated with the argillaceous and in these cases impart the banded structure characteristic of the series.

As soon as the section approaches to within about half a mile of the granite, knots appear in the slate, and from thence to the granite margin at Polwheveral the beds are also to a very large extent micaceous. The knots vary much in size and shape, and are sometimes flattened along the cleavage planes; at times they are ragged and sheaf-like, but with an approach to definite shapes. The micaceous zone extends for about one-third of a mile from the granite junction at Polwheveral, and is better developed the closer the granite is approached. For the sake of convenience therefore this part of the section will be described from the granite junction outwards.

Just below the corn mill at Polwheveral, although the original banded structure of the Mylor group is preserved, the bands themselves are richly charged with biotite and muscovite, the former preponderating, while the knots are represented by pale divergent sheaf-like masses resembling those of the *garbenschiefer*. A little further south, near an old adit, the bedding is fairly regular with a dip of 50° to the south-east, the banding is very conspicuous, and mica is abundant, especially in the more argillaceous seams. Some of the bands giving the dominant Mylor structure are very siliceous. In some parts the rock is now practically made up of biotite and muscovite in fine scales closely aggregated, and the small knots in this locality are apparently composed of the same material. The rock is everywhere folded and minutely sliced, and small quartz veins share in the puckering. In spite of the mineral alteration the beds are clearly seen to consist of close alternations of fine sandstones and argillaceous bands. A little further south the dip is noted as 35° to the south-east, with cleavage fairly coincident with it, while closely adjacent is a small elvan about a foot wide, which is seen for about 35 yards twisting between the disturbed strata, and is in places severed by small faults. About a quarter of a mile from the granite junction the knots are comparatively large, being about the size of peas, and of irregular shape, although occasionally there is a tendency to assume definite outlines, with frequently a stellate grouping. A little further south the knots are less frequent, and the mica less

[1] ½ mile N.W. of Calamansack.

abundant and in smaller scales and mainly confined to muscovite. Henceforward, towards the margin of the aureole, the mica is not present, and the alteration is confined to knotting. Near the edge of the aureole the slates are reddened and discoloured by hæmatite, which occurs in such abundance that it was formerly mined.

In its westerly course from Polwheveral Creek to Boskenwyn the Mylor band crosses an upland district, and rock sections are rare. Much of the land indeed consists of uncultivated downs, the poverty of the soil being mainly due to the profusion of quartz *débris*, as is especially noticeable on Merthen Downs, Naphene Downs, and Boskenwyn Downs. In the neighbourhood of Gweek the Mylor band is about a mile in breadth and is entirely in the metamorphic aureole, the knotting, however, in the outer limits is of a very small type. An east and west line from Gweek Downs to Loe Valley marks the southerly limit of metamorphism. While the southerly boundary of the Mylor group from Polwheveral Creek to Gweek follows a westerly course, it thereafter sweeps round to about west-south-west, past Gweek Downs to Fernycombe[1], when for about half a mile it is again diverted to the west as far as Nancemerrin, from which place it once more follows a west-south-westerly course through Helston Downs, skirts Eglosderry and Goonhusband, and reaches the coast at Loe Bar.

The metamorphic zone lying north of Gweek Downs and Pencoose has a breadth of about 1¼ miles, while further west, at Helston, it attains a width of 1¾ miles. For half a mile from the granite margin, south of Polglase, knotted schists are exposed in the valley with the normal dip to the south-south-east. To the west of Boskenwyn Downs the whole breadth of the Mylor band is trenched by a valley from Trevilges to Pollard Mill, along the slopes of which the rock frequently protrudes, and has been wrought in numerous quarries, four of which are in the close vicinity of Pollard Mill and outside the metamorphic aureole. In these openings the killas is seen to be comparatively undisturbed, although the dip which is to the south-east is sometimes undulating; in the quarry 100 yards south-east of the mill it is noted as 15°. It consists of alternations of argillaceous with very fine sandy silts, both showing the characteristic Mylor banding, while in the old quarry between Pollard Mill and Little Trevilgan vein-quartz lines the bedding planes. Further to the north, after crossing the aureole between Pollard and Pencoose, the killas is of precisely the same type, but small ' knots ' have been developed. These are succeeded further north by a coarser and more pronounced type of knotting, while the zone bordering the granite for about half a mile in width between Boskenwyn and Trevilges is rich in mica and forms the typical knotted schist and carries bands of hornfels.

The area lying to the east of Helston forms smooth land devoid of features, and in a high state of cultivation, but where quarries have been opened, the usual type of banded sediment is seen. Although the arenaceous bands are usually in the condition of fine sandy silts,

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[1] ⅓ mile W. of Little Trevilgan.

in some cases they are more typical sandstones, analogous to those in the Portscatho beds, while in rare instances they are highly quartzose in character and closely approach quartzites. In a quarry near Tresprison a very conspicuous banded type is seen in which highly siliceous laminæ, nearly a quarter of an inch in thickness, separate the argillaceous layers. The railway cuttings between Helston Station and the granite afford sections of the knotted schist in which it can be seen that there are marked variations in the relative degree of knotting, independent of the progressive distances from the granite margin.

To the west of Helston the deep valley of the Loe, running approximately north and south, traverses the whole extent of the Mylor band from the north edge of the map to the coast at Loe Bar, and affords numerous sections over a distance of three miles. From Lower Town to Helston the knotted slates are frequently exposed with bedding and cleavage both dipping to the south-east, and the knotting diminishing in a southerly direction. That the strata were contorted prior to cleavage is often clear and is well shown in a quarry on the roadside near Newham House[1], where massive banded killas, although full of minor contortions, has a steady cleavage dip. In the road cutting near the site of the hospital at St. John's, the irregular and changing nature of the dips is well brought out, and at this locality some of the sandy seams are very quartzose. In the road cutting at Weeth the bedding is gently inclined to the south-east, but the cleavage is lying almost horizontal. There are marked variations in the killas caused by contortion, a quarry 300 yards west of Castle Wary showing the typical banded Mylor beds practically undisturbed and with a steady south-easterly dip of both bedding and cleavage, while another quarry 250 yards south of the same locality exhibits violent contortions in the bedding so that the cleavage often crosses it at a high angle. As the interbanding in this quarry is very pronounced, with the laminæ varying in colour, the disturbances are vividly brought out. A little further south, near Oak Grove, at the head of the Loe, the contortion is very marked in the rock cutting abutting on the road leading to Penrose.

The sections on the coasts of the Loe Pool show a constant repetition of blue slate divided by very fine sandy silts with cleavage common to both, and the characteristic ribbon structure of the Mylor beds is absent or but feebly developed. This, in fact, is a common feature of the upper members of the Mylor group. The Loe section, although half a mile in length has only a narrow vertical range, as the beds are rolling and sometimes show a hade of but 5°. Before reaching Lower Pentire[2], where the Falmouth beds first appear, there is a transitional phase marked by the oncoming of seams that more closely approach the Falmouth type, and the evidence of the gradual and natural passage between the two groups is of the most satisfactory nature.

Between the Loe Valley and the valley running south to Porthleven Harbour, the land is in a high state of cultivation and good sections are rare. A quarry close to the main road north-west of

[1] $\frac{1}{3}$ mile S.E. of Mellangoose. [2] On the north side of Carminow Creek.

Antron reveals the banded Mylor slate with a steady south-easterly dip, with quartz veins running in parallel bands (the largest of which reach six inches in thickness) coincident in direction with the planes of cleavage. On the roadside a quarter of a mile north-west of Penrose massive beds, but far from compact, have been extensively quarried. They show contortion, but the cleavage dips steadily at a low angle to the south-east. A little further up the valley a small pit in puckered slate contains a strong seam, about three feet in thickness, of fine-grained cleaved, highly siliceous, impure quartzite. Although this is outside the metamorphic belt, a quarry closely adjacent in which greenstone and killas are both seen, shows the slate to be strongly ' knotted.'

The most satisfactory section of the Mylor group in the area is afforded by the cliffs and foreshores fronting Mount's Bay, on either side of Porthleven, and although entirely within the metamorphic aureole, the spotting of the outer zones is of a feeble character. This coastline on the north is nearly half a mile from the main mass of the Breage granite, but is less than 400 yards from Tremearne Cliff[1], where that granite sends off a plexus of veins amongst the killas. There is reason to suppose that this edge of the granite underlies the killas at a low angle, and is therefore nearer the surface than the outcrops would appear to indicate. After making full allowance for the probability of the Breage granite swerving to the south-east in its submarine course, the extent of the aureole in the Porthleven area must be at least three times as great as its normal width.

The coast from the north-western edge of the map to Tregear Point is largely bounded by a line of vertical cliffs which often exceed a height of a hundred feet, and as the foreshore is accessible at low tide, they present unrivalled facilities for studying the structures. From what has been written in a previous chapter (*see* p. 27) dealing with the general tectonics of the killas, the reader will have been prepared for much complexity of structure, but for an adequate grasp of the mechanical effects of the crustal disturbances a half an hour's inspection of these cliffs will do more than the most lucid description. Although the average dip of both cleavage and strata is to the south-east, with a low hade, the bedding exhibits marked contortion, and when to this is added the close array of fractures, thrusting, and slicing, the irregularity of the deformation can to some extent be understood. But in these sections the disturbances do not stop here, but the cleavage itself shares in the contortion. Moreover, the killas is traversed by an extensive system of quartz reefs, some of which are several feet across, and intersect the strata in all directions, sometimes running along the strike and sometimes rising vertically through the killas, and often coalescing. The quartz veining has likewise been contorted, which has produced in it a set of transverse fractures. Finally, the killas has been converted into *knotenschiefer* with the development of coarse knots that vary both in size and closeness of dispersion. In spite of the deformation the characteristic Mylor banding is well brought out and the killas

[1] A little beyond the western boundary of the Sheet.

is seen to be made up of the usual alternations of fine textured sandy silts and argillaceous bands.

Besides the smashing so common in the quartz veins some of the killas shows a very fine type of brecciation, although regular crush breccias are not present. The intensity of the slicing is also exhibited by the greenstone which is sometimes represented on the foreshore by lenticles a few feet in thickness that tail off abruptly between the thrust planes. The quartz veins sometimes contain a small amount of felspar, as well as nests of chloritic material analogous to that found in the quartz veins of the schists in the Scottish Highlands.

The knots range up to a quarter of an inch in size and are sometimes elongated in the direction of the cleavage. Although this does not necessarily prove that they have shared in the stresses, and there are strong grounds for the assumption that the intrusion of the granites marks the closing of the period of Carboniferous crustal disturbance, the stresses may not have been finally dissipated until after the granites had been injected, as we have pointed out in dealing with the area in the Sheet to the north (352)[1]. Moreover, as will be shown later, the intensity of these disturbances diminishes the farther we recede from the granite.

The section to the south-east of Tregear Point shows a diminishing metamorphism, only represented by a more feeble type of spotting, but after passing the Pargodonnel Rocks[2], knotted schists are restricted to certain bands or zones amongst unmetamorphosed slate. About 300 yards north-west of Porthleven Harbour greenstones in great profusion form bands in the killas, this igneous belt extending beyond Porthleven Harbour to the Porthleven Sands on the south-east side. These rocks represent intrusive sheets of basalt and andesitic basalt that were injected as sills before the killas was folded. They vary considerably in thickness, and notwithstanding the crustal disturbances in which they were subsequently involved, their behaviour unmistakably points to original lenticular sheets in which the sill rapidly dwindles from several yards in thickness to a few feet or even less. Moreover, it seems clear that the thinner sheets frequently coalesced.

This complex type of intrusion has subsequently shared in the folding and disruption of the area, that has not only reduplicated the various bands, but, as regards the thinner sills, has severed their continuity, and left many of them in the condition of small lenticles among the killas. A description of these rocks will be found in a subsequent chapter. The lenticular behaviour of these sills is well brought out by the large mass that traverses Methleigh Beacon, over forty yards in breadth, which tails out at either end, and is represented on the coast by a diminutive strip. Not less instructive is the deep rock section on the western side of the inner harbour at Porthleven, where, along a distance of 150 yards, these rocks are not represented, although lying on the horizon of the intrusive belt on the coast only a quarter of a mile distant, and on the same horizon across the Porthleven Valley the greenstones again appear. That these sills are hading at a low angle to the

[1] Geology of Falmouth, &c. (*Mem. Geol. Surv.*), 1906, pp. 60–61.
[2] ¼ mile N.W. of Porthleven Harbour.

south-east is seen by a band traced north-easterly from the Great Trigg Rocks[1] on the coast, where, on reaching the southern edge of the escarpment facing the inner harbour, the outcrop is suddenly diverted to the north-west.

The killas in the coast section south-east of Porthleven displays the characteristic Mylor banding in its most typical form; not only is the killas less disturbed than on the coast to the north-west but the metamorphism is likewise more feeble, the spotting being restricted to limited zones, although the killas is still somewhat phyllitic. The less disturbed character is reflected by the greenstones which preserve many of their original structures, while the felspars have retained their idiomorphism to a remarkable degree. Below Gravesend[2] the banded Mylor beds are well displayed in the cliff section in which the minor contortions are beautifully brought out. On the eastern side of the large greenstone at Western Tye[3] the slates are sprinkled with tiny crystals of pyrites which on weathering simulate the spotted character due to metamorphism.

On the northern side of Parc-an-als Cliff the bedding planes show much contortion and the knotting is feeble; then follow much disturbed strata with a belt of crush breccia about 30 yards in width which is bounded by a fault; a little further to the south there is another fault running north-east and this is succeeded by strata extensively veined with quartz. Further to the south-east at Caca-stubb Baw[4] there is a fault hading south-east, while a strong escarpment which strikes at the coast about 30 yards farther to the north probably marks a parallel fault. There is here much interstitial disturbance in the killas which is knotted, and, while of the normal Mylor type and colour, it sometimes assumes pale greenish hues.

Between Caca-stubb Baw and Vellin-gluz Rocks[5] strong sandy bands appear some of which are from five to six feet in thickness. These bands admirably show the contortion, some having been completely doubled back though the cleavage planes with a uniform direction cut right across the folds. These sandstone bands readily weather and their rusty brown colour strongly contrasts with the darker banded slate which divides them.

At Vellin-gluz Rocks greenish hues reappear in argillaceous beds of Mylor type, in which pyrites cubes are scattered up to $1\frac{1}{2}$ inches in size; knotting is prevalent but the individual spots are small. The section from thence to Loe Bar contains an admixture of sandy and argillaceous seams in which the former are sometimes fairly coarse, containing grains of quartz and felspar closely aggregated in a somewhat argillaceous matrix. Some of the sandy beds, however, are far more compact and highly quartzose, while very fine grey quartzite seams also occur some of which appear to grade into cherts. There are bands also, up to two inches thick, of normal chert of a light colour. Zones with greenish hues also characterise this part of the section. The

[1] On the western side of the entrance to Porthleven Harbour.
[2] $\frac{1}{4}$ mile S.E. of Porthleven Pier.
[3] $\frac{1}{3}$ mile S.E. of Porthleven Pier.
[4] The south-east end of Parc-an-als Cliff.
[5] $\frac{3}{4}$ mile S.E. of Porthleven Pier.

killas is here highly disturbed with much faulting and occasional crush breccias but not of a coarse type. The lamination is not confined to the argillaceous members but is seen also in the fine-textured sandy beds. The cleavage planes of the slate near the boundary of the Mylor beds are somewhat stained by manganese. The spotting at this end of the section is of a very feeble description although occasionally more pronounced; it is not so apparent, however, in the crush breccias.

With the oncoming of buff beds at Loe Bar we reach the edge of the Mylor Series and although the passage is not abrupt this has been taken as the most convenient boundary line between the Mylor and Falmouth groups. It will be noticed that towards the upper part of the Mylor sequence greenish beds here and there appear. This is one of the characteristics of the heterogeneous Falmouth Series in which such beds are particularly marked on the southern side of Loe Bar. These greenish beds, therefore, in the Mylor group no doubt mark a transitional phase between these two divisions of the Lower Palæozoic sequence. In one instance at Porthleven Sands some thin chert seams occur in the green slates, the chert containing much fine chlorite and mica (5734). Although there is the characteristic absence of lime in the Mylor Series some phyllite within the metamorphic aureole at Porthleven Sands contains narrow vesicular seams which under the microscope are seen to consist of dolomite (5736).

CHAPTER XI.

LOWER PALÆOZOIC—(*continued*).

FALMOUTH SERIES.

This group which lies to the south of the Mylor Series traverses the Sheet in a west-south-westerly direction, but pursues a somewhat undulatory course, the central portion of the band between Gweek and Polwheveral Creek having an east-and-west trend. It is mainly characterised by softer and less compact strata that readily yield to decomposition, the predominant colours being buff and brown, which frequently assume bright hues of yellow and orange. But it contains also killas of more normal type scarcely to be distinguished from the Mylor and Portscatho beds, and there are large tracts where it is marked by pale greenish and reddish hues, the latter being a result of decomposition.

Occupying an intermediate position between the Mylor and Portscatho groups, its marginal conditions frequently partake of the character of those divisions; where, for instance, the Mylor group carries its pronounced banding up to the top of that series, this structure passes up into the adjacent and overlying Falmouth beds. As much of the district occupied by this band is in a high state of cultivation, fresh rock sections are scarce, and as the adjacent rock groups, more especially in the outer parts of the granite aureole, somewhat resemble the Falmouth strata, there is often considerable difficulty in drawing the lines of demarcation between them. For these reasons the boundary is represented by a line that, although correct in its general trend, fails to express the minor undulations that attend its interfolding with the adjacent rock groups.

Infolded outliers and inliers of the adjacent groups have similarly to be disregarded. This is clearly demonstrated where good sections prevail as along the course of the Helford River where that estuary truncates the margin of the Falmouth and Portscatho groups. That tract therefore instead of marking a more complicated stratigraphy than the remainder of the 'killas' area as the map would suggest, may be taken as a fair representation of the mutual relations of the divisions throughout the entire region.

The only igneous rocks that have been met with in the Falmouth group are elvan dykes, one of which occurs on the eastern shore of Polwheveral Creek to the north-west of Calamansack, and another crosses the head of the Helford River near Bonallack.

A brief description will now be presented of the lithological characteristics and local variations in the passage of this band across the map. At Mawnan Smith, where it enters this Sheet on its continuation from Maen Porth in Falmouth Bay, it consists of the typical buff beds and has a breadth of about a third of a mile. Its outcrop rapidly contracts, however, to about a hundred yards at Penpoll, but gradually widens again so that at the head of Porthnavas Creek its breadth is at least a quarter of a mile, and further west, where it crosses Polwheveral Creek, it exceeds half a mile, and midway between that locality and Gweek swells to three quarters of a mile. While much of this variation in outcrop is undoubtedly the result of folding, it may also be to some extent the consequence of lateral changes in the sedimentation.

Whatever may be its thickness, the Falmouth Series has a much smaller vertical range than the Mylor and Portscatho groups which it separates, and it is extremely probable, from the transitional phases which frequently mark its upward and downward passages into those groups, that it likewise shows lateral variation, so that near the margins of those groups different types of sedimentation were contemporaneously deposited on parts of the sea floor that were closely adjacent. Excellent sections are afforded by the shores of Porthnavas Creek, which completely dissects the band. It consists of an admixture of buff sandy zones with blue clay-slate, in which the bedding and cleavage, although hading to the south-east are subject to much variation, ranging from strata that are almost flat to 45° and over.

This band in its westward course occupies the coast section of the Helford River below Calamansack. On the shores of Polwheveral Creek the section is very similar to that seen in Porthnavas Creek, displaying numerous alternations of buff sandy zones with blue clay-slate, but on the coast to the east of Calamansack, towards the margin of the band, there is an extensive tract in which the buff sandy strata are alone represented.

Before tracing further the course of the main band which separates the Mylor and Portscatho groups a brief allusion will be made to the inlying patches that occur within the latter group as a consequence of folding. Two of the more important infolds have been mapped on the northern banks of the Helford River. One of these extends for a distance of 170 yards to the west of Porth Saxon[1], and is marked by a development of strong buff sandstone beds with a south-easterly dip, but much disturbed; with these there are other gritty bands in which the characteristic buff hues are not so pronounced. They represent a transitional phase between the Falmouth and Portscatho types. At Helford Passage[2] another lenticle outcrops along the coast for about a third of a mile, and consists of an admixture of buff sandy and blue argillaceous strata with a dominant south-easterly dip, but planes of movement and sharp isoclinal folding are conspicuous. There is, however, a general absence of contortion and likewise of quartz veining.

The main band in its course from Polwheveral Creek to Gweek runs nearly east and west, but while its northern boundary can only be approximately traced and its undulations have to be ignored, its southern margin is dissected by the creek sections and permits of its more accurate delineation, as a consequence of which the interfolded nature of the Falmouth and Portscatho groups is clearly brought out by a set of sharp folds, the axes of which strike approximately north-east and south-west. The Falmouth beds that are exposed on the Helford River to the west of Polwheveral Creek consist of buff sandy and argillaceous killas intermixed with zones of blue slate.

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[1] ¼ mile N.W. of Toll Point. [2] ⅔ mile N.E. of Helford.

At Gweek the characteristics of the Falmouth type are not pronounced, and the passage into the adjacent Portscatho and Mylor groups is evidently of a very gradual nature. In the centre of the belt, however, the type form is more conspicuous, and the road cutting on the west of the valley near the Methodist Chapel shows laminated soft pale argillaceous beds and reddened grit bands similar to those seen on the beach at Falmouth. In this respect it is interesting to recall that the correlation of the strata at Gweek and Falmouth was recognised by De la Beche[1]. The metamorphic aureole of the Carnmenellis granite has here extended into a small portion of the Falmouth Series, and small knots are seen in the killas of the road cutting alluded to above. At Gweek the band is about half a mile across but in its west-south-westerly course from thence to Helston Downs the outcrop gradually expands to a mile and a quarter and preserves that breadth until it reaches the coast where it extends from Loe Bar to Gunwalloe Fishing Cove. As hitherto noticed, however, between Gweek and the west coast the rock exposures are so infrequent that the boundaries are only approximately drawn.

In its passage from Gweek to the coast the belt traverses a flat tableland, and over a large part of that area the nature of the bed-rock has to be surmised from the *débris*, which is usually of red and buff hues, but in the fields to the north of Rose-in-the-bush[2] some greenish detritus likewise occurs, and pale greenish beds are also seen in the road cutting at Tangies. An excellent section is seen on the shores of Carminow Creek where the characteristic buff beds are well displayed, as also in a quarry about 300 yards north of Carminow Mill. Over this tract of country quartz *débris* is often densely scattered and this is especially noticeable in the fields between Carminowvean and Tangies, and between Rose-in-the-bush and Little Trevilgan. While the dips of such strata as can be observed mainly hade to the south-east there are many variations ranging from east to south. In the district with Carminow as a centre the strike appears to be about north and south. Near Polgrean[3] some fine-textured sandy strata have been impregnated with oxide of manganese, the minor joints and cracks of the rock being blackened with this substance.

The coast section from Loe Bar to Gunwalloe Fishing Cove dissects the entire breadth of the Falmouth group. It succeeds the Mylor Series at the northern entrance of the Loe where it consists of hard buff sandy bands alternating with striped argillaceous seams having a low dip to the south-east. The strata are undulating but there is an absence of marked contortion. Its gradual passage into the Mylor Series is very well seen in the road cutting above the creek, where the strata arch over and the dip is sometimes reversed. The band is concealed for a space by the Loe Bar, on the south-east side of which it again appears and thenceforward presents a continuous section to Gunwalloe Fishing Cove.

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[1] 'Report on the Geology of Cornwall' (*Mem. Geol. Surv.*), 1839, p. 93.
[2] $\frac{1}{6}$ mile N.W. of Bowgyhere. [3] $\frac{1}{3}$ mile E. of Berepper.

On the southern side of Loe Bar the rocks are, for a short distance, covered by blown sand, and on their emergence consist of killas in which the normal Falmouth type is not prominent, and instead of the marked buff beds the strata are fairly solid and somewhat intermediate in lithological character between the Falmouth and the adjacent rock groups, and exhibit much contortion. This is succeeded by greenish killas with a small relic of the characteristic purple slate of the Falmouth group, like that seen below St. Mawes Castle and in the large dock at Falmouth, but which has not been hitherto recognised in this Sheet. In this locality there is a fault hading to the south-east. Beyond the fault the beds assume a greenish hue and recall the strata of St. Mawes Harbour. Still further south the sandy and argillaceous strata are fairly compact and of a coarse banded type, and quartz veining is very prevalent, while the rocks exhibit much disturbance and are sometimes puckered.

On the coast immediately below Chyvarloe are two parallel strike faults, about six yards apart, enclosing greenish killas, beyond which massive sandy beds appear exhibiting coarse banding, with arenaceous and argillaceous alternations. These are replaced by the more characteristic buff beds with alternations of blue slate which occupy the remainder of the section for upwards of half a mile. In the latter zone a quarry has been opened near the top of the cliff, in which coarse sandstone bands appear, from six to eight feet in thickness, the grains of which largely consist of shale fragments with subordinate quartz. The bedding although disturbed is approximately horizontal. The cleavage hades to the south and in some places traverses the sandy beds. The latter are of a greyish colour, but the argillaceous alternations are frequently blue. Along the coast the killas is frequently stained with manganese. In this section pale grey chert bands are exceptionally seen, one of which, from the coast southward of Chyvarloe, under the miscrope appears to be a grey chert, partly argillaceous, but without traces of radiolaria (5270).

CHAPTER XII.

LOWER PALÆOZOIC—(*continued*).

PORTSCATHO SERIES.

This division which is interposed between the Falmouth and Veryan groups occupies the east coast from the northern edge of the map in the vicinity of Meudon to Dennis Head, and is further dissected by the Helford River. That estuary follows for some distance the boundary of the group with the Falmouth Series, and brings out the folded character of that margin. East of Porthnavas Creek the Portscatho Series forms the northern shore, save for the two Falmouth inliers at Helford Passage[1] and Porth Saxon[2], while further west the Falmouth beds occur with subordinate infolds of the Portscatho division. On the other hand the southern banks of that creek exhibit almost an unbroken sequence of the Portscatho Series in which the Falmouth division is merely represented by two small infolds, one at the entrance to Mawgan Creek, and another in the small inlet half a mile further to the westward.

The Portscatho band in its passage across the peninsula from Falmouth Bay to Mount's Bay conforms in its strike to the adjacent Falmouth group, that is to say, instead of pursuing a direct course its central portion bulges to the north in the vicinity of Mawgan. The band, therefore, besides exhibiting isoclinal folding, as shown by its interfolded margin with the Falmouth group, is likewise thrown into a gentle normal fold, which, if our reading of the general succession is correct, must represent a syncline. While the average strike of the band from the east coast to Mawgan is about W. 16° S., from thence to Mount's Bay it is W. 38° S.

As the best sections across the band are afforded by the cliffs and foreshores of the east coast they will be briefly described. Commencing at the northern part of the section east of Meudon we see the typical alternations of blue sandy and argillaceous strata, some of the latter being very carbonaceous and occasionally slightly graphitic. The cleavage is oblique to the bedding, the former dipping about south-east and the latter about south-south-east. The killas, however, is cut by minor faults and thrusts which sever the continuity of the bedding planes. A little south of The Hutches blue striped slate is succeeded at Bream Cove[3] by a narrow band of the brown Falmouth type in which similar striping is seen, as well as fine brecciation.

Beyond Bream Cove blue slate dipping to the south-east again appears, some of which is finely banded, and about 250 yards south of the cove a small north-easterly fault diverts the strike. Here the beds dip at 36° to the east-north-east and the cleavage is markedly transverse to the bedding, as if such obliquity has some connection with the fault. Numerous parallel faults of similar

[1] $\frac{2}{3}$ mile N.E. of Helford. [2] $\frac{1}{4}$ mile N.W. of Toll Point.
[3] 200 yards south of The Hutches.

trend continue along the section to Sowan's Hole[1], and isoclinal folding is also exhibited, some of the sandy bands being sharply doubled back on one another with the noses of the folds clearly shown. Examples of this are seen in Gatamala Cove[2]. Although the faults are very numerous the bedding along this part of the section with the north-west strike is of a more regular character than in the strata further north with the north-east trend. At the point forming the eastern entrance of Sowan's Hole[3] there is compact bedded sandstone of fine texture that strikes a little to the north of west, while the cleavage which dips to the south-east crosses it at a high angle.

At Rosemullion Head, where the strike is still about west-north-west, the strata consist largely of strong sandy beds, with subordinate argillaceous divisions. They are characterised by extensive folding and contortions[4] giving the section a very irregular appearance which is still further complicated by many small faults, and in places the sandstone has broken down into crush conglomerate. This section exhibiting a strike ranging from north-west to a little north of west extends for half a mile and is then lost beneath the sea at Rosemullion Head, the coast-line there suddenly bending round to the south-west. Seeing, however, that in spite of the deflection of strike the cleavage planes in the sandstone pursue their normal trend dipping to the south-east, it is probable that we have here a relic of a pre-existing strike in which the strata have resisted the tendency to arrange themselves along the north-east and south-west bands common to this area. No doubt in such resistance the massiveness of the strata has played an important part, and as a consequence pre-Carboniferous structures are preserved which furnish a clue to the disposition of the strata prior to their deformation by the late Carboniferous crustal disturbances.

Beyond Rosemullion Head the beds revert to their normal strike and both dip and cleavage hade to the south-east, although there are many deflections due to disturbance, but here the massive sandstones are no longer present, and the strata consist of blue slate with subordinate sandy beds. In that section between Rosemullion Head and Mawnan there are some thin cherty-looking bands composed of very fine quartzose material; these also occur in discontinuous strips and lenticles amongst the slate as a consequence of the shearing movements. On the coast due east of Mawnan Rectory there is another band in which the sandy beds have been broken up into a crush conglomerate. In this locality, also, hæmatite occurs as strings along the cleavage planes, and some of the sandy bands weather with the curious honeycombed appearance so characteristic of many calcareous rocks. Near here, also, the folding is remarkable, producing very sharp inversions in the slate.

Below Mawnan the strata have been injected by sills of mica trap, one of which was figured by De la Beche[5]; these rocks are

[1] ¼ mile W.N.W. of Rosemullion Head.
[2] ⅓ mile W.N.W. of Rosemullion Head.
[3] ⅛ mile W.N.W. of Rosemullion Head.
[4] These structures at Rosemullion Head were described in 1894 by Mr. F. J. Stephens. See *Trans. Roy. Geol. Soc., Cornwall*, vol. xi., p. 544.
[5] 'Geological Report on Cornwall, &c.' (*Mem. Geol. Surv.*), 1839, p. 94.

specially described in a subsequent chapter. On the north-western part of Parson's Beach there is another small crush conglomerate of the same type as those already alluded to, and possibly on the same horizon. It has the appearance of a boulder bed, and is only a few feet in thickness, but as the fragments, which range from one to three inches in size, in spite of their being rounded, are of identical composition with the matrix in which they are lying, their deep-seated mechanical origin is only too probable, especially in view of the highly disturbed character of the adjacent strata. A little to the south-west of this the repetition by folding and faulting of the sandy and argillaceous alternations is most conspicuous. The folds and thrusts are so close together as to cut off and detach cores of more solid rock. Vein quartz occupies the cleavage planes of the harder beds and the cracks which cross them. In this section also the deflection of the cleavage planes in crossing the sandy and argillaceous beds is clearly brought out, the angle between cleavage and bedding being greater in the sandy bands than in the argillaceous. Beyond this some very massive sandy bands occupy the dip slope of the cliffs, the individual beds being from five to six feet in thickness.

At Tolly Hole, just west of Mawnan Shear, the inconstancy of the dip is marked by variations within seventy yards, where easterly dips of 60°, 40°, and 30° are recorded. At Toll Point, on the northern entrance of the Helford River, sharp reversed folding is seen in a quartzose band, but cannot be detected in the argillaceous members. At Porthallack there is a zone about five or six feet thick in which the folds and slides are so closely aggregated that the rock is almost a breccia, while the beds immediately adjacent are singularly undisturbed, with a steady dip of 40° to the south-south-east. For the present we need not follow the section in its westerly course along the Helford Creek, but it may be mentioned here that at Polgwidden Cove some thin seams of argillaceous chert, about an inch in thickness, are interbanded with the slate, as well as occurring in lenticles, which bear some resemblance to the dark quartzitic bands that were noted as occurring between Rosemullion Head and Mawnan.

On the south side of the entrance to the Helford River the coast-line from The Gew to Dennis Head and from thence to St. Anthony presents a continuous section of the Portscatho Series. While at The Gew we are evidently on the same horizon as on the shore below Mawnan, the coast towards Dennis Head, although somewhat oblique to the strike, presents an ascending sequence which at St. Anthony reaches the top of the Portscatho division.

From The Gew to Dennis Head the strata are lithologically similar to those already described from Toll Point to Rosemullion Head, but the disturbances to which the rocks have been subjected are increasing in a south-easterly direction, and finally reach a stage where the killas is broken down into a series of lenticles representing a coarse augen structure. A brief description of the coast section will show the nature of this deformation. At The Gew the strata are of the usual Portscatho type, showing alternations of blue slate with more massive beds of fine-grained sandy material, and with a comparative absence of vein-quartz; mica trap of a similar nature to the sills below Mawnan veins the strata in an irregular manner. The folding is seen in the sandy beds where the crests of the sharp isoclines stand out conspicuously, and the faulting is so close that slide-planes occur practically every few feet, while the crossing of these strike-fractures by others transverse to the strata adds still further to the complexity of the section. Although the individual fractures are minor faults with small displacement, there is a distinct thrusting of the strata towards the north-west, so that the resulting repetition is similar to that produced by the isoclinal folding. The larger fractures are frequently filled with vein-quartz. While in the vicinity of The Gew there may be an average dip of 40° to the south-east, the strata roll about considerably, and where the inclination approaches the horizontal, the cleavage is always at a higher angle, and follows its normal hade to the south-east.

About 300 yards from The Gew there is a well-marked fault trending east-north-east, and in the section south-east from that fracture the folding and faulting are especially conspicuous, probably due to the occurrence of the more massive sandy bands; these more resistant strata have, however, suffered more than usual from the stresses, while sharp bends, faults, and slides are closely repeated. On the coast due north of St. Anthony Vicarage a more persistent thrust than usual is seen. It is horizontal and can be followed for twenty or thirty yards. Beyond this larger thrust minor slides occur every few feet, but the dominant cleavage is fairly steady. The regularity of the latter somewhat masks the effects of the folding. From here onwards the disturbances are so numerous that even where strong massive beds prevail the section presents a very irregular and disordered appearance, with a tendency to the isolation of large lenticles of rock, which is especially well seen in the cliff north-east of St. Anthony Church.

Beyond this locality the strata are traversed by numerous slide faults which hade to the south-east and carry vein-quartz. At the cave about 160 yards north-west of Little Dennis a larger fault than usual is seen carrying breccia, and from here to Dennis Head the coarse lenticular structure due to the stresses is exceptionally well developed. Besides, however, the overriding of the strata by thrusting, there is a repetition brought about by step faults closely adjacent. At Dennis Head, the torn lenticles are so numerous as to induce a coarse conglomeratic structure in the mass, forming a huge crush breccia. At this locality the north-west fractures are very pronounced and one of them is evidently continuous across the peninsula.

The section from Dennis Head to St. Anthony consists of sandy and argillaceous strata highly faulted and smashed. A very coarse sandy band occurs at St. Anthony, and in this locality there are slight traces of calcareous veining. As thin chert seams likewise make their appearance on the western shores of Gillan Harbour, this has been taken as a convenient boundary between the Portscatho and Veryan groups. There is no abrupt transition, however, between the two groups, the base of the Veryan Series consisting of killas very similar to that of the Portscatho division, and the line taken as the margin is but an attempt to separate these two members of the Ordovician sequence.

The Portscatho division in its westerly course across the area presents a repetition of the phenomena already described on these eastern coast sections, except that the belt displaying the coarse augen structure of Dennis Head does not again appear, that zone of disturbance taking a more south-westerly direction along Gillan Creek, where it is extensively developed within the Veryan Series. Between The Gew and Helford numerous small infolds of the buff sandy beds of Falmouth type are seen, but not of sufficient extent to be mapped out. The isoclinal folding is conspicuous at many localities, and there is much variation in the dips, and in the amount of disturbance in closely adjacent strata, the bedding in some places showing a steady hade, and in others exhibiting undulation and contortion, and the faulting is often sufficiently marked to effect pronounced deflections in the strike. To the east of Padgagarrack Cove[1] the strata are dipping at 35° to the south-east, while at Helford Point the dip is 65°, and at this locality the arches of the anticlinal folds are clearly visible. At Penarvon Cove[2] the strike is diverted for some distance to the north-west by a north-easterly fault.

On the southern bank of the Helford River, to the east of Frenchman's Creek, massive sandy bands are striking north-north-west with a west-south-west hade, while the cleavage preserves its normal inclination to the south-east. On the eastern shore of Frenchman's Creek opposite the quay the strata are for a time horizontal, with cleavage to the south-east. In a quarry a quarter of a mile north-west of Mudgeon Vean[3] sandy and argillaceous strata dip to the west while the cleavage hades a little west of south. These beds are slightly calcareous, which is an exceptional occurrence in the Portscatho Series, and they may possibly represent a small outlier or infold of the Veryan Series. To the north of Ponsontuel Creek[4] the bedding hades at 25° to the south-south-east, whereas the cleavage which crosses it obliquely inclines at 45° to the south-east, while near the head of that creek the cleavage and bedding both incline at 45°.

In its south-westerly passage from Mawgan this band presents the normal features as already described. It fails to reach the coast of Mount's Bay, being cut off by the Devonian killas which extends from Gunwalloe Fishing Cove to Winianton. To the south-west of Millewarn the strike shows marked discordances in direction, often trending between north and north-west, possibly as the result of faulting. The late Charles Peach mentions Mawgan Church Town as a fossiliferous locality, without, however, giving further particulars[5].

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[1] Just west of Bosahan Cove. [2] ¼ mile N.W. of Helford.
[3] ⅓ mile West of Mudgeon. [4] ½ mile S.S.E. of Gweek.
[5] *Trans. Roy. Geol. Soc. Corn.*, vol. vi., 1846, p. 181.

CHAPTER XIII.

LOWER PALÆOZOIC—(*continued*).

VERYAN SERIES.

This division succeeds the Portscatho group which lies to the north and is bounded on the south by the metamorphic rocks of the Lizard. It is represented on the east coast between Gillan Creek and Porthallow, and on the west coast between Gunwalloe and Polurrian Cove. Like the Portscatho and Falmouth divisions it sweeps across the peninsula in a broad curve, so that after pursuing a course slightly south of west from the east coast to Skyburriowe, it is there deflected to the south-west and reaches the west coast at Polurrian and Poldu. As the main body of the killas which constitutes the principal portion of the Veryan group is not markedly different from that of the Portscatho division, the boundary between those two members across the peninsula, where good sections are absent, can only be approximately drawn, whereas the opposite margin bounding the Lizard group can be more accurately traced from the distinctive lithological condition of the latter, and is shown on the map by a sinuous line.

Lithological Characters.—In an earlier chapter it was pointed out that besides sandstones and slates, somewhat similar to the Portscatho group, the Veryan division also comprised quartzites, cherts, and thin limestones as well as igneous rocks. The sandy and quartzite members are frequently highly felspathic, and even where limestones are not developed the killas is often calcareous. The killas moreover is locally in an advanced state of metamorphism so that phyllites, mica schists and granulites have been developed. The group also contains contemporaneous pillow lavas and intrusions of dolerite and hornblende schist. This division is also characterised by a great development of crush breccias in which both the sedimentary and igneous bands have been involved, and even where these structures are absent on a large scale they are frequently represented in the interstitial portions of the mass.

The major members of the group consist of the following bands, commencing at the base and immediately next to the Portscatho Series:—

1. Sandy and argillaceous killas.
2. Quartzite.
3. Sandy and argillaceous killas.
4. Pillow lava.
5. Sandy and argillaceous killas.

It will be seen therefore that the group consists essentially of sandy and argillaceous killas in which quartzite and pillow lava mark definite horizons. Chert, limestone, and subordinate quartzite seams, and the local development of mica schists and granulites are for the present ignored.

Besides those major members there occurs within Group 1 a belt of hornblende schist, about three miles in extent, ranging from

St. Martin's Green on the west to Gillan Creek on the east. It is represented by a series of lenticles, the largest of which lying south of Manaccan is about a mile and a quarter in length with a maximum breadth of about a third of a mile. The most easterly of these masses occurs at Tregithey, but the belt probably underlies the killas between that locality and Penare. This rock is intrusive and although thoroughly sheared throughout does not exhibit the advanced type of crystallisation of the dominant hornblende schists of the Lizard region, but it would appear to occupy an intermediate position between the Cornish greenstones and the typical hornblende schists of the Lizard.

The quartzite is exposed in a series of lenticles from Penare on the east to Tregadjack on the west, while within and beyond these limits its presence is evidenced by the *débris* in the soil. It occupies an intermediate position between the hornblende schist and the pillow lava, and is occasionally in contact with the former and sometimes occurs near the margin of the latter.

Although the killas of the Veryan Series is frequently calcareous, limestones are of rare occurrence. Small bands, a few feet in thickness, are seen at Nelly's Cove, Porthallow, and on the coast to the north of this, and narrower seams an inch or more in width may be observed in the killas between Polurrian Cove and Gunwalloe; bands of limestone also occur in association with the pillow lavas and radiolarian cherts of Mullion Island. In the inland tract of the Veryan belt no limestone has been detected.

Chert bands are principally developed in close association with the pillow lava within Group 3. They may occur however in other parts of the Veryan Series, but in such cases are usually poorly developed and very thin and are sometimes represented by cherty shales.

While the main body of the Veryan killas consists of dark slates and fine sandy silts, sandstones of coarser texture like those of the Portscatho division also occur. The main distinction, however, between the sandy beds of the two groups is the felspathic character of the Veryans, a condition which is only exceptionally present in the Portscatho division. Felspathic quartzites, although not so prominent as the more typical siliceous quartzites, are not infrequent, and owing to different conditions of metamorphism there are connecting links between those felspathic quartzites or granulites and the more normal sandy bands of the killas.

Crush breccias are of enormous development in this division, and are especially conspicuous in the basin formed by Gillan Creek and from thence to St. Martin's Green. The hornblende schist band just referred to has been especially affected and is rarely in any other condition than that of a breccia. The pillow lavas along the belt extending from Porthallow Cove, though often brecciated, have suffered to a much less degree. Unlike the hornblende schist further north, however, the bulk of the rock has escaped from these processes, and, doubtless, the close fissility of the schist has contributed to its destruction. Even the quartzite, which is the most refractory rock in the area, is often completely brecciated, but the interstices having generally been since infilled by secondary silica the solidity of the rock has usually been restored. These crush conglomerates in all stages of development can be studied along the shores of Gillan Creek, and where the process has gone sufficiently far they closely resemble normal conglomerates, as, for instance, in the deep road section at Manaccan. A large quarry has been opened in a crush breccia on the roadside west of Carn, the material of which is mainly sandstone, while calcite frequently infills some of the minor cracks.

Although the dominant strata of the Veryan division are represented by killas in which the original layers of mud and sand have suffered only the mechanical effects due to compression, yet in some instances deformation has gone further and typical mica schists and granulites have been produced similar to those in areas of regional alteration. As such crystalline rocks are nowhere else represented in the killas of Cornwall, their presence in this area points to conditions of metamorphism that did not prevail elsewhere.

One of the principal localities of these crystalline rocks is Manaccan where phyllites pass over into mica schists somewhat resembling certain bands lying within the Lizard group, on the coast east of Porthallow. At Penpoll Mill, at the head of Gillan Creek, the hornblende schist is bounded by mica schist, the thickness of which cannot exceed a dozen yards and may be less. On the hillside above, a small quarry has been opened in this rock and its *débris* can be traced past Roscaddon to the Vicarage at Manaccan[1]. It varies in metamorphism, and whilst in parts is not far removed from the killas of the area, it is principally in the condition of a typical mica schist. A specimen collected for microscopic examination (4648) is a muscovite chlorite schist, very highly sheared, in which the quartz forms bands that are practically mylonised. Besides much white mica and a little chlorite there are a few small prismatic green crystals of tourmaline, grains of iron ores and stains of limonite. Other specimens (5300-5301) are described by Dr. Flett as foliated micaceous phyllite, approaching mica schist. Although this band has a range of about half a mile, it is probably very thin and may not even be continuous. It is evidently a very argillaceous zone, and is succeeded to the south between Penpoll Mill and Roscaddon Mill[2] by the more normal sandy and argillaceous killas, the latter often in the condition of phyllite, and the former indurated, while both are highly brecciated.

Further to the south-west, along the northern banks of the stream, argillaceous beds appear which are in the condition of micaceous phyllites and of a lower grade of metamorphism than the mica schists just described that border the hornblende schist. The lower stage of crystallisation, however, is accompanied by spotting, which clearly points to contact action. Dr. Flett has described a specimen (4649) as not highly schistose but rather resembling a hornfels in structure; it is spotted with large

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[1] Its occurrence on the glebe at Manaccan was recorded by the Rev. E. Budge in 1846. *Trans. Roy. Geol. Soc. Corn.*, vol. vi., p. 288.

[2] $\frac{1}{6}$ mile E.S.E. of Manaccan Church.

tabular crystals of biotite which enclose grains of quartz, &c. The spotted phyllite is about 200 yards from the nearest outcrop of hornblende schist although the latter may approach it much closer beneath the surface.

Still further to the west, a little north-east of Tregiddris, some micaceous phyllite flanks the western margin of the hornblende schist. The rock is not seen in place, but is so abundant in the *débris* on the fields as to leave no doubt of its position there beneath the soil. Under the microscope (5267) it is seen to be an arenaceous phyllite consisting of quartz, felspar, muscovite, and chlorite. Similar schistose *débris* is seen near the northern margin of the same igneous mass at Carnbarges (¼ mile west of Landrivick). On the main road south of Tregonwell Mill there is a section of Veryan killas in contact with the hornblende schist. It is not schistose, but exhibits induration while the thin quartzose seams are passing over into quartzite. A little further to the north-east, on the main road east of Lanarth[1], some of the killas in the vicinity of the igneous band is in the condition of phyllite or mica schist. The most easterly outcrops of the igneous band is at Tregithey, and here also on the main road just south of that locality there is some typical mica schist like that of Manaccan.

It will be observed that all the exposures of mica schists are either in contact with the hornblende schist or in close proximity to it, and it would also appear that only the purer argillaceous killas assumes this habit. The spotted phyllite moreover has only been detected in the less metamorphic portion, and the conditions point to the thermal metamorphism having been accompanied by dynamic action in connection with the intrusion of the hornblende schist. It has been shown that the latter rock, unlike the normal greenstones, has been finely sheared throughout, and that at a later period it shared in the brecciation of the area. Now the question arises under what conditions could this intrusion have been so finely sheared while the older rocks of the district, like the pillow lavas and the bulk of the killas, had practically escaped this type of deformation. This can only be satisfactorily accounted for on the hypothesis that this intrusion took place while the area was still under conditions of stress and that the closely sheared structure was imparted to the rock before it had finally cooled. The development of mica schist, moreover, in the vicinity of that intrusion may be explained on the assumption that the marginal sediments were undergoing deformation while at a high temperature due to the heat given off by the igneous band.

Now, although Tregithey marks the eastern limit of the intrusion, the killas belt, extending from thence to the coast below Penare, exhibits such analogous conditions that it can scarcely be doubted that its metamorphism has been similarly induced. At Tregasso the killas shows in places a fine type of spotting. At Lestowder, on the western side of the farm steading, the argillaceous portions of the killas have mica largely developed, and

[1] 700 yards S.W. of Manaccan Church.

are in the condition of mica schist. On the roadside between the farm and the stream leading to Caermenow (Men-aver Beach), there are some banded siliceous rocks interstratified with micaceous phyllites that are almost true schists, while west of the stream the sandy beds alternate with phyllites of the same type. The fine-textured harder bands are in the condition of sheared dark grey quartzite (5306) and the coarser appear under the microscope as gritty schist or sheared greywacke containing pebbles of quartz and felspar (orthoclase and oligoclase) in a matrix of quartz, felspar, muscovite and a little biotite, iron ores, &c. (5305). On the coast below Penare the killas likewise shows perceptible alteration; much of the argillaceous material is very hard and in places presents the typical biotite spotting like that of Manaccan (6403), and some is lustrous and micaceous, in which greenish hues are beginning to appear, and are in the condition of sheared phyllites (5308, 5315). The arenaceous bands are represented by granulitic quartzites with a variable amount of felspar, and contain also much biotite, and their metamorphic condition is of an advanced type (5307, 5312, 5313, 5314, 6402).

To sum up the evidence of this metamorphic tract, it will be seen that a belt of country about four miles in length, and within a mile of the boundary of the Lizard group encloses an intrusion of hornblende schist, the foliation of which was induced before the rock had finally cooled, and that the killas lying on the line of that hornblende schist has not only been spotted as the probable result of its contact action, but has undergone dynamic metamorphism resulting in the development of phyllites, mica schists and granulites. Further, this access of crystallisation is nowhere else seen in the Veryan killas, except along its southern margin, where it is conterminous with the Lizard group as will be described later. The field evidence does not support the possibility of this metamorphic belt representing older rocks brought up by a thrust. It occupies a definite position within the Veryan group and passes into the normal killas through lower grades of metamorphism. Moreover, where it strikes the coast at Penare there is no evidence of such a major thrust, although minor fractures are abundant; on the other hand its close association there with the Veryan quartzites and cherts seems very evident.

Coast Section between Gillan Creek and Porthallow.—Before describing further the distribution of the Veryan group across the peninsula a brief account will be given of the eastern coast section. At the entrance to Gillan Creek it is represented by strong sandy beds and argillaceous strata in the latter of which are a few thin chert seams. Between the south of Gillan Harbour and Nare Head the Veryan strata are overlain unconformably by Lower Devonian deposits, although the tidal shelf at Nare Point is formed of Lower Palæozoic killas presumably belonging to this division. Midway between Nare Point and Polnare Cove a small patch of Veryan strata is seen lying irregularly beneath the Devonian beds, consisting of dark argillaceous killas largely in the condition of crush breccia, and enclosing lenticles of quartzite and limestone. The Devonian occupies the coastline to a little south of Nare Head, between which and the headland south-east of Penare the Veryan strata reappear and form the seaward limit of the Manaccan metamorphic belt already described, consisting of felspathic quartzites, siliceous schists and phyllites highly disturbed and intermixed with a considerable amount of crush breccia.

To the south-east of Penare a band of pure quartzite striking approximately north-west rises from the softer killas and forms a conspicuous feature. It is from a dozen to twenty yards in breadth, dips to the south-west, and is highly brecciated throughout, although the interstices have been infilled by secondary silica, and the rock is full of small quartz veins. It ranges in colour from white to pale grey. Its continuity to the shore is cut off by a small band of Devonian conglomerate. South of the latter the Veryan killas is highly phyllitic and disturbed, and is of the nature of a crush breccia with rude augen structure, in which lenticles and small bands of quartzite, chert, &c., are lying confusedly in an argillaceous matrix. In this vicinity also there is much faulting, which follows directions both north-west and north-east. A little beyond, in the bay, ¼ mile south-east of Penare, there are some thin bands of fine-grained dark grey quartzite and narrow calcareous seams amongst killas which is much sliced and disturbed, while the beach is also strewn with huge quartzite blocks, many showing intense brecciation.

From this point to Nelly's Cove[1] the strata consist of sandstones which are slightly calcareous, interposed between argillaceous beds highly disturbed and often brecciated but with a prevailing dip to the south or south-south-east. A few chert seams are also observed and a thin limestone appears at Snails' Creep[2]. Some of the calcareous sandstones are not far removed from limestones and crinoids can be detected in them. North of Nelly's Cove, chert bands are of rare occurrence, but in this small inlet they attain a great development, forming bands, two or three feet in thickness, made up of seams from half an inch to two inches across, and are much folded. Some dark phyllites in this cove contain pyritous bodies, and traces of spike-shaped objects that appear to be organic, and in this locality the late Mr. Charles Peach obtained fossils, one of which he described as a portion of an *Orthoceras*[3]. There is also here a small limestone part of which is much honeycombed. There is likewise a five or six feet lenticle of quartzite seen on the beach amongst killas that is highly disturbed, and another higher up the cliff.

Between Nelly's Cove and Porthallow Cove there is a mass of pillow lava associated with soda felsite, both of which have suffered a great deal from deformation, the latter especially being often intensely shattered.

The felspathic grit bands of Nelly's Cove in the vicinity of the pillow lava contain volcanic fragments of the spilite type. Such ingredients however are too sparsely represented for the identification of the tufaceous strata, except with the aid of a microscope,

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[1] ¼ mile N. of Porthallow. [2] ½ mile N. of the Mill at Porthallow.
[3] *Trans. Roy. Geol. Soc. Corn.*, vol. 9, p 55.

although their presence is of stratigraphical importance in pointing to the contemporaneous origin of the pillow lavas (5555-5556). Similar evidence has been obtained from the sediments immediately bordering the pillow lavas in their passage across the peninsula. Beyond the igneous rock there is calcareous phyllite with a few thin chert seams as well as much crush breccia, the latter also occurring below tide mark at the south of the cove. These strata are succeeded by strong sandy beds resembling those of the Portscatho group, but as bands of this type sometimes occur in the Veryan division, and they are here of limited extent, it would be hazardous to separate them from the latter. This normal type of killas is suddenly terminated by a fault hading to the south and accompanied by a well marked breccia, to the south of which mica schists occur which are included with the Lizard group.

Distribution and Field Relations.

The eastern coast section having been described it will be convenient to present briefly the general character of the Veryan group in its passage across the peninsula, reserving its marginal relations with the Lizard group for more detailed treatment.

Quartzite.—One of the most important sedimentary rocks of the group is the quartzite. Although in this area it has only in one instance yielded fossils[1] its correlation with the quartzite of Veryan and Gorran is not open to question. In those localities it occasionally contains fossils, which were first obtained many years ago by the late Charles Peach and were determined at that time as Caradoc. Later researches, however, have assigned their age to a lower position in the Ordovician sequence and they have been provisionally placed with the Llandeilo[2].

While the present strike of the Veryan band has obviously been the result of the Carboniferous movements that have so extensively deformed the Palæozoic strata of Devon and Cornwall and masked the effects of the earlier pre-Devonian stresses, there is but scanty evidence of the original strike. In the description of the Portscatho group it has been pointed out, however, that some of the more massive beds in the vicinity of Rosemullion Head strike to the north-west almost at right angles to the general trend of the major band, and it will be seen that the main quartzite of the Veryan division exhibits a similar discordance in its relation to the general trend of the killas group in which it is lying. If there is any rock likely to furnish a clue to the pre-Devonian strike it would probably be the quartzite from its resistant character. The mapping not only brings out the fact that these bands frequently strike from north to north-west, but also their tendency to be sliced and isolated in detached lenticles. It will be seen, moreover, that such lenticles considered as groups still have a strong tendency to

[1] Mr. J. H. Collins found *Orthis* (Lower Silurian) in some of the blocks removed for road making. *Trans. Roy. Geol. Soc. Corn.*, vol. x, p. 51.

[2] 'Geology of Mevagissey' (*Mem. Geol. Surv.*), 1907, pp. 4, 15, 22, 35, 36, 39.

conform to the northerly strike. It would appear that instead of bending round in response to the Carboniferous stresses in conformity with the less refractory killas amongst which they are lying, they have either been strong enough to resist such stresses altogether, or have been broken off into a line of lenticles, the individuals of which conform to the later strike, while the direction of the chain betrays the earlier trend.

The north-westerly strike of the quartzite on the coastal border south-east of Penare is most clearly shown and bands of similar trend occur at Trewarnevas. Further to the west on the eastern slopes of the Carn Valley there is a group of four lenticles which lie in a line almost north and south. In the valley still further to the west between Treworgie Mill[1] and Tregonwell Mill[2], there is a long line of quartzite lenticles closely contiguous running in a similar direction, the largest member of which, whose outcrop can be continuously traced, follows a similar trend, while the smaller lenticles apparently conform to the post-Carboniferous strike.

The small quartzites near Trenower and Carplight[3] cannot be accurately drawn as their margins are not visible. On the valley slope, however, near Colenso ($\frac{1}{2}$ mile west of St. Martin) where the quartzites project from the killas the strike (north-north-west) is clear. To the north of Tregadjack a small quarry has been opened on a quartzite band the boundaries of which, however, are not exposed although the excavation is from eight to ten yards in width. The rock contains cracks the walls of which are coated with manganese. Beyond this locality its presence is indicated only by *débris* near the margin of the group between Boscawen[4] and Bochym. In many other localities where the rock is not seen *in situ* the evidence of the *débris* points unmistakably to its occurrence, the more important instances being noted on the six-inch maps. In many cases the larger blocks have been removed from the fields and built into the hedges or broken up for road metal. A typical specimen obtained from a quarry, half a mile south of Manaccan, shows under the microscope a mosaic of small quartz grains with a limited amount of finer quartz and green chlorite between them (4652).

Cherts.—The radiolarian cherts of Mullion Island were described by Mr. Fox and Dr. Teall[5], while the investigations of Mr. Fox and Dr. Hinde[6] have still further contributed to our knowledge of these beds in the Meneage peninsula, and fresh localities have been brought to light by our recent survey of the district. Their occurrence on the east coast between Porthallow and Gillan Creek has already been alluded to. In the inland districts their presnce is usually indicated by *débris* but they have been recognised *in situ* at the following localities within the Veryan group:—on the roadside about 150 yards north of

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[1] $\frac{5}{8}$ mile S.S.W. of Manaccan. [2] Almost immediately S. of Manaccan.
[3] $\frac{1}{3}$ mile N.W. of Trenower. [4] Immediately W. of Gwealeath.
[5] *Quart. Journ. Geol. Soc.*, vol. 49, 1893, p. 211.
[6] *Journ. Roy. Inst. Corn.*, No. 40, 1895, vol. xii, pp. 34–38. *Trans. Roy. Geol. Soc. Corn.*, vol. xii, pt. i, 1895, pp. 39–70. *Trans. Roy. Geol. Soc. Corn.*, vol. xii, pt. iv, 1899, pp. 278–282.

Withan, with indistinct radiolaria (5573); in the road-cutting, 150 yards N.W. of Pengarrock Mill (Porthallow); 100 yards S.W. of Reskorwell; adjoining the mainroad at Treglossack; on the roadside at Tregidden; in the stream section west of Trethewey; in the quarries, 750 yards N.W. of Trelowarren, and at Lower Garras[1] with indistinct radiolaria (5574); in association with the brecciated pillow lava where the bridge crosses the stream below Bojorrow[2], the chert being here in the form of hard grey splinters and containing radiolaria (5205); on the roadside at Boscawen[3]; at White Cross, near the school at Cury; between Gilly and Nantirret; and on the road leading to Gwills at about 300 yards W.N.W. of that farm where it occurs in association with the Cury dolerite (5642); on the west coast between Polurrian Cove and Poldu Cove very thin chert seams form inconspicuous members of the killas group.

Besides the normal type there also occur cherty shales some of which contain radiolaria. They have been mainly observed in the western region and often closely associated with the intrusive dolerite of Cury which has effected a certain amount of contact alteration on them. They are well seen in a rock exposure 250 yards N.N.W. of Towan Cott[4], and under the microscope show rounded bodies that are probably radiolaria (5637-5638). Similar argillaceous cherts are exposed on the roadside 400 yards N.N.E. of Towan Cott (5643). On the road leading to Gwills and about 200 yards W.N.W. of that farm (5642) there is an exposure of fine cleaved shale which under the microscope shows spotting and contains rounded bodies of doubtful origin (5645). Cherty slate is likewise seen at Polurrian Cove, but a specimen that was sliced shows no traces of radiolaria.

Seams of argillaceous chert also occur at the entrance to the private road leading to Skyburriowe, amongst the schistose sediments flanking the margin of the Lizard group at this locality; the argillaceous cherts, although nearly recalling those already described and more especially those at Towan Cott, have a more metamorphic appearance, the less pure being slightly micaceous, which in the more solid and purer bands is not observed, and under the microscope do not reveal the presence of radiolaria (5275).

Radiolaria sufficiently large to be detected by the naked eye or with the assistance of a hand lens have only been observed at Mullion Island, so that elsewhere it is only with the aid of the microscope that the presence of these organisms can be ascertained. Mr. Fox and Dr. Hinde, however, have made extensive researches on the radiolarian cherts of West Cornwall, and the reader is referred to their publications already cited where the microscopic characters of these organisms are not only minutely described but have been extensively figured. The presence of these chert beds has been of great assistance in unravelling the complicated stratigraphy of the Palæozoics of West Cornwall, and the researches of those authors clearly indicated definite

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[1] ¼ mile W. of Gilly. [2] Midway between Tregadjack and Chygarkye.
[3] Immediately W. of Gwealeath. [4] ½ mile W.S.W. of Gwills.

horizons in the Ordovician killas which the mapping of the district has sustained.

Slates &c.—The main body of the Veryan group in its passage across the peninsula, that is to say, the normal killas consisting of sandy and argillaceous slate, does not require detailed treatment, and only its salient features need be presented. Between the east coast and St. Martin's Green it is frequently in a highly brecciated condition, and, as already pointed out, parts of the belt have been metamorphosed and pass over into phyllites, mica schists and granulitic quartzites. The sandy bands are most commonly represented by greywacke, and the felspathic beds are especially prominent in the district between Garras and Cury. The sandy seams contain fragments of quartz, felspar (partly plagioclase, sometimes epidotized) white mica, biotite (fresh), slate or shale, quartzite, grit, rarely calcite or dolomite, and iron oxides (5558 to 5568).

In the vicinity of Cury there are intrusions of dolerite and the killas near those masses not only shows induration, but the effects of contact alteration are seen in some of the micro-slides (5642 to 5647). A more pronounced type of spotting is observed just south of Nantirret, and amongst the *débris* immediately north of Penvories[1], both localities being almost half a mile from the nearest dolerite exposure, but an elvan passes somewhat closer. The type of spotting, however, does not resemble that brought about by the Cornish elvans, and has more probably been induced by larger igneous masses lying below the surface.

Between Cury and the west coast the killas is mainly represented by dark argillaceous beds and fine sandy silts in which cherts and cherty shales appear as already indicated, and these lithological types are represented on the coast section between Gunwalloe and Polurrian Cove, where also very thin seams of limestone can be observed.

The eastern portion of the band, as far west as Trelowarren, in spite of the severity of the stresses exhibits a prevailing south-easterly dip, but beyond that point to the west coast, the dips are in all directions and frequently transverse to the general course of the group. The coast section north of the boundary fault at Polurrian Cove as far as the northern margin of the band at Gunwalloe shows the most marked disturbance in the strata, and is crowded with small faults and contortions. The killas, however, shows no advance in the metamorphism, and not only is there an absence of the phyllites and schists of the eastern area, but the crush breccias of the latter tract are also unrepresented. The killas on this coast only represents the lower members of the Veryan division, the upper horizons containing the quartzites, pillow lavas, and the strong chert bands associated with the latter, being cut out by the Polurrian fault.

Igneous Rocks.—The Veryan Series is associated with a varied and interesting assemblage of igneous rocks containing within its boundaries not only mica trap and elvan of post-Devonian age, but more ancient intrusives represented by hornblende schist

[1] ⅓ mile E.N.E. of Nantirret.

and dolerite, and contemporaneous volcanics marked by the pillow lavas and their associated tuffs. There is, moreover, a little granophyre represented by lenticles in the crush breccias at Manaccan, but no other exposure of the rock has been observed although it is doubtless concealed in larger quantity beneath the soil, as its *débris* has been recognised in the Devonian conglomerate.

Tuffs.—Although well marked ash beds cannot be traced in the field, yet the microscope shows that the sediments associated with the pillow lava are charged with igneous fragments of that type. This has already been alluded to in the description of the eastern coast section at Nelly's Cove, and these tufaceous grits have likewise been noted at the following localities:—about 300 yards south-west of Tredower there is a fine sheared volcanic grit full of igneous material (5219). To the west of Relowas a brownish fine argillaceous grit with much detrital felspar contains also fragments of igneous material similar to the pillow lava closely adjoining, and under the microscope the rock appears as almost a tuff (5216); another volcanic grit was obtained from the same locality (5217). A fine felspathic grit with volcanic fragments was obtained 250 yards south-east of Bojorrow[1] (5281), and a volcanic grit with fragments of pillow lava, &c., about 230 yards W.N.W. of Skyburriowe.

Fossils.—Although this group has yielded few organic remains, those obtained indicate its Ordovician age. The most promising fossiliferous locality was discovered in the course of our recent survey in the parish of St. Martin, where an old quarry that was formerly used as a marl pit shows abundant brachiopod remains in a very fine-textured sandy silt. It is marked on the six-inch map (77 S.W.w.) as an old gravel pit, and lies a quarter of a mile south of Mudgeon[2]. None of the fossils can be very definitely determined, but Dr. Ivor Thomas names some of them as follows:—*Orthis calligramma* Dalm; cf. var. *Carausi* Salt; *Rafinesquina?* According to Mr. Clement Reid the enclosing rock is identical with that of Perhaver Quarry in the Gorran areas, and yields two fossils of the same type—*Orthis calligramma* and *Orthis porcata?*, fine ribbed variety. The latter Mr. Reid believes to be a new species, first yielded by the quarry at Perhaver.

The occurrence of Ordovician fossils in the Gorran tract has long been established, and as the same rock bands are represented in the Veryan group of this region, this, coupled with the fossil evidence, meagre as it is, sufficiently determines the Ordovician age. The fine silty beds containing these fossils would appear to be below the quartzite, and similar lithological types extend across the tract to the west coast, where it is hoped that in the future more characteristic fossils will be discovered. A fine sandy silt in a quarry south-west of Millewarn appears to contain small organic fragments which are, however, too obscure for determination. The fossil remains from Nelly's Cove have

[1] Midway between Tregadjack and Chygarkye.

[2] $\frac{1}{3}$ mile N.N.W. of Tregiddris.

already been alluded to, as also Mr. Collins's discovery of an Ordovician fossil in the quartzite[1]. The radiolaria in the chert beds are perhaps in themselves of no great stratigraphical value. It must be borne in mind, however, that the radiolarian cherts of Cornwall and their associated pillow lavas so closely recall the corresponding assemblage occurring at Ballantrae on the coast of Ayrshire, which are of Arenig age, as to suggest their correlation[2].

Apart, however, from this fossil evidence in the Meneage district, there can be no question that the Veryan group of this tract is a continuation of the same group in the Gorran region, the Ordovician age of which has been fully demonstrated, and the fossils of which may be of Llandeilo or even of Arenig age. The discovery of fossils at Fletchings Cove[3] by Mr. Sherborn[4] and their possible Silurian age is referred to in the Devonian Chapter. Near the head of Gillan Creek almost immediately north of Carn some fossils are seen weathering in calcareous slate but none that were observed were sufficiently well preserved for extraction. The precise locality is indicated by the 'fossiliferous' sign on the one-inch map. Mr. Fox and Dr. Teall also mention a microscopic fossil in the shale of Mullion Island which was not identified[5].

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[1] J. H. Collins, 'On the Geological Structure of the Northern Part of the Meneage Peninsula,' *Trans. Roy. Geol. Soc. Cornwall*, vol. x, 1879, p. 47.

[2] *See* 'Summary of Progress of the Geological Survey' for 1901 (*Mem. Geol. Surv.*), pp. 17–18.

[3] Due E. of Reskorwell. [4] *Geol. Mag.*, 1904, p. 289, and 1906, p. 34.

[5] *Quart. Journ. Geol. Soc.*, vol. xlix, 1893, p. 211.

In 1895 Mr. F. J. Stephens reported the discovery of graptolites in the Porthallow district (*Trans. Roy. Geol. Soc. Corn.*, vol. xii, p. 87). In the course of the survey no trace of these organisms has been detected, either by the surveyors, or by Mr. J. Pringle, who searched the Porthallow coast.

CHAPTER XIV.

IGNEOUS ROCKS IN VERYAN SERIES.

Pillow Lavas (Spilites).

The rocks of this class occupy an horizon in the Veryan Series above the quartzite, and occur between that band and the Lizard group, and at times extend to the margin of the latter. Although some of these rocks may represent intrusions they are in the main lavas; they are often highly vesicular, and their lapilli are found in the adjacent killas, showing that volcanic ash was an accompaniment of the lava flows. Their contemporaneous nature was long ago recognised by De la Beche,[1] while on the other hand, the intrusive origin of the Mylor greenstones of Porthleven was likewise pointed out by him[2]. The peculiar characters of this rock and its identification as a pillow lava were first shown by Messrs. Fox and Teall in their paper dealing with the rocks of Mullion Island[3]. In 1901 we recognised this rock on the Cornish mainland at Gorran Haven[4], while in 1904 Dr. Prior pointed out its occurrence at Tregidden, Porthallow, &c.[5]

Owing to the rocky nature of Mullion Island and the comparative absence of vegetation, it offers facilities for examination such as the bands on the mainland fail to equal. The following description is extracted from the paper by Messrs. Fox and Teall:—

"The predominant rock is of igneous origin. It is greenish, fine-grained, much jointed, and often highly decomposed. The old term 'greenstone' may be appropriately applied to it. In the mass it is separated into rude rolls by curvilinear joints. These rolls show circular or elliptical outlines in cross-section and measure from a few inches to 2 feet in diameter. Flat surfaces of this rock, such as are exposed in many places at the base of the cliff, remind one somewhat of the appearance of a lava of the *pahoehoe* type. A few spherical amygdaloids are scattered through the mass.

"Under the microscope the common type of rock is seen to consist of felspar, augite, iron ores, and secondary products, such as carbonates and chlorite, derived from these minerals. The felspar may occur as porphyritic crystals sparsely scattered through the groundmass, or as long, slender microlites forming a constituent of the groundmass. The augite occurs as small grains and microlites, and is sometimes only represented by secondary minerals. Iron ores are comparatively scarce. In structure the rock is more allied to a lava than to an intrusive mass. Small veins filled with calcite are very common.

"One somewhat exceptional variety may be described as a fine-grained, dark greenish-grey dolerite. It is composed of pale brown augite showing a strong tendency to form long, slender prisms, lath-shaped felspars, and iron ores (scarce)."

In addition to these microscopic characters of the pillow lava of Mullion Island, we may call attention to the variolitic character

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[1] 'Geological Report on Cornwall, &c.' (*Mem. Geol. Surv.*), 1839, p. 95.
[2] *Ibid*, p. 99.
[3] *Quart. Journ. Geol. Soc.*, vol. 49, 1893, p. 211.
[4] 'Summary of Progress of the Geological Survey for 1901' (*Mem. Geol. Surv.*), p. 17.
[5] *Geol. Mag.*, 1904, pp. 447–449.

which these rocks sometimes display. One specimen described by Dr. Flett exhibits tufts and radiating groups of long narrow plagioclase felspars, often arranged to form a complete star consisting of from 10 to 20 individuals, while in other cases they form divergent fan-shaped masses. Between them there lies a turbid brown material which under high power is seen to be mainly granular non-idiomorphic brownish augite, which is always moulded on the felspars. Chlorite and calcite are fairly common, and magnetite is present in small grains (3421).

As pointed out by Messrs. Fox and Teall, the pillow lava is associated with subordinate sedimentary material represented by limestone, shale, and radiolarian chert. Although the pillow lava is massive and unsheared, movement has taken place along more or less horizontal planes in which the spilite has broken down and shows a rude lamination. Those authors point out that at Tol Du, on the southern side of the island, " the rolls exhibit a tendency to elongation in a north-westerly and south-easterly direction, and there are indications of a dip towards the north-east." They also give reasons for its representing a lava flow rather than an intrusion, remarking the uniformly fine texture of the rock notwithstanding its extensive development, that the ropy structure is quite unlike that of any intrusive mass of equal size, and finally the absence of evidence of metamorphism in the sedimentary strata.

On the mainland the boundary between the Lizard group and the Veryan Series is marked by a fault between Bochym Lodge and the coast at Polurrian Cove. That fault runs approximately north-east and south-west and its seaward extension would carry it to the north of Mullion Island. Its throw has been sufficient to bring the hornblende schist into contact with the lower members of the Veryan Series, so that the quartzite and overlying horizons are missing. Beyond Bochym, however, that fault runs into the Lizard group and thereafter the boundary of the latter is conterminous with the higher bands of the Veryan Series in which the pillow lava is a conspicuous member.

The first good exposure of this rock is seen in the road cutting between Gwealeath and Trease, from which the band extends north-easterly through the farmyard at Gwealeath and south-westerly across the farmyard west of Trease. In the latter locality the rock is fresh and compact, but is brecciated; the other sections along the band are thoroughly decomposed and show signs of disturbance. In the road cutting west of Gwealeath farm a similar decomposed band is seen, while to the west of Boscawen[1] the rock is exposed sufficiently fresh but in a complete state of brecciation. These three bands are closely adjacent and doubtless represent the repetition of a single flow. They occur amongst the Veryan killas, in which chert seams are seen in the road cutting at Boscawen, but the easterly band succeeds garnetiferous mica schists of the Lizard group.

Between Gwealeath and Belossack the geology is concealed, but at the latter locality the pillow lava, brecciated and decomposed, is seen in a pit where it has been raised for marl, and it is exposed in the road cutting in a similar condition at the entrance to Belossack.

[1] Immediately W. of Gwealeath.

Its relation to the mass closely adjacent is somewhat obscure and there is a possibility that it has been shifted by a north-north-easterly fault, but whatever obscurity attends the relations at Belossack, the adjacent mass forms a continuous band, with an east and west course extending from near Belossack to beyond Bojorrow[1], a distance of two-thirds of a mile, with an average breadth of a quarter of a mile, tailing off beyond Bojorrow.

This mass is bounded by normal killas except at Skyburriowe where it is succeeded by mica schist as at Trease, but as the actual contact of the two rocks is not visible their relation cannot be determined. The pillow lava is exposed in the cutting of the high road below the entrance gate of the drive leading to Skyburriowe and is here seen to be brecciated. In the quarry, however, across the valley and near its contact with the Veryan killas, it is in the condition of a coarse crush breccia or pseudo-conglomerate, solid cores of fresh compact rock, often vesicular, which range up to six inches in size being thickly studded in a laminated or sheared matrix which is in a still finer state of brecciation. In other parts of the mass the rock is absolutely undisturbed and might be mistaken for a Tertiary basalt, as for instance, at Skyburriowe Mill where it is fresh and slightly vesicular, and an excellent section precisely similar is seen at Tregadjack.

Further east, however, at Bojorrow[2] it is in a remarkably shattered condition, and rude shear planes are developed, but this shearing which affects the rock mass does not penetrate the fragments in the breccia which show no reconstruction. A specimen of this breccia shows that the pillow lava is associated here with radiolarian chert. Under the microscope soft pale green fragments of devitrified volcanic glass (palagonite) with concave broken edges, and hard grey splinters of radiolarian chert are cemented by a matrix of calcite, chlorite, chalcedony, &c., the two latter minerals likewise filling the vesicles (5205). To the south of the pillow lava at Bojorrow, pillow lava again occurs, forming a band adjacent to the serpentine.

Between Bojorrow and Relowas the geological evidence is so obscure that the pillow lava if it occurs cannot be traced. It is seen, however, in the road cutting at Relowas in a highly brecciated condition, amongst killas that is also much disturbed, the two rocks being brecciated and intermixed. Under the microscope it consists of small, rarely idiomorphic, rounded, or irregular grains of untwinned felspar in a matrix of small felspars, epidote, &c., while in some parts the structure resembles that of a grit or crystal tuff, but this is doubtless due to crushing (5203).

A little further to the east the pillow lava makes a considerable spread to the south of St. Martin, a continuous band extending for three quarters of a mile, with a breadth near Trethewey of 350 yards. Whether the larger extent of this outcrop as compared to the small band at Relowas is altogether due to its lying at a more gentle angle is uncertain, but from the depth to which it is trenched by the valley that traverses it on the west of

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[1] Midway between Tregadjack and Chygarkye.
[2] ¼ mile E. of Tregadjack.

Trethewey it would appear to be likewise of greater thickness. This mass is on the whole very compact and undisturbed. Its southern edge, however, near Trethewey shows brecciation, and there is sometimes a rude shearing as at Barrimaylor[1]. On the west side of the stream (a quarter of a mile north-west of Trethewey) there is also some rude lamination, but it appears to bound the larger cores and may either represent flow structure, or shearing set up in the planes of weakness between the pillows. This rock is of very fine texture throughout and is sometimes vesicular. On the west of the stream, a third of a mile north-west of Trethewey, a block is seen rich in epidote and crossed by epidosite veining; although not in place it is within the boundaries of the pillow lava and is probably derived from that mass. Chert occurs close to its margin at Barrimaylor and fragments are also seen on its northern boundary below Nance[2].

From Newtown to Roskruge the pillow lava can be traced for a distance of $2\frac{1}{2}$ miles through Tregidden, Treworgie, and Higher Boden, while to the south of this main band there are small exposures of the same rock in the valley running westward from Tregidden and in the farmyard at Roskruge. The larger band which will be first described is far from uniform in structure, parts being compact and undisturbed while other portions have suffered a high degree of brecciation. In some parts of the band the rock is so extremely vesicular that there can be little doubt of its extrusive nature even if other evidence was wanting. The rock also presents a new feature that is absent in the bands described to the westward, in the occurrence of markedly porphyritic varieties.

This band has an average breadth of a quarter of a mile but contracts at Tregidden to a width of about forty yards; these fluctuations, however, are largely the result of its being partly overlain uncomformably by the Devonian sediments. The best sections are afforded by the quarries at Tregidden and Higher Boden in which the pillow or sack structure is brought out. The rock, however, varies considerably in its decomposition, being in parts fresh and compact at the surface while in other places the weathering is so advanced that it has been raised for marl in pits of considerable depth.

In the quarry at Higher Boden the rock is of very fine texture and vesicles are rare, the sack-like lenticles range from two or three feet to a few inches, and are sometimes bounded by a thin skin of argillaceous material in which sandy grains are exceptionally present. The rock is veined with quartz and calcite, the former mineral predominating. The large quarry at Tregidden on the eastern side of the valley affords a deeper section and exhibits joints hading steeply south-south-west. It is a compact rock of fine texture, showing large spheroidal bodies bounded by thin laminated material that appears to be sedimentary, and there is much calcite veining.

In the quarry on the western side of the valley there is some pale chert associated with the spilite, and the pillow structure is more perfect, but parts of the mass show brecciation. As in the quarry on the eastern side and at Higher Boden there are some

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[1] $\frac{1}{3}$ mile N.E. of Trethewey. [2] $\frac{2}{5}$ mile W.N.W. of Newtown.

shreds of laminated material that suggest films of mud incorporated by the lava in its flow over the sea bottom. Under the microscope a specimen from the eastern quarry at Tregidden is a sub-ophitic or micro-ophitic variety of dolerite, without olivine, in which pale brown augite envelops prisms of decomposed felspar. Iron ores and leucoxene are also present, and there are small rounded vesicles filled with chlorite (4643). A specimen somewhat coarser and showing calcite veining is a porphyritic, vesicular, sub-variolitic variety of spilite, and the rock is veined with calcite and chlorite; leucoxene and pyrite are abundant (4644).

On the valley slope below Treworgie there are small exposures of conglomeratic material of the nature referred to by De la Beche as 'trappean conglomerate.' It occurs in contact with the solid spilite, and although having the appearance of a palagonitic tuff, the structure has probably been the result of brecciation. The matrix is calcareous, and cements many fragments of decomposed basic glass which are usually slightly vesicular and often fluidal, and contain small decomposed phenocrysts of felspar. Their original glassy character is in most cases obvious, but some are more crystalline. Some fragments of chert also appear to be present (4646). The solid rock adjoining the breccia is an unsheared spilite, comparatively rich in plagioclase felspar, which forms small phenocrysts and occurs also in the groundmass. The ferro-magnesian minerals are represented by two generations of well-preserved nearly colourless augite. There is a rudely radiate disposition of the felspars imparting a somewhat variolitic character. Iron ores, apatite, and chlorite are also present (4642). At Tredower[1] the lava is of an extremely vesicular type, some bands closely approaching the condition of pumice, and this highly vesicular rock is also seen at Roskruge.

The western limit of this large band is exposed at the surface on the southern side of the small valley a quarter of a mile W.S.W. of Tredower where it occurs in an extremely brecciated state. The rock is not foliated although the brecciation follows a rudely parallel banding. Under the microscope its igneous structures prove to be in an excellent state of preservation. It contains augite of a pale brownish colour, still partly fresh, but not idiomorphic. The felspars are acicular and often sub-radiate, while small phenocrysts occur sparingly (5202).

The porphyritic type is seen on the main road between Roskruge and the valley below Higher Boden[2], and in a large marl pit, a quarter of a mile north-east of Roskruge, and occurs in association with the normal fine textured rock. In the latter locality the matrix of the rock is of the fine-grained compact type, but is studded with porphyritic felspars, some of which attain an inch in size. Many of the porphyritic individuals have rounded outlines, but the bulk of them are idiomorphic. These porphyritic types are clearly members of the pillow-lava series because their groundmass has all the structural peculiarities of the ordinary spilites of this region (5311). The large felspars are always decomposed.

It has already been remarked that small exposures of the pillow lava lie to the south of the band. They probably represent detached outliers. Two patches are seen along the southern bank of the valley between Tregidden Farm and Tredower, and another small band passes through the farmyard of Roskruge.

A patch of pillow lava occurs at Treglossack the southern portion of which is bounded by the Porthallow fault which here separates the Lizard

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[1] ¼ mile W. of Tregidden.

[2] This porphyritic type was recognised by Dr. Prior. *Geol. Mag.*, 1904, p. 448.

group from the killas area. This fault has possibly severed the Treglossack mass from the main band already described between Newtown and Roskruge. Chert bands are seen in close association with it on the main road at Treglossack, an association that is common to the pillow lava group of this area from Mullion Island on the west to Porthallow on the east. The Treglossack rock is of coarser texture than the normal pillow lavas. Under the microscope it is seen to be a coarsely porphyritic ophitic dolerite, with many larger phenocrysts of plagioclase felspar in an ophitic matrix of augite, plagioclase and iron oxides. The augite is partly chloritised and the large felspars are converted into sericite and zeolites, but the rock shows little evidence of dynamic alteration, the igneous structures being very perfect. The smaller felspars are fresh; the augite is very pale or colourless towards its centres but has darker brown borders (4949).

The last rock of this type to be described occurs on the coast extending north from Porthallow Cove. It is in a highly disturbed condition, and rudely sheared, but it is chiefly remarkable by its association with pale acid bands, which, under the disturbances, have broken down into a breccia, and present the appearance of a shattered quartzite. The two rocks are in contact and interfolded, and the disturbances are such that it does not appear possible to disentangle their original mutual relations. In spite of the disturbances, however, the resemblance of the basic rock to the pillow lavas of Mullion Island is sufficiently obvious, although at Porthallow there are subordinate bands of coarser texture like those just described from Treglossack. These coarser bands appear to be ophitic diabase, but the felspars are rotten, and the ferro-magnesians have been replaced by chlorite and uralite (4645).

Soda Granite Porphyry.

The acid bands associated with the pillow lava consist of granite porphyry or soda felsite. A specimen from the southern edge of the solid band at Porthallow Cove is a porphyritic rock consisting almost entirely of untwinned or polysynthetic alkali felspar; quartz and ferro-magnesians are very scarce, and there are veins of calcite. There is a parallel structure which may be due to fluxion (4951). A somewhat similar rock occurs at Perhaver in the Gorran district, close to the horizon of the pillow lavas, and has been described by Messrs. Teall and Reid[1].

Cury Dolerite.

At Cury there is an irregularly shaped mass of fine-grained dolerite passing to the north of Chymder and on its southern side skirting Gwills. Other outlying patches appear to occur to the north of White Cross, to the south-west of Trease, and to the north-east of Nanfan; but as in these three localities the field evidence is meagre we are unable to trace them with certainty, and they may even represent the pillow lava. The mass at Cury, however, is exposed in numerous sections. Although in the field the rock somewhat recalls the pillow lavas it cannot be exactly matched among the latter, and the microscopic examination fails to yield the peculiar structures of the spilites. It moreover occupies a lower horizon in the Veryan Series and the adjacent

[1] 'Geology of Mevagissey' (*Mem. Geol. Surv.*), 1907, p. 56.

shales show clear evidence of contact metamorphism. The peculiar sack-like structure of the pillow lavas is also wanting, although at one locality close to the public school spheroidal cores were noticed from 6 to 8 inches in size which might be of a similar nature.

The intrusive nature of the sheet seems sufficiently clear, and, unlike the killas which borders the pillow lavas, the sediments adjacent to this dolerite show under the microscope no evidence of the presence of volcanic ash. On the whole, looking to the remarkable preservation of the augite in this rock and to the general absence of decomposition, we may provisionally regard it as representing an intrusive phase of the pillow lava group. Under the microscope a specimen obtained 330 yards north by west of White Cross is an ophitic diabase with much fresh augite, and probably remains of olivine (5634). Others obtained 300 yards north-west of Cury Church are porphyritic diabase, with fresh augite, and comparatively little sheared (5640-5641), while another collected at Cury Vicarage is described by Dr. Flett as a very fine grained basic igneous rock, unsheared, and consisting of fresh felspar and augite (5639). It is probably the fine grained marginal facies of the dolerite.

About half a mile south-west of Tregidden a peculiar igneous rock has been opened in a small quarry, of a type of which there is no other representative in the killas area of this sheet. In the field it appears as a very felspathic rock of coarse structure which, however, varies considerably. The felspars range in size from one-sixth of an inch downwards, and besides this variation in size they are very irregularly dispersed, and are often lying in a felsitic or felspathic matrix. There is also a dark ferro-magnesian mineral that is subordinate to the felspar both as regards quantity and size of its individuals. The rock is brecciated and slightly sheared; under the microscope it is described by Dr. Flett as a highly decomposed igneous rock, probably a dolerite, and full of secondary quartz and epidote but showing remains of original felspars 2 mm. or more in diameter in a dark green matrix full of secondary products. It is massive rather than schistose, but brecciated and veined with quartz (5207).

Petrographical Characters.

Dr. Flett adds the following notes on the petrographical characters of the Veryan pillow lavas and the intrusive rocks associated with them:—

Pillow Lavas.—The Ordovician pillow lavas of South Cornwall, that occur in the Veryan Series from Mullion Island to Porthallow, have many peculiarities of microscopic structure that mark them as a well-defined and closely related group of rocks. The majority of them are fine grained, dark green rocks with small rounded steam cavities; but highly vesicular varieties also occur. On Mullion Island it may sometimes be noted that concentric rows of vesicles are disposed parallel to the surfaces of the pillows, and occasionally the sack-shaped masses have a large cavity at their centres. Epidotisation is a common secondary change in these spilites, as in the pillow lavas of Anglesey, the Lleyn, and other parts of Britain, and then the specimens appear bright green in colour. A fair number of the pillow lavas of this Sheet contain large idiomorphic phenocrysts of felspar, but in the microscopic slides these prove usually to be much decomposed.

It may be said without hesitation that the pillow lavas of this district are the least sheared and least decomposed of the pre-Carboniferous igneous rocks of Cornwall. They are often intensely brecciated, but they are very seldom sheared or foliated. Perhaps the only exception to this rule is an obscure rock, that may be sheared pillow lava, which is found to the west of Gwealeath, but its parallel structure may be due to fluxion (5767-8). None of the spilites, even when quite near the Lizard boundary shows the least sign of contact alteration. The fragments in the breccias retain the minutest details of their igneous structures. This is somewhat remarkable as the Devonian and Carboniferous pillow lavas of North Cornwall and Devon are, as a series, both more foliated and more decomposed than the Veryan lavas, though they certainly belong to a much later epoch of igneous activity.

The microstructure of these rocks is not always the same, but the commonest type may be described as sub-variolitic (Plate XII., fig. 4). The felspars are long thin rods and tend to arrange themselves in radiate groups or sheaf-like aggregates. Perfect variolites with pale spherulites of felspar have not been found among the Veryan pillow-lavas, but many of the micro-sections show a fairly close approach to that type. The pyroxenes form irregular masses that wrap round the ends of the felspars; but the structure cannot be described as ophitic as these masses consist of grains that do not build up large irregular crystals. In some slides the augite appears as feathery crystals made up of many small branches set upon a stem. The augite is often very fresh and of pale brown colour, sometimes almost colourless in thin section; and at other times it has a distinctly violet tinge. Like the felspar it occurs occasionally as idiomorphic porphyritic crystals. Olivine was either absent or very scarce as recognisable pseudomorphs after it have not been observed. The felspar belongs to a variety rich in soda, mostly oligoclase or albite, and is far less frequently in good preservation than the augite. Other minerals represented in the slides include apatite, iron ores and leucoxene, epidote, chlorite and calcite.

Although this sub-variolitic type of structure is well-known as characteristic of the pillow lava group both in Britain and on the Continent it has very seldom been observed in the pillow lavas that accompany the Devonian and Carboniferous rocks of north Cornwall and Devonshire. Hence there is no probability that the pillow lavas of this sheet belong to the Devonian.

Tuffs.—Along with the spilites in various parts of this district rocks occur that may have been palagonitic tuffs. As an example of these we may describe a specimen from Bojorrow (5205); it consists of small angular fragments of clear brown glass with irregular bands of different colours, sometimes a few spherulites and rounded steam cavities filled with secondary minerals. Though often decomposed and devitrified the glassy material is sometimes still isotropic. Small felspars are visible in some fragments but they are the only original minerals; the matrix is principally calcite and chlorite. These rocks are possibly breccias rather than tuffs, but it is interesting to note that they have been observed also in the Mevagissey area[1]. Some of the grits that occur with the pillow lavas at Porthallow and other localities contain broken felspars and occasional fragments of spilite that may possibly represent pyroclastic material.

Chemical analyses of two pillow lavas from this district have been prepared in the Survey's laboratory, and we quote them here with two others, one from the Arenig rocks of Scotland and the other from the Devonian rocks of the Plymouth area. They show a very great similarity, and prove how well defined are the chemical characters of this group of rocks. They are of basic composition with silica under 50 per cent., yet comparatively rich in alkalies. This is especially brought out by analysis III.; of the alkalies, soda greatly preponderates over potash. All the pillow lavas are much decomposed and yield a considerable amount of water at temperatures over 100° C. They also contain much carbonic acid, usually combined with lime to form calcite. The Veryan spilites have their pyroxene in a fresh condition and are, as the analyses show, not quite so much decomposed as is usual in rocks of this class.

Analyses of British Pillow Lavas.

—	I.	II.	III.	IV.
SiO_2	47·56	48·58	46·4	40·55
TiO_2	2·40	1·77	0·24	2·95
Al_2O_3	14·27	14·58	20·4	16·65
Fe_2O_3	1·63	1·89	6·9 (with FeO)	1·13
FeO	6·80	7·65		9·46
MnO	0·30	0·46	—	0·20
(CoNi)O	0·08	0·03	—	0·07
BaO	nt. fd.	nt. fd.	—	nt. fd.
CaO	10·95	9·80	7·7	6·06
MgO...	4·90	6·36	3·5	5·20
K_2O	0·27	0·43	0·54	0·27
Na_2O	4·61	4·02	6·93	4·76
Li_2O	? tr.	nt. fd.	—	—
H_2O 105° C	0·42	0·68	1·1 (with next)	0·27
H_2O above 105° C	2·65	2·93		3·89
P_2O_5	0·19	0·19	—	0·73
FeS_2	0·22	0·26	—	—
Fe_7S_8	0·05	—	—	—
CO_2	2·95	1·00	5·8	7·85
S	—	—	—	0·10
Cl	—	—	—	nt. fd.
Total	100·25	100·63	99·51	100·14

I. Spilite (Ordovician), Tregidden, Cornwall (5791); anal. E. G. Radley.
II. " " Mullion Island, Cornwall (6391); anal. W. Pollard.
III. " " Gatelochside Burn, Scotland; anal. J. J. H. Teall, 'The Silurian Rocks of Britain; vol. I., Scotland' (*Mem. Geol. Surv.*), 1899, p. 85.
IV. Spilite (Devonian), Devonport Workhouse Quarry (E. 4947); anal. E. G. Radley, 'The Geology of the Country around Plymouth and Liskeard' (*Mem. Geol. Surv.*), 1907, p. 97.

[1] 'Geology of Mevagissey,' (*Mem. Geol. Surv.*), 1907, p. 54.

Dolerites.—At many places along the Veryan zone other rocks occur that are more coarsely crystalline and probably represent intrusive sills derived from the spilite magma. They, too, are seldom sheared, and never really metamorphic, but their igneous minerals and structures are in remarkably good preservation. The Cury dolerite is typical of this class, and Mr. Hill has obtained field evidence of its intrusive character; other examples come from Treglossack (4649) and Gallentreath, north of Porthallow (4645). Very similar dolerites are known to occur as intrusive facies of the pillow lava series in North Cornwall.

These dolerites are of ophitic structure with large irregular crystals of pale-brown augite enclosing lath-shaped plagioclase felspar. The augite is mostly fresh; the felspar is often decomposed with production of albite, prehnite, calcite and epidote, but where best preserved has a zonal structure and varies in composition from labradorite to oligoclase. Olivine was probably originally present though now weathered to serpentine, but it was not abundant. The other minerals of these rocks are apatite and iron ores.

Epidiorites, Uralitic Diabases.—There are also a few coarse-grained basic rocks of the diabase type which have been so much crushed and altered that their augite is replaced by hornblende and their igneous structure more or less effaced. It is not certain that they belong to the Veryan eruptive rocks, though hornblendic diabases (minverites) are known to assompany the spilites in north Cornwall. Examples of these epidiorites occur in the bank east of the inn at Porthallow, where perhaps they have been brought into their present position by the fault between the Lizard and the Palæozoic rocks (5152 and 5195). Another rock of this type is found south of Bojorrow (the farm south-west of Chygarkye) in contact with the serpentine (5206). The peculiar epidiorite of Tredower[1] (5207) previously alluded to, contains hornblende, but is much brecciated, veined with quartz, and filled with secondary epidote; the alteration is so complete that it is impossible to say to what class it originally belonged. Although they are unlike the Veryan dolerites, these rocks differ still more from the thoroughly metamorphic hornblende schists of the Lizard.

Soda Granite Porphyry.—The 'soda felsite' (soda granite porphyry) which appears among the pillow lavas in the north corner of Porthallow Cove is one of the most interesting rocks of this Sheet, and is undoubtedly intrusive. In hand specimens it is white or grey and reveals little of its minute structure, being rather like a compact quartzite. In microscopic section (Plate XII., fig. 6) the rock is by no means uniform in character, some specimens (probably from the margin of the intrusion) having a fine cryptocrystalline groundmass while in others the matrix is coarser and consists of alkali felspars and quartz. In all cases it is porphyritic and the principal phenocrysts are alkali felspar, mostly albite with complex twinning; orthoclase, or at least untwinned alkali felspar, occurs also, and in the marginal varieties there are rounded crystals of quartz. No ferromagnesian minerals are preserved in this rock, but there are pseudomorphs of chlorite that may have replaced biotite. Iron ores and apatite are the principal accessories. The groundmass is often an aggregate of

[1] ½ mile S.W. of Tregidden.

small nearly rectangular crystals of clear albite, with subordinate quartz. The rock has suffered much crushing and brecciation, and is veined with quartz and carbonates, but there is little granulitisation.

The close relations of this rock to the pillow lavas in the field have been pointed out, but in a petrographical sense it is also closely connected with the spilite magma. In various parts of Britain soda felsites and soda granites occur in this association; thus, at Gorran and in the Ordovician volcanic rocks of Scotland, there are keratophyres which are rich in albite, but contain no quartz and a good deal of chlorite. In Devon there are quartz keratophyres among the spilites. The closest parallel to this rock, however, is found in Argyllshire, where a soda granite porphyry occurs as an intrusive sill penetrating the pillow lavas on the coast about three miles south-west of Tayvallich[1].

An analysis of the Porthallow rock has been made in the Survey's laboratory, and with it we quote for comparison analyses of the similar rock from Argyllshire and of the keratophyre from the Gorran District. The abundance of soda and scarcity of potash in these three analyses are very striking. The Porthallow rock must contain about 53 per cent. of albite and 10 per cent. of orthoclase. The keratophyre has much more chlorite and iron ores than the other two, which must have been very poor in ferromagnesian minerals. In these rocks the tendency of the spilite magma to give rise to facies very rich in albite is exceedingly well exemplified.

Analyses of Soda Granites and Keratophyre.

—	I.	II.	III.
SiO_2	65·67	72·51	66·05
TiO_2	0·19	0·31	0·49
Al_2O_3	13·72	13·10	13·29
Fe_2O_3	0·50	2·81	3·22
FeO	1·17	0·90	5·07
MnO	0·13	0·20	tr.
(CoNi)O	0·02	nt. fd.	—
BaO	0·04	nt. fd.	—
CaO	3·21	1·84	0·50
MgO	1·52	0·20	1·36
K_2O	1·68	0·33	0·87
Na_2O	6·26	6·76	6·67
Li_2O	tr.	nt. fd.	—
H_2O 105° C	0·28	0·04	0·96
H_2O above 105° C	0·84	0·35	1·88
P_2O_5	0·09	0·06	0·09
FeS_2	0·03	nt. fd.	tr.
CO_2	4·86	0·76	—
Total	100·21	100·17	100·45

I. Soda Granite Porphyry, Gallentreath, Porthallow (E. 6377); anal. E. G. Radley.

II. Soda Granite Porphyry, 4 miles S.S.W. of Tayvallich, Argyllshire (S. 13221); anal. E. G. Radley.

III. Keratophyre, Trevennen, Gorran, Cornwall (E. 4372); anal. W. Pollard.

[1] 'The Geology of Knapdale, Jura and North Kintyre' (*Mem. Geol. Surv.*), 1911, p. 94.

CHAPTER XV.

IGNEOUS ROCKS IN MYLOR SERIES.

Greenstones.

The greenstones are represented in a belt of country about four miles in length and a mile in width extending from the vicinity of Trewennack, near the margin of the Carnmenellis granite, in a south-westerly direction through Helston to the coast at Porthleven. Within this narrow tract these rocks are very abundant, while beyond it there are two exposures about a third of a mile north-east of Breage and rather over a quarter of a mile from the margin of the Godolphin granite. They all occur within the Mylor Series through which they have been intruded as sills, but as they have shared in the Carboniferous crustal movements they have often been reduplicated by folding, and the numerous outcrops[1] must be greatly in excess of the individual sills that were injected into these strata.

These rocks all fall within the epidiorite group and, as pointed out long ago by Messrs. Allport and Phillips[2], were originally dolerites or basalts, in which the primary augite has been replaced by hornblende. As will be seen later, however, they also include types of intermediate composition that originally approached the porphyrites.

The greenstone belt is truncated on the north-east by the Carnmenellis granite. Beyond the latter boss, however, between Penryn and Flushing (in the Sheet to the north) the greenstone sills reappear on the same geological horizon and with similar petrological characters. In both areas along this horizon there is a marked preponderance of highly felspathic or andesitic types, while the more basic representatives corresponding to dolerites are confined to lower horizons in the Mylor sequence.

Where they occur in the neighbourhood of the granite these rocks have suffered thermal metamorphism. The great bulk of the sills extending from Helston to Porthleven, however, are sufficiently distant from the granite intrusions to have escaped modification from this source; many of them have porphyritic felspar with its idiomorphic shapes remarkably well preserved, but frequently fractured and bent, although some of the crystals are very small, slender laths. The original augite, however, has probably all disappeared. Even the larger macroscopic spheroidal structures, &c., assumed by the rock on cooling are still preserved, and many may be seen on the shore to the south of Porthleven. In the neighbourhood of the granite, however, the contact alteration has been more complete, and biotite and more rarely augite are frequently developed.

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[1] Both at Porthleven and at Helston they are too numerous to be shown on the 1 inch map.

[2] *Quart. Journ. Geol. Soc.*, vol. xxxii., 1876, pp. 155 and 407, and vol. xxxiv., 1878, p. 471.

The greenstones of this area are intrusive but have effected only a very limited amount of contact action on the killas, as may be seen on the coast at Porthleven. They vary considerably in size and are frequently represented by thin sills only a few feet in thickness and often closely contiguous. It is exceptional for these rocks to show much foliation as the result of shearing or to exhibit structures in any way analogous to a normal schist. Many of them, indeed, scarcely show the most rudimentary parallel structures or even granulitisation. In nearly all cases felspar is the porphyritic constituent, but the rock is often of a fine even texture and non-porphyritic.

They are distinguished by a great readiness to decompose and often weather into earthy substances of bright yellow and brown hues. Frequently this extremely decomposed rock is in contact with rock perfectly fresh which retains its compactness up to the margin of the greenstone. Instances of this may be seen in the railway cutting close to Helston Station. The masses nearer the granites that have been subjected to thermal metamorphism have offered greater resistance to disintegration.

With these few general remarks on the dominant characters of the group we may now refer briefly to their local distribution and field relationships. At the north-east portion of the belt a large and compact sill follows a course about east-north-east through the village of Trewennack where it is seen within a quarter of a mile of the Carnmenellis granite and its prolongation, where it can be traced by its *débris* in the fields, still more closely approaches that mass. This greenstone is a compact rock full of bands and veins of paler material, in some places these streaks preponderate over the darker fine-textured bands which separate them, and in parts the banding is so close and pronounced as to impart a laminated structure to the rock. This mass although its boundaries cannot be accurately delineated is probably from sixty to seventy yards in width. Its westerly course beyond Trewennack is obscured by the cultivated nature of the ground, but between Trewennack and the west of Helston Railway Station it is probably represented by some of the greenstone exposures whose presence can still be detected notwithstanding the unsatisfactory nature of the evidence. Under the microscope, a specimen of this rock from Trewennack is seen to contain a large amount of pale green or colourless augite, and pale yellow epidote, minerals which do not participate in the foliation, being the result of contact alteration. The rock also contains granular sphene and brown isotropic grains which Dr. Flett considers to be probably zinc-blende (4641).

Nearly half a mile to the south-east of Trewennack a quarry has been opened on greenstone that is hading at a low angle to the south-east between coarsely knotted Mylor slates. This greenstone appears to be represented by at least three bands, of which the southern is the largest, being about twenty feet in thickness; it appears to contract, however, in a lenticular form, and is divided from the adjacent band by about twelve feet of slate. It is a fairly fresh rock of fine texture with greenish epidotic veins, and closely resembles the mass at Trewennack; it is veined by bands of paler and coarser-textured material, while one of the smaller bands is of much more acid composition. The three bands, however, in such close proximity very probably represent parts of a single intrusion.

At Crasken, about three quarters of a mile south-west of Trewennack, a greenstone about ten feet in thickness has been quarried, with a similar low hade to the south-east between slightly spotted Mylor slates. This is also a fine-textured rock which weathers with buff hues.

Between Trewennack and the Great Western Railway at Helston, as already remarked, these rocks although undoubtedly present cannot be satisfactorily traced. The cutting, however, near Helston Station reveals no fewer than eight of these bands within the distance of 250 yards, the presence of which before the building of the railway could only have been indicated by the *débris* in the soil, while the number and extent of the various bands could not have been ascertained. If such a section could have been continued across the entire width of the greenstone belt it cannot be doubted that many such bands would be exposed over this tract of fertile country where sections are practically absent.

The bands in the railway cutting occur amongst Mylor slates towards the outer part of the metamorphic aureole in which the alteration has been slight and knotting more feeble than in the inner zones. The igneous bands vary from five or six feet to as much as twenty yards in breadth. They are all fairly uniform being fine-grained greenstones of basaltic texture and not conspicuously sheared. As already mentioned they vary considerably in decomposition, some being fresh and compact, while others have largely weathered to a bright ochreous powder. In the most western sill the latter material encloses cores of the still solid rock, while in the adjacent intrusion there is a sharp junction between the compact unweathered and adjoining decomposed material.

Between the railway and the town of Helston the rock sections are again concealed, but the lower part of the town forming the steep slope of the Cober Valley affords good rock sections where small greenstone bands are visible.

On the south-eastern outskirts of Helston large quarries have been opened in bands of this rock of the more felspathic types previously alluded to, which appear to mark the upper limits of the belt. At the Beacon, for instance, there is an old quarry in which a highly felspathic greenstone of doleritic texture is seen for a width of fifteen to twenty yards, but the band cannot be traced as the ground is under pasture. A similar rock, but mainly of coarser texture is seen in the large quarry adjoining the Union workhouse. This rock as exposed in the quarry is from sixty to seventy yards in width, but it divides into at least three bands which are irregularly mixed with knotted slate, and both rocks are evidently undulating so that the thickness has been exaggerated. This band has been extensively used in the building of Helston, but the rock at present visible in the quarry is soft and decomposing. Although an inferior building stone, the ease with which it dresses has probably proved a sufficient inducement to work it.

The pit, now covered in and grassed over, adjoining the high road a quarter of a mile to the north-east, probably represents the continuation of this band in one direction, while the quarry a third of a mile to the south-west may also be on the same band in the opposite direction. The latter rock, however, does not appear to be more than about ten feet thick and hades at a low angle to the south-east between knotted Mylor slates. It is of a similar type to the felspathic greenstones already described, has commenced to decompose, and the shearing as seen in the field is but rudimentary. Towards the south-west it contracts, and may even tail out altogether.

Further to the south-west, on the eastern edge of the Loe Valley, there is another greenstone band that has been quarried to the south of Castle Wary. It is fine-textured and very felspathic, and the foliation is not of an advanced type. Between the Loe Valley and Porthleven these rocks are rarely exposed at the surface, but from the large number that appear on the coast at Porthleven this is evidently due to the high state of cultivation and the absence of rock sections, and it is certain that between those areas the bands traced on the map inadequately represent those intrusions.

At Parkventon, a little north-east of Weeth, there appear to be two broad bands of greenstone divided by slate which is so narrow as to suggest that the igneous bands represent a single intrusion repeated by folding. Part of this greenstone is very felspathic, but in the quarry adjoining the high road it is of fine texture, and not so felspathic as in other parts, nor is it highly sheared, while the adjacent killas shows an incipient stage of spotting. A little further north, close to the site of St. John's Hospital, there is a band of fine-textured felspathic greenstone, but only about six feet wide, while on the roadside, about 250 yards further to the north, another narrow sill is exposed.

About a quarter of a mile further north a broad band has been quarried of the fine-textured compact type similar to those seen near Helston Station, and apparently on the same horizon. At Lanner Vean a small band, about six to eight feet in width, of very decomposing fine-textured greenstone is seen in the farmyard in which, however, small felspars in great profusion stand out quite conspicuously from the weathered matrix. About a quarter of a mile south-south-west of Ventonvedna a quarry has been opened in a fine-textured band which is practically unsheared; in parts, however, the rock contains porphyritic felspars similar to those at Porthleven. It is very irregularly disposed with regard to the killas, some of which shows clearly the effects of contact metamorphism. At Penrose Hill a quarry has been opened in a greenstone which is much decomposed.

Greenstones of Porthleven.—The coast sections on either side of Porthleven extending for a mile from Tregear Point to Porthleven Sands dissect the entire width of the greenstone belt where these rocks are clearly displayed amongst the killas which contains them.

The most westerly sill of this group is a tiny band seen on the coast west of Methleigh Beacon; it is only a few feet thick and its continuity is severed by the disturbances which are here so marked a feature of the Mylor killas. The intensity of the movements has set its mark on this small band in the shearing which it has undergone, which is more advanced than in any other band of the assemblage; it does not, however, show such a uniform and consistent state of foliation as the hornblende schists of the Veryan group near Manaccan that are described in another chapter. Not only has this greenstone shared in the intense stresses that have affected this part of the coast, but it is also more ancient than the quartz veining with which the killas is here abundantly traversed. About forty yards further to the south-east a lenticle of greenstone about six to eight feet thick is seen to tail out seaward but reappears as a thin band along the foreshore, while forty yards distant another band similar to the last, compact, sheared, and of very fine texture is only separated from another small band one or two feet in thickness by about ten feet of killas. The strata are so highly disturbed that these outcrops probably represent different portions of a single lenticle. One of these bands can be traced for a quarter of a mile inland occupying a wide outcrop across Methleigh Beacon following a north-north-east direction, and has been quarried; it appears to be a lenticle sharply tailing off at either end.

On the western shores of Porthleven Harbour the killas for about three hundred yards is so closely divided by greenstone bands that only the most important can be laid down on the six-inch map. The killas is here less metamorphosed and disturbed than at Tregear Point, and the greenstone bands show but small traces of shearing. It is a fine-grained compact rock with a vesicular appearance, but this is probably due to the weathering of some of its minerals (presumably the felspars) rather than to an original vesicular structure. Some of these bands are fifteen to twenty yards wide but they are usually very much smaller and their breadth is very irregular; one sill contracts from about four feet to a few inches in about twenty yards. In places the killas and greenstones are so irregularly intermixed as to be practically inseparable. The evidence suggests that one or more intrusions of variable thickness have been injected as sills along the bedding planes and subsequently have been folded and displaced by small faults. Although the greenstone closely conforms to the bedding planes of the killas yet a critical examination reveals that it sometimes slightly truncates the strata. Moreover, the killas on either side of the sills is sometimes indurated and bleached for a few inches from the margin.

On the east side of Porthleven Harbour a greenstone about eight feet wide is seen traversing the killas on the east of the breakwater. It is a fine-textured rock similar to the greenstone west of the harbour, in which the original cooling structures are preserved in a well-marked transverse platy cleavage, while the marginal phenomena clearly point to its intrusive nature, and it is flanked by another sill with spheroidal weathering. The irregularity of these bands is well seen on the eastern side of the pier, where a sill about ten feet wide near the cliff contracts within a short distance to two feet, while further seaward it again widens to about a dozen yards. A band still further east is very irregular, with an average width of ten or twelve yards, often sending branches or infolds into the killas. The strata are much less disturbed than to the west of Porthleven, and this band retains its original structures together with a coarse spheroidal weathering.

Only a few yards east of this sill another band occurs, but instead of the fine-textured basaltic-looking greenstones that we have been hitherto dealing with, this rock is of the felspathic type already described from the neighbourhood of Helston. It is highly charged with porphyritic felspars, many of which are perfectly idiomorphic, although sometimes these crystals are rounded and often bent; some are stumpy forms about a square inch in size, but most of them are elongated. They are crossed by numerous fractures but suffer little distortion notwithstanding that the majority are delicate lath-shaped crystals. This rock is so rich in felspar as to be distinct from the basic greenstones. Numerous sills of this type occur along the shore. About 600 yards south-east of the pier there is a much larger mass, having a breadth of about forty yards. This rock, however, is of variable composition, being in parts highly felspathic and in others of the normal greenstone type. The more acid portions, rich in felspar, contain idiomorphic felspars up to an inch in length.

Besides this belt of greenstones extending from Trewennack to Porthleven there is another band that has been quarried to the north-east of Breage, and within a third of a mile of the margin of the Godolphin granite. It is of fine texture and contains much biotite, the result of contact metamorphism by the granite. Under the microscope (3915) fibrous actinolite is seen to form clusters and bundles in a fine granulitic matrix. Besides brown biotite there are iron ores passing into sphene and apatite.

CHAPTER XVI.

MANACCAN HORNBLENDE SCHIST AND GRANOPHYRE.

Manaccan Hornblende Schist.

The rocks to be described under this heading occupy a belt in the Veryan Series, immediately south of Manaccan, of about three miles in extent ranging from Gillan Creek on the east to St. Martin's Green on the west. Their geological horizon in the Veryan division is below the main quartzite band, with which however, they are sometimes in contact. Unlike the Mylor greenstones which form a series of elongated and parallel sills, with a maximum width of 60 or 70 yards, these hornblende schists have broad outcrops of rudely lenticular shapes, that suggest a considerable thickness. It is possible, however, that the folding in the Veryan Series may be of a shallower type than in the Mylor group, and that the Veryan division may, therefore, be in a general sense somewhat flatter, but after making due allowance for this contingency there is no escape from the conclusion that this hornblende schist is considerably thicker than the Mylor greenstones. While the latter, moreover, in spite of obvious repetition as the result of folding, represent several intrusions in which the sills are often closely adjacent, and many of them only a few yards or even feet in thickness, the Manaccan belt more probably represents a single intrusion which denudation has but partially laid bare, so that instead of forming a continuous band at the surface, it occurs as a line of rude lenticles separated from each other by killas. In spite, however, of their continuity being broken the surface outcrops of this rock occupy at least two-thirds of the belt.

The largest mass is situated in the centre and is about a mile and a quarter in length, with a maximum breadth of about one-third of a mile. It crosses the burn a little south of Tregonwell Mill[1] and extends in a west-south-west direction through Crowns[2] skirting Choon and Tregonwell[3] on the north side and Trelowry[4] on the south side. About 300 yards further to the westward a smaller outcrop nearly half-a-mile in length and rather less than a quarter of a mile in width lies immediately south-west of Landrivick. About a third of a mile further west a small patch is seen at Henforth, to the north of St. Martin's Green, and two others occur a little to the north-west of Landrivick.

The large mass south of Tregonwell Mill appears to tail out in its course towards Gillan Creek, but after a space of about a quarter of a mile in which this rock is missing it is again seen

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[1] 330 yards S.S.W. of Manaccan Church.
[2] 1,500 yards S.W. of Manaccan Church.
[3] ½ mile S.W. of Manaccan Church.
[4] ⅔ mile S.S.W. of Manaccan Church.

at the head of that creek where it skirts its northern bank, while about 250 yards further east another smaller patch is seen on the same shore. This rock is not exposed along the southern coast of the creek, but is seen at a short distance beyond it below Tregithey. There are reasons for supposing that this hornblende schist underlies the killas between Tregithey and the coast east of Penare, but as the evidence in support of this is given in the description of the Veryan Series (p. 168) it need not be repeated.

This rock differs from the Mylor greenstones in being thoroughly sheared throughout, and in the absence of porphyritic felspars. The foliation is of a very fine type, in which the planes of lamination are almost as close as in the slates, but is unaccompanied by the banded structures which are such common features in the hornblende schists of the Lizard group, neither does it exhibit the advanced type of crystallisation of the latter. It is true that so far as absence of banding and the low state of crystallisation are concerned that it resembles certain types in the Lizard group and more especially rocks seen on the road-side to the south of Pengarrock Mill at Porthallow, but in spite of this Dr. Flett is of opinion that the Gillan Creek type is not represented in the hornblende schists of the Lizard area. The rock therefore would appear to occupy an intermediate position between the Cornish greenstones and the Lizard hornblende schists. The Palæozoic greenstones are themselves frequently sheared, but their foliation is a subordinate structure and is generally confined to very thin seams or to marginal portions of the larger bands. In this hornblende schist, on the other hand, the foliation is the dominant structure of the rock, and its absence is exceptional.

The tectonics of the Veryan Series are marked by an extensive belt of brecciation, and as the hornblende schist lies within that zone of disturbance it is either represented by a crush breccia, or when not broken down has suffered a more minute degree of brecciation that is seen in the microscopic sections, but in this respect it does not differ from the sedimentary members of the Veryan group. As the brecciation, however, has been later than the foliation of the rock, the best specimens for microscopic examination are those obtained from the larger pieces of the crush breccias, as the hornblende schist which has not broken down has been generally sufficiently affected by the stresses to have been crushed interstitially, although the field exposures may not betray it.

In spite of the large areas occupied by this rock, exposures are comparatively rare in which it is sufficiently fresh to be satisfactorily studied. One of the best is that dissected by the head waters of Gillan Creek. Besides being laid bare by the coastal margin and the road sections along that estuary, it projects from the soil on the steep slope close to the mill. This mass is in the very heart of the crush belt and forms a crush breccia in which the finely schistose fragments are lying at all angles, but within the central portion of the mass two small bands are preserved, that not only have escaped brecciation, but in which the characteristic foliation is likewise absent and the rock exhibits the normal habit of an ophitic greenstone. This is the only instance in which the fine lamination is wanting, and it is probably owing to its absence that the rock has here been enabled to resist brecciation. These two bands are only a few feet thick and occur on the north shore of Gillan Creek to the south-east of Penpoll[1]. Under the microscope they are seen to be slightly sheared uralitic diabase, in which while the augite is completely uralitised the felspars are partly fresh (5263-4).

Specimens obtained from the brecciated rock in a quarry a quarter of a mile north-west of Landrivick (5257 to 5260) are described by Dr. Flett as sheared greenstone approaching hornblende schist, fairly well foliated but less crystalline than the typical Lizard schists. They contain many small, irregular crystals and frayed needles of pale green to colourless hornblende in a streaky matrix of finely granular quartz, felspar, epidote, iron oxides, chlorite, &c., while the rock is veined with carbonates and epidote. The finer matrix between the rock fragments contains more epidote and less hornblende than in the larger individuals. The rock on Gillan Creek north-east of the mill, contains fragments similar to the last, but more sheared and less crystalline (5261-2).

The large mass to the south of Manaccan is exposed in a solid and fresh condition at the surface at the mouth of a small valley where it has been quarried[2]. The rock is here a breccia in which some of the fragments are thoroughly foliated, with lamination of the same perfect parallelism as is so often seen in the Lizard hornblende schists. A specimen from that quarry shows under the microscope much decomposition, and is finely schistose with granular epidote and small prisms of hornblende (5317). This mass in its westerly course is usually highly decomposed as may be seen at Trelowry[3] where the brecciation is absent or feebly represented and the rock exhibits sections of fine schists so weathered that a fresh specimen cannot be obtained.

To the north-west of Carplight[4] the solid rock is exposed on the western side of the valley, and a quarry has been opened in it. In the quarry the hornblende schist is solid throughout, and there are bands in which the texture is coarser, and brecciation on a small scale is also developed in other seams. Under the microscope the specimens are seen to have a flaser structure without being true schists. They are full of epidote and chlorite, and what appear to be phenocrysts lie in a finer, partly granulitic matrix (5246-7-8). The rock from the quarry therefore is a sheared diabase or diabase porphyrite, but a specimen obtained about 120 yards further to the south-west between the quarry and the ford (5246) contains fine acicular hornblende, in addition to felspar, quartz, epidote, and chlorite. It is sheared and moderately well foliated, but not highly crystalline, and Dr. Flett observes that it is not one of the typical hornblende schists.

The most easterly outcrop occurs at Tregithey, where the rock is a fine grained hornblende schist of thoroughly metamorphic

[1] A ruin a quarter of a mile E. of Roscaddon.
[2] 630 yards S.S.W. of Manaccan Church.
[3] $\frac{1}{4}$ mile N. of Trevaddra. [4] $\frac{1}{5}$ mile N.W. of Trenower.

type (6401) with a more advanced degree of foliation than has been recognised in the exposures elsewhere.

The relations of this hornblende schist to the Veryan group are more fully treated in the chapter dealing with that division of the Ordovician sequence.

Granophyre of Manaccan.

In the deep road cutting immediately south of the village of Manaccan a fine grained reddish rock is seen in association with killas, but as the whole mass, both igneous and sedimentary, has been reduced to a breccia its original form and relations are lost. In all probability however it represents but a small sill or dyke in the Veryan Series. Its pre-Devonian age is clear from the presence of precisely similar fragments in the Devonian conglomerate. Dr. Flett describes its petrographical characters as follows: —

This granophyre is in some ways a remarkable rock. In hand specimens it is fine-grained, pinkish and very compact, looking like a fine felspathic quartzite, but under the microscope (6302) it proves to be the most beautiful example of its class that has yet been found in Cornwall. Practically the whole rock consists of rather coarse micropegmatite (Plate XII., Fig. 5) with angular patches of brightly polarising quartz embedded in a matrix of fresh felspar that gives pale grey polarisation colours. In some parts the graphic intergrowth is rather coarse, in others excessively fine, and the micropegmatite has often a tendency to divide into sectors of wedge-shaped form as the slide is rotated between crossed nicols. There are no phenocrysts, but sometimes grains of felspar, comparatively free from quartz, can be detected in the slides, and represent probably the earliest crystallisation. Some of the later elvans have graphic structure, but never in such perfection as this rock. It is certainly, for reasons which Mr. Hill has stated above, a pre-Devonian rock, but though intensely brecciated its minute structure is quite unaffected by the crushing which it has undergone.

CHAPTER XVII

DEVONIAN ROCKS.

MANACCAN SERIES.

Between the Lower Palæozoic sequence, the top of which is marked by the Veryan Series and the rocks now to be described, there is a great break represented by a considerable unconformity. The fossil evidence unmistakably points to the Ordovician age of the Veryan Series, which is probably Arenig. Between this group and the Lower Devonian the only strata that are represented in Cornwall consist of Wenlock or Ludlow rocks that occur at Porthluney[1] in faulted association with the Veryan group. In this area Mr. Sherborn discovered in the black slates of Fletching's Cove, to the north of Porthallow, an impression which he identified as a fragment of *Serpulites longissimus* J. de C. Sow, of Ludlow age[2], also a pyritised *Orthoceras*[3]. Although a careful examination of the coast section north of Porthallow reveals no trace of strata showing lithological distinctions from those of the Veryan group, yet with the evidence at Porthluney it is possible that Upper Silurian strata may be represented in this area. If such is the case, it probably points to an unconformity between the Silurian and Ordovician rocks of West Cornwall, and in this connection the recent discovery by Mr. Dixon of a similar unconformity in the Pembroke district of South Wales is suggestive, where in the valley opening on Freshwater East, Wenlow-Ludlow rocks are resting unconformably on Arenig strata[4]. This area, however, has yielded insufficient evidence for the question to be profitably discussed, and the relation of the Silurian to the Ordovician rocks of Cornwall is one of many problems in the complicated structure of the county that yet remain to be solved.

The relation of the Devonian to the Ordovician strata presents, however, no such ambiguity, and although the lack of a correct solution of this problem has remained a stumbling block to the interpretation of the geology of West Cornwall since the original survey of De la Beche, the recent survey of the area has resulted in this question being satisfactorily settled, and the Geological Survey maps of West Cornwall clearly define the relation and boundaries between the Devonian and Ordovician strata. The researches of former observers have in some instances foreshadowed the direction from which such solution would ultimately come. In this connection we would refer to the work of Mr. J. H. Collins, who has made strenuous efforts extending over many years to elucidate Cornish stratigraphy, and one of his papers in which he correlated the conglomeratic series of Meneage with the Ladock Beds, and assigned both to the Lower Devonian is of particular significance[5]. Subsequently

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[1] 'Geology of Mevagissey' (*Mem. Geol. Surv.*), 1907, pp. 21–27, by C. Reid.
[2] *Geol. Mag.*, 1904, p. 289. [3] *Geol. Mag.*, 1906, p. 34.
[4] 'Summary of Progress of the Geological Survey for 1907,' p. 40.
[5] *Journ. Roy. Inst. Cornwall*, vol. viii., p. 186.

Mr. Ussher in 1891[1] published a map with his paper dealing with the Devonian rocks as described by De la Beche, in which he placed the Grampound Grits at the base of the series classed as undoubted Devonian, and coloured the killas south of that horizon as (?) pre-Devonian.

The Devonian rocks of this area which are referred to as the Manaccan Series are represented by discontinuous bands or outliers extending from Nare Point on the east to Gunwalloe on the west. Lithologically, the group consists of conglomerate, sandstone and clay-slate, the two latter being often calcareous, and they are all so clearly interbedded that their natural sequence is obvious. The coarser conglomerate is confined to the east coast, but even there is only of local distribution and the base of the formation is sometimes of fine texture. There is, moreover, a tendency for the coarser deposits to die out in a westerly direction as was long ago recorded by De la Beche[2], so that there is often a difficulty in the absence of good sections in demarcating the beds of this formation from those of the underlying Ordovician, and it is probable that the Devonian formation may have a greater development than has been represented on the map, especially in the inland tract between Trelowarren and Gunwalloe. On the other hand the sketch map which accompanied our paper[3] dealing with this important unconformity before the area had been fully investigated shows too wide a development of this band. In that publication the pillow lava that occurs between Roskruge and Tregidden was referred to as of Devonian age. The extension of our recent survey does not confirm that suggestion and we are inclined to ascribe the phenomena that gave rise to it to the extensive brecciation of the district which has often produced pseudo-conglomerates so rounded in character as to be almost indistinguishable from the basal Devonian deposit.

The Manaccan Series rests indiscriminately on the several members of the Veryan group within the limits of which it is principally restricted, but is likewise seen on the Portscatho group, and in one instance at Gunwalloe Fishing Cove in juxtaposition with the boundary of the Falmouth group, but as it is nowhere found resting on the Mylor group either in this area or the Sheet to the north (352) the presumption is that at the time of its deposition that division was not exposed at the surface, and this is one of the principal reasons for the assumption that the Mylor group represents the base of the Lower Palæozoic sequence.

The clearest exposure of the Manaccan Series occurs in the coastal tract between Gillan Creek and Nare Head, in which not only is there a wide development of the coarse conglomerate, but the other members of the group are also represented and their relations to one another are admirably seen. The most important member of the group is undoubtedly the conglomerate

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[1] *Trans. Roy. Geol. Soc. Corn.*, vol. xi., p. 173.

[2] 'Report on the Geology of Cornwall, etc.' (*Mem. Geol. Surv.*), 1839, p. 95.

[3] 'The Older and Newer Palæozoics of West Cornwall,' by J. B. Hill, R.N., *Geol. Mag.*, 1906, pp. 206–216.

from the evidence it affords of the derivation of its detritus. At its northern margin where it is in close relation with the Portscatho Series it is almost entirely composed of fragments from that group, as may be seen at Gillan Harbour where the boulders often exceed a foot in size, and practically represent every type of the Portscatho group seen in the immediate vicinity.

Further to the east the members of the Veryan group have largely contributed to this formation, conspicuous amongst which are derivatives from the quartzite, while the pillow lavas and cherts are also represented. The vast interval of time that separates this conglomerate from the killas on which it is lying is clearly brought out by the nature of the incorporated fragments, from which we learn that the Ordovician groups had reached their present state of metamorphism long before the platform was excavated which formed the floor of the Devonian seas. The evidence is clear that the killas boulders were veined with quartz before their deposition, that the quartzite was brecciated and similarly veined, that the pillow lava was likewise brecciated, and that the Manaccan hornblende schist and its associated mica schist had reached their present condition before such incorporation.

Besides fragments of local derivation the conglomerate also contains a small proportion of foreign ingredients, all of which consist of igneous and metamorphic rocks, represented principally by granitic and felsitic rocks, epidiorite, mica schist and metamorphic quartzite. It is a noteworthy feature that the serpentine and gabbro which enter so largely into the composition of the Lizard group have not been detected in the conglomerate. Moreover, hornblende schist is but rarely represented, and according to Dr. Flett such fragments as have been sliced for microscopical examination are foreign to the Lizard peninsula; under these circumstances it would certainly appear that the Lizard group formed no part of the Devonian land surface, and that rocks of this type were not represented in the area now occupied by the sea to the north-east and east which presumably contributed the foreign detritus to the conglomerate.

Turning now to the other members of the group, calcareous slate succeeds the conglomerate at Halamana (on the south side of Gillan Harbour) and Flushing Cove with fine bands of the conglomeratic arkose interbedded with it. Similar deposits line the coast between Eastern Cove[1] and Men-aver Beach, and likewise form the headland north of Parbean Cove[2] and Polnare Cove. These slates were searched for fossils by Mr. J. Pringle, who obtained numerous plant remains together with a few corals and brachiopods, but beyond indicating a marine fauna they throw no light on their geological age. A careful search was made for graptolites but without success.

The shores of Gillan Creek present numerous crush breccias with which some of the conglomerate may be associated but not

[1] $\frac{1}{4}$ mile E. of Flushing. [2] $\frac{1}{3}$ mile N.N.E. of Penare.

to any great extent. That this formation is definitely represented in the Creek, however, is seen from a small outlier of Devonian arkose that lines the shore to the north-east of Tregithey.

Further to the south a band over three miles in length is coloured on the map between the coast south-east of Penare and Newtown. Where seen on the shore it is represented by the conglomerate, but this coarse deposit does not again appear in the westward trend of the band, and the coastal conglomerate may possibly represent a detached outlier, as no section is seen for two-thirds of a mile when sandy beds of Devonian type are exposed bordering the road a quarter of a mile south-east of Trewarnevas.

At Trewothack killas of this type is again seen together with some sandy beds in which isolated pebbles up to an inch in length are lying in a sandy matrix, and this lithological association pervades the remainder of the band, and is well seen in the valley between Treworgie and Tregidden. At the former locality the finely laminated shales are conspicuous, while higher up the valley the sandstones are represented with which are intercalated seams studded with larger pebbles as already described. The latter may be seen in the small quarries on either side of the valley close to Tregidden, and in the road-cuttings below Bervanjack[1] and Trevaddra, where the finer deposits are studded with the larger pebbles. In these beds there is much variation in the number of the latter which are often sparsely scattered in the matrix, and they include pebbles of pillow lava, chert, quartzite, and ingredients foreign to the area represented by granite and mica schist. Although the southern boundary of this band is shown conterminous with that of the pillow lava it really overlaps the latter further to the south, as is shown by the *débris* south of Treworgie, and there is also evidence that it has entirely transgressed that igneous band and appears on the southern side amongst the small strip intervening between that band and the Lizard group.

A small outlier of this group has been mapped at Carplight[2] in which quarries have been opened on the western side of the valley. Although at the hamlet the rock is of the types just described, that in the quarries more closely approaches the typical conglomerate than has been hitherto met with since leaving the east coast, although not presenting the coarse type of the latter. It contains fragments of quartz, felspar, grit, shale, dolerite, epidotic schist, granitic rocks (5250-5251), while a large pebble that was sliced (5252) is a granitic rock, richly charged with secondary epidote and chlorite, and highly granulitic (cataclastic). Some of the pebbles in this band appear to be derivatives from the Manaccan hornblende schist, rich in epidote.

Another outlier, somewhat similar to the last, and in which pebbles of a metamorphosed granitic rock are seen, flanks the pillow lava between St. Martin and Relowas. A pebble examined under the microscope proves to be a uralitised slightly sheared diabase (5570). Between this locality and Gunwalloe the Manaccan Series has not been recognised, and although it may be represented in that tract, it is clear that the coarse lithological types which readily lead to its detection have died out.

On the west coast, however, where the sections can be critically examined, a patch of Lower Devonian strata occupies the cliffs

[1] ¼ mile N. of Tregidden. [2] ⅓ mile N.W. of Trenower.

between Gunwalloe Fishing Cove and Church Cove, resting apparently for the most part on the Portscatho group but also abutting at its boundaries on the Falmouth and Veryan groups. The strata consist of sandy and argillaceous beds often displaying faint greenish hues, while thin calcareous seams and cherty carbonates are also represented. Although large pebbles are absent the sandy beds when submitted to microscopic examination display the characteristic composition of the Devonian and include besides quartz and felspar, grains derived from the quartzite and pillow lava of the Veryan group (5777, 6396). The seams of cherty carbonate rarely exceed an inch in thickness, and their weathered edges are frequently represented by carbonate of iron. In their normal condition they resemble cherts and in some instances this substance enters into their composition and is probably of secondary introduction (5778, 6398, 6399, 6400). A specimen of one of these bands analysed in the laboratory at Jermyn Street shows the rock to be essentially a carbonate of iron. It was analysed for manganese, iron, lime, and magnesia with the following results:—

MnO	·20
Fe_2O_3	22·80
CaO	2·20
MgO	2·30

These cherty carbonates have not been found elsewhere in the Meneage peninsula either in the Ordovician or Devonian sequence, but similar seams have been observed in the basal Devonian strata between Mevagissey and Perranporth[1] and this helps to mark their horizon. In the Mevagissey district some of these bands are rich in manganese, and Dr. Teall[2], some years ago before the re-survey of Cornwall was commenced, pointed out to Mr. Howard Fox, who had collected the specimens, the probable value of the horizon from a stratigraphical standpoint and more especially as manganese was mined in the Arenig beds of Merionethshire.

Although this section in Mount's Bay presents lithological types that do not recall those of the east coast, yet the plant beds of the latter area are present at Baulk Head where they were discovered by Mr. Howard Fox[3], and thus tend to link up the two tracts. A collection of these plant remains was made for the Survey by Mr. John Pringle, but like those collected from the Nare Point peninsula they are valueless as a key to their geological age.

The sharp contrast in the sandy and argillaceous strata brings out the folding in the clearest manner, and the highly plicated nature of the formation is well seen on the coast of the promontory centering at Pedngwinian, but the most sharply folded strata appear on the Gunwalloe coast at Jangye-ryn, where the beds are thrown into a closely packed set of inversions (*see* Plate XIII.) that were long ago described by Sedgwick[4], and later

[1] The Geology of the Country around Mevagissey' (*Mem. Geol. Surv.*), 1907, p. 42.

[2] *Trans. Roy. Geol. Soc. Corn.*, vol. xii., 1896, pp. 51–52.

[3] *Trans. Roy. Geol. Soc. Corn.*, vol. xii., 1899, pp. 357–359.

[4] A. Sedgwick, 'On the Physical Structure of the Lizard District.' *Trans. Cambridge Phil. Soc.*, vol. i., 1822, p. 325.

Folded Devonian Rocks at Gunwalloe.

by Mr. Howard Fox, who in his communication to the Royal Geological Society of Cornwall[1], has illustrated them by photographs.

This Devonian patch of Mount's Bay is also disturbed by faults, some of which as at Halzaphron Cove have produced marked discordance in the strike. The extremities of the formation both at Gunwalloe Fishing Cove and at Church Cove are concealed beneath superficial deposits. In the former locality the strata extending to Baulk Head present a discordant strike to that of the prevailing strike of the Falmouth group, but as in the Gunwalloe area the strike in the Lower Palæozoic bands is very irregular too much stress must not be laid on this feature. Nevertheless, seeing the highly faulted condition of the tract, it is possible that this Devonian patch may be separated by a fault from the Ordovician strata; moreover the fact that elsewhere in this area the Devonian outliers are confined to the Veryan division, and to the edge of the Portscatho group, whereas in this instance only are such strata found on lower horizons supports the hypothesis of a faulted junction. This, however, cannot be demonstrated, more especially as the landward boundary cannot be drawn with any approach to accuracy, and the margin shown on the map is little more than a colour-boundary.

Having briefly described the Manaccan group so far as it is known to occur in the Meneage peninsula, a few words are necessary to explain the arguments on which its precise geological age has been determined. So far as this peninsula is concerned it has merely been demonstrated that it was deposited in the interval that elapsed between the metamorphism of the Ordovician groups and the subsequent extensive deformation that affected the south-west of England towards the close of the Carboniferous period and in which this group has fully shared. While this series therefore must be separated from the Ordovician by a stupendous gap, it might so far as the evidence of this tract is concerned be as late as the Carboniferous. We have shown, however, in the area lying within the Sheet to the north (352)[2] that the fine-grained conglomerate representing the base of the Devonian at Grampound and Probus is lithologically precisely equivalent to that of Manaccan, containing a similar assemblage of rock fragments, resembling one another so closely as practically to preclude the possibility of their derivation from different sources, or at widely different periods, and this resemblance is fully borne out by microscopic examination. Moreover, the associated sandstones and clay-slates bear an equally close relation, and it has already been pointed out that the thin seams of cherty carbonate are also represented in both areas. In the Probus and Grampound region the evidence is clear that we are dealing with the basement beds of the Devonian as they pass naturally to the north into fossiliferous Devonian

[1] Howard Fox, 'Gunwalloe,' *Trans. Roy. Geol. Soc. Corn.*, vol. xii., 1900, p. 435.
[2] J. B. Hill, *Geol. Mag.*, 1906, pp. 206–216, and 'Geology of Falmouth and Camborne' (*Mem. Geol. Surv.*), 1906, p. 39.

strata. In view of the precise nature of the correlation in the Probus and Meneage districts, there can be no hesitation in arriving at the conclusion that the Manaccan group of the latter area likewise represents the Lower Devonian.

There is, moreover, a similar correlation in the two areas as regards the position of the coarse conglomerate. As we have shown in the Meneage district this deposit is confined to the east coast, and this is also the case in the northern area where that deposit is limited to the coastal districts of Gorran, &c. It is evident, therefore, that the Devonian land surface lay to the east, and so far as the Meneage district is concerned the position of the conglomerate points to a north-eastern source, while it is equally evident that the coarseness of the boulders at Gillan Harbour indicates the site of part of the actual coast-line of the Devonian land. An inspection of the map will show not only the paucity of the Devonian deposits, but, with the exception of the patch at Gunwalloe, their restriction to a limited tract only five miles in length and one mile in breadth between Nare Point and St. Martin, where they are represented by a series of outliers within the Veryan group. They are, moreover, situated within the most highly disturbed tract of the area, and the preservation of these lenticles is doubtless due to their lying in troughs that were produced by the folds that originated with the Carboniferous movements.

Although we have no direct evidence of the nature of the floor that lay beneath the Devonian sea, such facts as can be gleaned point to a plane of marine denudation, analogous to the platform that emerged from the Pliocene seas, and which is even at the present day so conspicuous a feature in the Lizard peninsula. If the floor had been uneven and deeply trenched denudation should have laid bare lower portions of the Ordovician sequence on the Devonian floor, but save in the doubtful case of Gunwalloe there is no evidence that in this area any portion of the succession below the upper members of the Portscatho group reached the Devonian surface, and in this connection it must be also recollected that the Ordovician rocks were in Devonian times in practically the same state of deformation and disturbance as the Devonian rocks themselves present to-day. We have already drawn attention to the fact that rocks of the Lizard group are apparently not represented in the conglomerate. That coarse deposit, however, does not occur near the Lizard margin where the Devonian sediments are of the finer type, and the direction of sedimentation is towards the Lizard group which if they occupied their present position in relation to the Veryan Series in Devonian times, formed the bed of the sea, and the absence of its detritus in the areas to the north is easily understood if this was contrary to the drift of the Devonian sedimentation, as the lithological distribution clearly implies.

These Devonian sediments are not represented in the area occupied by the Lizard group, a fact which is not surprising in view of the few and disconnected outliers that are their sole representatives to the north of that tract, and the preservation of which is due to their position in the synclinal basins formed by the Carboniferous movements. Although the stresses of that epoch doubtless set their mark on the Lizard group in increasing their deformation, their constitution is such as would be unfavourable to the production of the deeper folds which have been set up in the Cornish killas.

In the recent survey of the Lizard district Dr. Flett has noted a small exposure of killas to the south-east of Trenance, near Mullion. The killas is much shattered and is lying on the sole of a thrust, between serpentine and hornblende schist, the former having been thrust from the south presumably by the Carboniferous stresses, and the preservation of the killas is probably due to the protection of the serpentine that partially overlies it. This killas, which shows no contact alteration, is possibly Devonian, and may represent the sole relic of that formation now remaining on the Lizard platform.

On the other hand, the absence of definite Devonian deposits on the Lizard group may be due to the latter having lain beneath the surface. In this connection it will be seen that the absence of the Devonian on the Mylor group has been used as an argument in favour of the latter occupying the base of the Lower Palæozoic sequence that was not trenched by pre-Devonian denudation.

CHAPTER XVIII.

THE LIZARD BOUNDARY.

One of the most important problems in the geology of this region is the relation of the Ordovician rocks of the northern tract to the crystalline rocks of the southern.

The line which constitutes the boundary of the killas with the Lizard group is the most critical in the area, and although the inland evidence is sometimes obscure it has been traced with far greater accuracy than has been found possible in separating the lithological divisions of the killas to the north.

At Polurrian Cove a well-marked fault with characteristic breccia divides the killas on the north-west from hornblende schist on the south-east. The fault hades to the south-east (at an angle of 45°), and incorporated in its breccia are some quartzite, and fragments from chert seams somewhat similar to those of Mullion Island. These fragments of quartzite and chert belong to upper members of the Veryan division that are not represented on the west coast, and have found their way into the fault fissure from higher horizons. The killas in the direction of the fault shows neither contact alteration nor increase in metamorphism. This fault after running north-east as far as Bochym Lodge, with the rocks on either side retaining the same sharply contrasted metamorphism, thereafter penetrates the Lizard group and dies out about half a mile within the boundary of the latter, in the vicinity of Bonython. That fault if prolonged to seaward would pass to the north of Mullion Island, where the pillow lava and cherts representing the upper parts of the Veryan division, that are missing on the coastal tract of the mainland, again appear. In its landward direction from Polurrian Cove to Bonython it has given rise to an extensive hollow, and this feature dies out with the fault towards the latter locality.

This fault is the largest in the whole area, but the exact amount of its throw can scarcely be estimated owing to the disturbed nature of the killas; all that can be said is that the upper members of the Veryan group ~~have been cut~~ out, and that where it enters the Lizard group at Bochym Lodge it cannot be of great magnitude as it shortly dies out. Moreover, the very fact of its entering the Lizard group shows that it is only of local importance. On the east coast at Porthallow a similar fault is seen with well-marked breccia and also with a southerly hade of 45° dividing the metamorphic group from the killas. This fault has also given rise to a deep valley along its course.

The greater part of the Lizard boundary stretches between those two faults and is of entirely different character. Not only does it follow an irregular and sinuous course, but it is marked by no feature that would suggest a marginal fault. Moreover, the sinuosities of the boundary are shared in to a marked degree by the stratigraphical bands in the adjoining Veryan group, and this correspondence is especially well brought out by the outcrops of the pillow lava, as an inspection of the map will show.

Another feature which marks that margin is the frequent presence of a narrow metamorphic sedimentary border interposed between the igneous rocks of the Lizard group and the killas, which is absent along the faulted boundary that runs for over two miles in a north-easterly direction from Polurrian Cove, where the normal killas abuts against the fault on the one side and igneous rocks of the Lizard group on the other. The metamorphic sediments of the marginal belt consist of mica schists, felspathic, and quartzo-felspathic grits, with a varying amount of authigenic garnets, and they range in structure from granulites, that resemble hornfels in their compactness and mode of fracture, to true schists which split readily along the planes of schistosity.

Besides these rocks, most of which are characterised by the presence of garnets, and of a granular structure imparted by grains of felspar and quartz, in which the felspar usually predominates, there is also a development of micaceous phyllite, which although rarely reaching the metamorphic condition of a typical mica schist, is nevertheless sometimes so micaceous and cataclastic as to recall the mica schists along the metamorphic belt on the horizon of Manaccan, but with a lower grade of crystallisation than the mica schists that occur on the coast south of the boundary fault at Porthallow. These phyllites represent more argillaceous sediments than the garnetiferous schists just alluded to, and are in a lower condition of metamorphism. This character enables their identity with the Veryan Series to be established as conclusively as that of the argillaceous mica schists of the metamorphic belt of Manaccan, whereas the higher crystallisation of the garnetiferous schists precludes such a definite determination.

From Bochym to Polglase the margin of the Lizard group pursues a north-westerly direction. At Bochym the outer boundary of the hornblende schist is flanked by garnetiferous granulite (5779-5780) seen in the yard adjoining the out buildings, and also in the quarry. It is evidently a very narrow zone, and the nearest killas between 30 and 40 yards distant shows no alteration. From Bochym to Polglase the margin can only be traced by means of the *débris* in the fields, amongst which at the latter locality is some garnetiferous mica schist and some argillaceous mica schist like that of Manaccan and Porthallow. At Polglase the boundary is shifted about 200 yards to the north-east by a transverse fault running north-east along the course of the valley. From here to Trease[1] the boundary runs in a north-east direction across pasture land, and the marginal rocks are not seen in place until the latter locality is reached, when for the first time the pillow lava makes its appearance, near the boundary of the Lizard group, and conforms approximately to this horizon for the remainder of its course across the peninsula.

From Bochym to Penvearn[2] the boundary has approximated to that of the quartzite zone, that rock being so thickly represented in the *débris* and its blocks often so huge as to leave no doubt of the horizon. At Trease a band of pillow lava is seen in the farmyard west of the main road, from whence it crosses the latter in the direction of the watering, and reappears on the northern side

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[1] The farm on the Lizard-Helston road beside Gwealeath, where the road to Cury branches off. [2] S.W. of Gwealeath.

of the alluvium in the farm-yard at Gwealeath. To the west are two more outcrops of pillow lava closely adjacent, one of which is exposed along the main road at Boscawen[1], while a still larger mass occurs just to the west of that farm. These spilites are generally much decomposed, and often reduced to the condition of a crush breccia as is so frequently the habit of these rocks, but preserve their igneous structures in perfection.

The most easterly band is separated from the hornblende schist by mica schist, often charged with rounded grains of felspar, and compact granulite, all of which contain small garnets. These rocks are exposed in the road cutting at Trease, in an old quarry 200 yards east-south-east of Gwealeath, in a small pit just east of Gwealeath farm-yard, and in the farm-yard of Trease. In the latter locality there is a little hornblende schist near the main road amongst the granulite, so that the width of the band between the pillow lava and the first oncoming of the hornblende schist is very narrow, in fact is just the breadth of the Lizard road. To the west of Gwealeath the evidence is limited to the two pits alluded to, and it is possible that between those exposures there may be some hornblende schist just as at Trease, and that the mica schist band, as drawn on the map, may include some of the latter.

The rock in the quarry east-south-east of Gwealeath is seen under the microscope (5272-5273) to consist largely of rounded fragments of untwinned felspar (orthoclase, perthite, &c.) with a little plagioclase and quartz, which lie in a somewhat schistose matrix of quartz, felspar, muscovite, chlorite, iron oxides and epidote, while small clear pale brown idiomorphic garnets are of common occurrence. The band in the road cutting at Trease (5220, 5271) is more schistose, and (although not so metamorphic as the mica schists of Porthallow) bears rather a close resemblance to some of the latter. These garnetiferous schists that flank the marginal hornblende schist at Trease and Gwealeath are less metamorphic than the granulites which are incorporated with that igneous rock[2]. Granulites interbanded with the hornblende schist are also seen at Polglase, and in the quarry 700 yards east of Bochym, and some of these more metamorphic types contain hornblende.

The eastern pillow lava band at Gwealeath intervenes between the garnetiferous sediments and killas of more normal type. The metamorphism, however, although broken by the igneous band, has not been altogether extinguished by that barrier. The killas occurring on its western side in the farm-yards at Gwealeath and Boscawen, and in the road cutting between those farmsteads shows not only development of mica along planes of foliation, but also a certain amount of criss-cross structure[3]. There is no feature suggesting a fault at Trease and Gwealeath, either between the hornblende schist and garnetiferous granulite, or between the latter and the spilite, and although the last-named band appears to have acted as a metamorphic barrier, yet phyllites, some of which are

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[1] A few yards to the W. of Gwealeath, on the opposite side of the Lizard road.

[2] *See* microslides 5,274, 5,760-5,761-5,762-5,763-5,764, 5,783-5,784.

[3] W. M. Hutchings, 'The Contact-Rocks of the Great Whin Sill,' *Geol. Mag.*, 1898, p. 74.

highly micaceous and cataclastic (5775), extend beyond it, and are unmistakably of Veryan age, as small chert seams are seen in the road section between the farms of Gwealeath and Boscawen.

Between Gwealeath and Skyburriowe the marginal belt between the Veryan and Lizard groups is concealed beneath the soil, but at the latter locality the section reappears on the roadside, just where the private road from Skyburriowe emerges on the highway. A thin belt of sediment divides the spilite from the hornblende schist, which at this locality is less coarsely crystalline than at Gwealeath. Here, as at the last locality, there is no feature suggestive of a fault separating either of the three members. The sediment exposed between the hornblende schist and spilite is less than a dozen yards in breadth and is much decomposed. It is of fine texture and varies from sandy mudstone to argillaceous chert. It is spangled with very fine specks of authigenic white mica, some of which may be bleached biotite. Although the metamorphism is slight and garnets do not appear to have been developed, the rock is evidently of the same type as that described from Trease. A specimen examined under the microscope shows that foliation is present although not strongly marked. It is rich in felspar, but contains also a considerable amount of quartz, with chlorite, white mica, iron oxides, &c. (5276). There are intermediate passages from this rock into the argillaceous chert in which the mica specks are diminishing. The more pure argillaceous chert (5275) resembles similar chert already described in the Veryan group from Towan Cott[1], &c., except that this rock as seen in the hand specimen presents a more metamorphic appearance. A thin seam resembling this argillaceous chert was also observed associated with garnetiferous mica schist in the small pit close to the farm-yard at Gwealeath. It is quite evident that the same phenomena are presented both at Gwealeath and at Skyburriowe, although at the latter locality the metamorphism is still less, in fact it hardly deserves a place in a metamorphic group, while the presence of the argillaceous chert in association with it helps further to define its horizon, and the evidence suggests that these marginal rocks of Trease and Skyburriowe may be metamorphosed members of the Veryan group.

At Skyburriowe is situated the apex of the big curve which affects not only the Lizard group, but the Veryan, Portscatho, and Falmouth divisions, which succeed it on the north, that deflection being common to the entire rock assemblage, including the adjacent pillow lava, and tending still further to link the Lizard group with the Ordovician sequence. Notwithstanding that the boundary of the Lizard schists now swings sharply to the eastward, it still preserves the same position in its relation to the pillow lava which bends round in the same direction to Bojorrow, the nature of the ground, however, does not admit of the marginal relations being critically examined, except that the serpentine soon replaces the hornblende schist as the outer member of the Lizard group. The killas, however, exposed in the burn to the east of Bojorrow[2], rather more than a hundred yards from the Lizard group, is phyllitic, with development of secondary mica along the foliation

[1] ½ mile W.S.W. of Gwills.

[2] Midway between Tregadjack and Chygarkye.

planes, some of which partakes of a criss-cross structure (5279), but the alteration is very slight. South-east of Chygarkye the serpentine bends to the north-east, and the boundary may have been thrown slightly by a transverse fault running north from Trevassack.

Between Chygarkye and the road between Polawyn and Relowas, there is an absence of section and the boundary can only be drawn approximately, and it is not even certain whether the pillow lava is represented along that belt. At Relowas, however, where the hornblende schist forms the Lizard margin, the pillow lava is again seen following a course close to the boundary. The actual margin, however, of the hornblende schist is not visible, but it is evident that if the killas in contact is metamorphosed the altered zone must be very narrow. A little east of Relowas the hornblende schist swings round sharply to the south-east towards St. Martin's Bridge[1]. This deflection in its margin may be due to a north-westerly fault traced in this direction by Dr. Flett along the valley between Traboe and Trewince, but in this case the fault must be pre-Devonian as it does not affect the Devonian rocks immediately adjacent extending from St. Martin to Relowas. Moreover, the pillow lava margin for some distance conforms likewise to that change of direction; unfortunately, where the margin crosses the stream below St. Martin's Bridge[1], there is no section for nearly a hundred yards, between the killas on the one side and hornblende schist on the other, so that the fault cannot be proved.

There are good stream sections of the killas below Trethewey, where it has not only a more homogeneous character than is its usual habit, but there is sufficient development of mica to impart a lustrous sheen which recalls some of the phyllites in the less metamorphic areas of the Highland schists, such as the Loch Awe group in Argyllshire. With these phyllites some pale chert bands are associated. Under the microscope it is seen that these beds are passing over into phyllites with a fine type of mica developed along the planes of foliation (5213-5215). A higher grade of metamorphism, however, is seen in a rock exposed above the stream[2] in which rather abundant and well developed white mica is seen; quartz, chlorite, and iron oxides being the other ingredients (5211), and the rock is far advanced in the direction of a mica schist. These rocks are unmistakably part of the Veryan Series, and the advance in crystallisation is, as cited in other instances along the border, coincident with the close proximity of the Lizard boundary.

Although the actual margin is concealed in the stream the eastern slope exhibits the marginal portions of the hornblende schist, in which granulite appears between its boundary and the phyllite. One of these exposures of granulite is seen at the top of the waste ground[3] largely occupied by gorse. It resembles the rock last described, especially in its highly brecciated condition, but it weathers into a more massive form and has a more indurated appearance. In its field characters, however, it exhibits all the aspect of the killas group and appears to be part of the

[1] ¼ mile N.W. of Trewince. [2] 250 yards W. by N. of Trethewey.
[3] 320 yards S.W. of Trethewey.

Veryan Series. It has evidently been hornfelsed as its field appearance suggests, and under the microscope appears as a fine textured quartzose granulite studded with small clear idiomorphic garnets (5786). A little farther south[1], along the path leading to the ford, there are small openings in which the rock has been wrought where banded structures of Lizard type are seen, and evidently on the very margin of the hornblende schist. Here the granulite seen under the microscope is very similar to the last slide except that the banded structures are also present (5785). It is evident that this granulitic zone is very narrow and passes into the phyllitic rocks described probably within a distance of 20 yards.

These granulites differ from the rocks at Trease in being highly brecciated, more quartzose, and in the garnets being very small. The quartzose nature of the granulite is reflected by that of the sediments in this area, whereas in the vicinity of Trease they are more felspathic and agree in that respect with the granulites of that locality. Not only does the evidence at Trethewey point to the metamorphism of the Veryan sediments, but they appear to be likewise overlain in that locality by the hornblende schist, which together with the granulites occupy the upper slopes of the valley, while the phyllites line the bed of the stream immediately below. This does not imply, however, a natural succession, as the relative position may be due to a thrust of low hade.

Beyond Trethewey the hornblende schist boundary pursues an easterly course, but between Newtown and Tretharrup it curves more to the south in the direction of Tregidden farm, before reaching which it bends back to the north-east and crosses the Tregidden valley about 150 yards south of that hamlet. Although the boundary from Trethewey to Tregidden can be drawn with a fair approach to accuracy by means of the rock *débris*, no actual junction is seen. A quarter of a mile south-south-west of Newtown some mica schist of Manaccan type, and killas that appears indurated, occur amongst the rock fragments at the boundary. About a quarter of a mile south of Tredower some phyllite occurs *in situ* a little north of the boundary (on the southern bank of the small valley leading to Tregidden) which resembles the micaceous phyllites of Trethewey with mica well developed along the planes of foliation, the rock being intermediate in character between the normal killas and mica schist (5214). As in other parts of the boundary zone this phyllitic belt divides the hornblende schist from the pillow lava which is closely adjacent, and this igneous band swerves round in conformity with the hornblende schist boundary to the south-west of Tregidden. At that locality the *débris* of the latter rock is so thickly strewn that the phyllitic zone must be very narrow.

On the east side of the Tregidden valley the boundary crosses the main road, where phyllite is seen succeeded by a decomposing igneous rock made up of aggregates of granular epidote and green hornblende, in which little foliation has been developed, although the igneous structures are obliterated (5197). The adjoining phyllite can be clearly recognised as belonging to the

[1] 350 yards S.W. of Trethewey

Veryan group, and has suffered a certain amount of alteration, the rock having an indurated aspect, with mica developed along the planes of foliation (5212).

From this locality the boundary runs a little to the north of Rosemorder and then passes a little south of Roskruge with the same remarkable parallelism to the pillow lava band from which it is separated by a narrow zone of killas. Between these places, however, there is no section exposing the marginal relations, although at Trewince[1] the hornblende schist is seen within a hundred yards of the killas which, however, may possibly be Devonian. To the south of Roskruge the boundary crosses the road leading to the Beacon but the junction is not clearly seen, although hornblende schist appears to be succeeded on the north-west side by some brecciated and micaceous phyllite.

To the north-east of Roskruge the boundary soon merges in the Porthallow fault which follows an east-south-easterly direction to the coast, its course being marked by a deep valley, and this line of dislocation here forms the boundary between the Lizard and Veryan groups just as the Polurrian fault does on the western side of the peninsula.

The rock which first appears south of the boundary fault at Pengarrock Mill, Porthallow, is a very finely striped phyllite with the original stratification well preserved. It has distinctly the facies of the killas, and although presenting a massive and somewhat indurated aspect, its metamorphism is of the slightest, and not to be compared with some of the Veryan phyllites along the Lizard border, or in the metamorphic belt of Manaccan. It strongly recalls the Dodman phyllites, and it is possible that the latter may succeed the Veryan division, although in the Dodman area their landward boundary is faulted so that there is no evidence of their stratigraphical position[2]. With the phyllites at Pengarrock Mill there is a small outcrop of crushed basic rock which might be described as uralitic diabase, and showing no distinct foliation. A similar rock is found in the fault zone behind the Porthallow Inn. Dr. Flett is of opinion that these phyllites and diabases are enclosed between the boundary fault on the north and another curved fault to the south of them. The latter fault cannot be seen, and this conclusion rests on the marked difference in the metamorphic condition of the rocks on either side.

Beyond this zone, in the road cutting which runs south of Pengarrock Mill, for about 200 yards very fine-grained hornblende schists are exposed, often epidotic and yellowish-green in colour. They differ from the usual type of Lizard hornblende schists in possessing small rounded felspar crystals, apparently the remains of phenocrysts. These may be replaced by epidote, and in other cases small porphyritic hornblendes are visible in the slides. At a point 260 yards south of the mill, mica schists of normal Lizard types occur, but at Pengarrock house, in a small pit on the south side of the farm, there is a fine grey schist, well foliated, but possessing hardly a trace of white mica, though rich in chlorite. In the coast section east of Porthallow mica schists occur along

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[1] $\frac{1}{3}$ mile S. of Higher Boden.

[2] 'Geology of Mevagissey,' (*Mem. Geol. Surv.*), 1907, p. 18.

with grey schists of similar appearance, fine banded epidosites and epidotic hornblende schists so that these Pengarrock rocks evidently belong to the Lizard Series.

Inferences from the Boundary Evidence.

Having traced the marginal features of the Veryan and Lizard groups across the peninsula, we may briefly consider to what extent they elucidate the mutual relations of the two groups.

The most striking feature of the boundary is the sharp difference of the rocks on either side both as regards their composition and metamorphism. The Lizard group is in the main igneous with subordinate sediment, while in the killas belt these conditions are reversed. In the former the structure of the sediments and much of the igneous rock is that of the crystalline schists; in the latter they are mainly those of cleaved rocks, although including crystalline types ranging from phyllites to mica schists and granulites, but in which, nevertheless, the metamorphism is lower than that of the dominant Lizard type.

These sharp distinctions naturally suggest that the juxtaposition of the two groups is the result of unconformity or dislocation. There may, however, be a transitional passage between the two groups, and this hypothesis has been enforced by Messrs. Collins, Somervail, and others. Professor Bonney, on the other hand, has been the principal exponent of the hypothesis that, while the serpentine may have been intruded into the killas, the remainder of the Lizard group is of Archæan age.

We may first consider the hypothesis of an *unconformity*. It will be seen by the map that the inland tract for a distance of eight miles between Roskruge and Bochym shows a marked parallelism between the killas subdivisions and the Lizard margin, the member conterminous with the latter being the Veryan group which is of Ordovician age. For about a mile, however, between Penvearn[1] and Bochym, the marginal line slightly transgresses the stratigraphical horizon. Further, along the boundary there is no trace of a basal conglomerate, nor any tendency even for the killas deposits to be of coarser texture in that direction. Moreover, as already observed, the Veryan Series appear to represent the top of the Older Palæozoic sequence, so that the Lizard group is in contact with the upper members of the Veryan division. We must conclude therefore that this is not the result of an unconformity.

We may now consider the evidence in favour of the hypothesis that the Lizard boundary is a series of *dislocations*.

Wherever the sections are good the position of the Lizard boundary can be defined within a few yards, and the rocks on either side of it are of very different character. At Gwealeath, for example, the coarse hornblende schist and garnetiferous mica schist or granulite are within a few yards of radiolarian cherts and brecciated pillow lavas. At Relowas and Tregidden the transition is equally sudden, and the breadth of the passage zone or 'aureole' of the hornblende schists cannot be more than thirty yards. There

[1] S.W. of Gwealeath.

is no good section across it in which its characters can be satisfactorily studied. A very large number of microscopic sections has been prepared from the rocks adjoining the Lizard boundary. They fall naturally into three groups: (1) Lizard rocks, highly metamorphic, with the original sedimentary and igneous structures obliterated by recrystallisation; (2) Veryan rocks, often much crushed and brecciated, but with both sedimentary and igneous structures in good preservation; and (3) a few rocks which cannot be placed with certainty in either of the above classes.

Of the third group some are probably Veryan rocks in an unusually high state of crystallisation, but on the hypothesis that the Lizard boundary is a thrust or complex of thrusts, it seems also reasonable to expect that rocks not elsewhere known in the district might occur as lenticles in the thrust planes, and some of the third class might thus be accounted for.

While the boundary line maintains a general parallelism to the strike of the Veryan group, it is often in marked discordance with the structures of the Lizard rocks on the south. Thus it truncates the north end of the serpentine at Trevassack, cutting right across the northerly foliation which is well developed in that quarter, as may be seen in the quarries on the west side of the St. Keverne road near Chygarkye. The cherty Veryan shales in the fields adjoining the serpentine show no contact alteration. At Relowas, Polglaze, and many other places the hornblende schists have a strike that is directly across the boundary line. There is, however, a tendency for the Lizard schists as they approach their northern limit to assume a strike that is more or less parallel to the margin, but a precisely similar change of strike is observable in the hornblende schists at the Lizard in the vicinity of the thrust that forms the southern boundary of the serpentine.

The Veryan Series to the north of the Lizard rocks is often so intensely brecciated that it can hardly be distinguished from the Devonian conglomerate. The Lizard schists and serpentine, on the other hand, are never much brecciated. At two different periods great earth movements have affected this region, forcing the crystalline rocks of the Lizard against the slaty killas, cherts, and limestones. These two series have very different powers of resisting stresses, and one can readily believe that there would be an overwhelming tendency to disruption along their junctions. We may point out also that in the very similar district of Mevagissey[1] the presence of an extensive system of thrusts has been demonstrated by the Geological Survey.

This theory would help to explain also why no specimens of Veryan rocks showing contact alteration have been obtained from the Lizard margin. When we consider the great size of the Lizard intrusions it seems reasonable to expect that there should be some sort of contact aureole. If the Lizard hornblende schists were intruded into the Veryan rocks during a period of movement and folding they might have changed the Veryan shales and sandstones to schists and gneisses rather than to ordinary hornfelses; but in that case the marked dissimilarity between the Lizard sedimentary schists in the Porthallow and Trenance area

[1] 'The Geology of Mevagissey' (*Mem. Geol. Surv.*), 1907.

and the Veryan rocks everywhere beyond the Lizard boundary is so great as to suggest that if an aureole existed it has been cut out by a series of boundary thrusts.

The evidence of the Devonian conglomerate also cannot be overlooked. In many places it is quite close to the Lizard rocks yet contains no fragments of them; and if we admit that the hornblende schists are a peculiar set of intrusions into the upper part of the Veryan Series, it is difficult to believe that their present geographical limit marks the position of their original margins. They are certainly immensely thick and must have extended northwards among an upper series of Veryan rocks of which no trace is left; great masses of these rocks must have been destroyed before the platform on which the Devonian conglomerate rests was finally levelled. The absence of Lizard rocks from the conglomerate can be explained on the hypothesis that their present relative positions in this district are due to a post-Devonian dislocation.

There is nothing in the sedimentary schists of the Lizard by which their age can be definitely established. They show intense metamorphism, varying somewhat in degree and in type, and though no similar rocks in Britain have been proved to be of Ordovician age, there is no reason why in certain imaginable circumstances Ordovician rocks should not have been similarly metamorphosed. The north-north-west strike of the Lizard schists, however, is very strong evidence of their pre-Cambrian age, for neither in Brittany, South Wales, nor the south-east of Ireland, where extensive areas of these rocks occur, has any reason yet been found to lead us to the belief that the late Silurian or Caledonian movements produced folds striking in that direction.

Within the Lizard area faults and thrusts are numerous and powerful; there are at least five series of major dislocations in that district, each having a characteristic trend or assignable to a definite epoch. It is a fact which can hardly be without significance that the whole of the Lizard boundary can be resolved into segments which are parallel to one or other of the principal systems of Lizard faults. This subject will be further considered in the Chapter on 'Faults.'

We will now discuss the hypothesis of a *transitional passage* between the Lizard and Veryan groups. The close conformity (for a distance of about eight miles) of the margin of the former to a definite stratigraphical position in the latter, with the slight transgression already noticed, is readily explained on the theory that the igneous rocks of the Lizard Series represent a laccolitic belt of intrusions overlying the Veryan division and forming a group of closely contiguous sills. In this case the advanced degree of crystallisation of the enclosed sediments would have resulted from their having experienced repeated metamorphism by the successive injections, most of which were intruded under conditions of stress. Under those conditions while the incorporated sedimentary wedges would be profoundly altered, the sediments of the extreme margin might suffer comparatively little metamorphism. After making due allowance for undetected faults in the marginal zone, the latter must be exceedingly narrow, in some places less than twenty yards. It is uncertain, moreover, whether the most metamorphic part of that zone, such as the garnetiferous granulites of Trease, &c., passes laterally into the less altered phyllites and phyllite schists that can be definitely recognised as metamorphosed Veryan killas. Such granulites can be matched in the Lizard area, and they may represent part of that group from which the igneous cover has been removed.

If these marginal features be compatible with the intrusive hypothesis, the latter may be supported by the hornblende schist of the Manaccan belt. As already noticed, that rock is considered to have been intruded under conditions of stress, so that not only did it consolidate as a schist, but the argillaceous sediments in its vicinity have been converted into mica schists, while siliceous bands along the same belt have been considerably granulitised. The hornblende schist, however, and associated mica schists and granulites are less metamorphic than those of the Lizard group, although the sediments are just as altered as those along the Lizard border, with the exception of the garnetiferous granulites to which attention has been drawn. In this connection it must be remembered that the Manaccan belt has experienced but one intrusive phase, while in the Lizard area such phenomena have been often repeated.

Perhaps, however, the strongest argument in favour of the intrusive hypothesis is the difficulty of otherwise explaining the marginal phenomena. The close correspondence of that sinuous boundary to a definite stratigraphical position in the Veryan group must be regarded as a remarkable coincidence if it is the result of a thrust or thrusts at however low an angle of hade. Although the marginal features may be the result of dislocation, the system of faulting brought out by the mapping fails to harmonise with them.

The fact that the Lizard rocks appear to be unrepresented in the Devonian conglomerate cannot be satisfactorily explained. It is true that the drift of the Devonian sedimentation is towards the Lizard group, and that the latter might have occupied the bed of the sea. On the other hand the group may not have reached the surface at all, and might have been brought up later by a post-Devonian thrust. In that case, however, the latter has no relation to the zone of crush breccias in the Veryan Series as those structures are pre-Devonian.

So far as Britain is concerned, the nearest analogy to the Lizard problem is furnished by the Ordovician rocks of Ayrshire, where a somewhat similar igneous assemblage has been intruded into Arenig strata[1]. At Ballantrae, pillow lavas and radiolarian cherts are found precisely similar to those of Cornwall, while in their immediate vicinity at both localities are gabbro and serpentine. In Ayrshire, moreover, both serpentine and gabbro pass over into banded varieties, and Professor Bonney[2] and Dr. Teall have noted their resemblance to the rocks of the Lizard peninsula. Unlike the Cornish area, however, the hornblende schists appear to be rare in the Ayrshire tract.

[1] 'The Silurian Rocks of Britain,' vol. 1. (*Mem. Geol. Surv.*), 1899, pp. 87, 91, 471, 479.

[2] *Quart. Journ. Geol. Soc.*, vol. 34, 1878, p. 769.

CHAPTER XIX.

GRANITE AND ELVAN.

Granite.

The granite that occupies a narrow tract on the northern edge of the map extending on either side of Constantine forms the southern margin of the Carnmenellis granite, the bulk of which lies in the adjoining Sheet (352) and extends north to the great mineral area of Camborne and Redruth. Likewise the very small tract on the north-western edge of the map at Breage represents a part of the Godolphin granite that lies beyond this Sheet to the westward. As these granites have been described in the Memoirs[1] on the adjoining areas in which they play an important rôle, it will be unnecessary to treat in detail the limited tracts which extend from those bosses into this Sheet.

They form part of the chain of intrusions that extends from Dartmoor to the Scillies, and have been injected into strata as high as the Culm Measures. Probably they represent the closing stage of the period of Carboniferous disturbances that has so profoundly modified the strata of the south-west of England. They have no connection, therefore, with the granites that are associated with the metamorphic rocks of the Lizard peninsula, which are undoubtedly pre-Devonian and of an entirely different facies.

These various granite bosses of West Cornwall do not represent the upper surface of a single mass projecting here and there from the overlying killas that formerly covered them, but express independent intrusions from a common magma basin at a deeper seated source[2]. Although their mineral habit and composition leave no doubt of their common origin, the various bosses differ from one another, as regards texture and proportion of the various mineral ingredients, sufficiently to give them individuality. As a rule the larger masses have a coarser texture than the smaller even where such masses are closely contiguous, and there is likewise a difference in the extent of the metamorphic belt in the killas which flanks them. As will be seen later, both these distinctions are expressed as regards the Carnmenellis and Godolphin granites that enter into this Sheet.

Although the mode of intrusion of the granite is a moot question, the evidence presented by the character of the metamorphic aureole of the Carnmenellis granite suggests that it is a laccolite. While the aureole flanking the eastern side seldom exceeds a thousand yards, and is often considerably less, that on the western side often exceeds a mile, and on the north the killas is metamorphosed for distances of even two and three miles. It would appear likely, therefore, that the material uprose on the eastward

[1] 'Geology of Falmouth,' &c., 1906, pp. 52-60, and 'Geology of the Land's End District', 1907, pp. 40–60.
[2] *See* 'Geology of Cornwall' (Victoria County History), by J. B. Hill, 1906, pp. 24, 25.

side and spread from thence in a lateral direction. On that side not only is the boundary straighter, but the adjoining strata have been deflected at right angles to their normal course and run parallel to the granite margin. Moreover, that marginal zone of the granite is of finer texture than the remainder of the periphery, which suggests that where it plunges beneath the surface at a high angle cooling has been more rapid than where its hade is low.

Carnmenellis Granite.

The southern part of the Carnmenellis granite occupies a strip about five miles in length along the northern border of the Sheet extending from Driff on the east to the vicinity of Tremenhere on the west. The village of Constantine is situated on this granite tract at about one and a half miles from its eastern margin. The granite has a sinuous boundary, but never extends as far as half a mile from the northern edge of the Sheet.

It is essentially a muscovite biotite granite, with tourmaline in varying abundance, while andalusite is often present. Apatite and zircon also occur, but topaz and pinite are rare. Where mineral lodes are present the rock has often been modified by silicification and tourmalinisation and the introduction of new minerals. It is frequently of porphyritic habit, large idiomorphic crystals of orthoclase and plagioclase being dispersed in a finer-grained matrix. These felspars often exceed an inch, and exceptionally two or three inches in length. While fairly uniform it nevertheless exhibits local deviation in composition and texture. The marginal variety already alluded to which characterises the eastern part of the boss retains this character for some distance within this Sheet to the east of Driff; thenceforward, however, as the metamorphic aureole widens, there is no perceptible difference in structure between the margin and the interior, although here and there finer-grained granite may still be seen. Even where there is no difference in texture the granite along the southern margin is, on the whole, perceptibly richer in biotite than in the more central portions of the mass. Contemporaneous veins of fine-grained granite or aplite are common over the mass, while pegmatite veins are not infrequent. In this area tors are absent, but the rock frequently develops the stratiform structure prevalent in the granites of Devon and Cornwall.

Structures.—The rock is characterised by a system of jointing which bears a definite relation to its crystallisation. There are three well-developed series of joint planes; one set of vertical joints with a prevalent trend of about north-north-west being traversed by another vertical set at right angles. These two systems, together with a third, more or less horizontal, divide the rock into rough prisms, which have constituted an important factor in the successful development of the Cornish granite industry. The north-north-west joints are known as "cleaving-way" joints, those at right angles to them are termed "tough-way" joints, while the horizontal fissures are designated "floors" or "quartering-way" joints. As the grain of the rock closely corresponds with the direction of the joints, quarrying operations are guided by them. It has been found that the "horizontal joints" are separated by wider intervals in depth, and where the vertical joints are likewise far apart blocks of enormous size can be raised such as can be obtained from no other British granite, blocks of from 1,000 to 3,000 tons being frequently detached from the main beds in the quarries.

The rock cleaves easiest along planes parallel to the horizontal joints, but it also readily splits along the "cleaving-way" joints, and cleaves least regularly parallel to the "tough-way" joints. There is, moreover, in this granite a distinct tendency to orientation parallel with the horizontal and "cleaving-way" joints. It must not be inferred, however, that the joint planes are strictly constant in direction, as frequent cases of deflection occur, particularly where finer-textured veins are mixed with the normal rock. The cleaving planes are not always strictly parallel to the joints, but on the whole their close mutual relation is unmistakable. Not only is there an intimate connection between the dominant joints and the grain of the rock, but the latter is determined by the mineral arrangement, and all three phenomena are closely related.

The crystalline structure appears to depend, first, on a tendency for the mica to lie with its basal planes horizontal; secondly, on a disposition of the felspars, both as constituents of the matrix and as porphyritic individuals, to rest with their flat sides in a similar position; and, thirdly, in the orientation of the felspars with their long axes parallel to the "cleaving-way" joints. The first and second of these structures probably explain the tendency to cleave parallel to the horizontal joints, while the third seems to show why the rock splits parallel to the "cleaving-way" joints. The rock has evidently undergone a rude and initial degree of foliation, probably brought about by fluxion, whereby its component minerals have arrayed themselves in a definite direction.

The set of major joints which trends approximately east-north-east corresponds to an extensive system of fissures that has been formed in the granites and Palæozoic rocks of Cornwall by the Carboniferous disturbances. These fissures, moreover, are parallel to the axis of granite intrusion running from Dartmoor to the Scillies, and also to the general trend of the elvan dykes and mineral lodes, the fissures having afforded the channels along which the elvans have flowed, and by which the metallic vapours and solution have travelled, while their walls have received the mineral deposits with which these currents have parted.

As that part of the Carnmenellis granite that lies within this Sheet is of limited extent and exhibits no petrological characteristics that are not represented in the main mass lying further north, its microscopical characters call for no further description than those already published in the Memoir of the northern area[1]. Owing to the land being under cultivation, the junction of the Carnmenellis granite and the killas has not been encountered within this area, but in some instances, as at the head of Polwheveral Creek, there is a continuous section of the slates almost up to the granite with no indication of veins from the latter[2]. In all probability, therefore, this granite does not vein to any extent the adjoining killas, as is the case with many of the granites of West Cornwall.

Godolphin Granite.

The Goldolphin granite, a small portion of which lies within this Sheet at Breage, is like that of Carnmenellis in its colour and mineral composition. It is, however, of much finer texture, and, except towards the south-east, the metamorphic aureole is narrower. This granite, moreover, sends veins for some distance into the adjoining strata, as may be seen in a quarry 300 yards south of Penbro. They can best be studied, however, on the

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[1] 'Geology of Falmouth, &c.' (*Mem. Geol. Surv.*), 1906, pp. 56–59.

[2] De la Beche, however, records the presence of veins near the Mill at Polwheveral. See 'Geol. Report on Cornwall, &c.,' 1839, p. 166.

cliffs below Tremearne, a little beyond the western margin of the Sheet. As the outer limits of the metamorphic aureole, instead of following the south-westerly bend of the granite from Breage to Trewavas Head, continue south-easterly to Porthleven and the Loe Bar, the granite probably occurs beneath the sea opposite Porthleven, or is present at a short distance below the surface.

ELVANS.

The dyke phase of the Carboniferous granites is represented by an acid group of intrusions of similar composition to the granite itself, and the petrological relationship of both classes of intrusion is obvious. Most of the elvans are granite porphyries, micro-granites or felsites, and some are aplites, while others are related to the granophyres. Their average trend in this Sheet is north-east and south-west. They frequently cut the granite in the area to the north, as may be seen in the published map of that tract (Sheet 352), but such intersection cannot be shown in the area now being described.

They exhibit considerable variation in texture and mineral composition, as also in their readiness to disintegrate, some affording excellent building-stone, while others have suffered extreme decomposition. The colour ranges from pale grey to pink, while some are of darker hues. Their groundmass varies in texture from fine to fairly coarse. In this matrix phenocrysts, often idiomorphic, are scattered, and consist of quartz, felspar, usually perthitic orthoclase, sometimes plagioclase, biotite, and occasionally muscovite. The porphyritic quartz shows generally corroded edges, while the felspars are frequently wholly or partially decomposed, with the production of secondary white mica, and the biotite often passes into chlorite. The matrix consists of quartz, felspar, usually orthoclase, white mica, biotite, and apatite. Pinite is rare, but tourmaline is often present. The groundmass frequently contains micropegmatite, and is sometimes micropoikilitic. In the mineralised areas, where the rock has been impregnated with silica and schorl, the felspar has been almost entirely removed, and the biotite has often been replaced by chlorite, but in some cases the latter mineral has not been attacked, while apatite has also offered considerable resistance to decomposition. The general petrographical character of the Cornish elvans was described by J. A. Phillips over thirty years ago[1].

In this area the elvans occur in a narrow belt of country about seven miles in length, extending from Porthnavas Creek on the north-east to Sowanna in the south-west, within little more than a mile from the coast of Mount's Bay at Gunwalloe. Beyond this belt these dykes are restricted to a small tract around Sithney and Breage. The latter group is confined to the Mylor Series, while the former assemblage occurs in a tract occupied by the whole Lower Palæozoic sequence.

The larger and south-easterly elvan group will now be briefly described. At the head of Porthnavas Creek two elvans are seen

[1] J. Arthur Phillips, 'On the Rocks of the Mining Districts of Cornwall,' *Quart. Journ. Geol. Soc.*, vol. xxxi., 1875, pp. 334.

on the shore about half a mile south of Roskillen, while another along the same line is exposed on either side of the small inlet fronting the village of Porthnavas. These dykes are about 6 feet in width, and may be described as granite porphyries, with quartz, felspar, and white mica porphyritically disposed in a finer felsitic matrix. Another dyke is seen on the eastern shore of Polwheveral Creek, about one-third of a mile north-west of Calamansack. It is probably 5 or 6 yards in width and somewhat similar to the Porthnavas elvan, except that the porphyritic constituents are only quartz and muscovite. Two small elvan dykes are seen at the head of Polwheveral Creek, one of which is close to the granite boundary.

A dyke that has been traced for about two miles crosses the head of the Helford River at Bonallack, near which place it has been quarried. Its margins are not seen in the quarry, but its width there must be at least 12 or 15 yards; on the eastern shore of the Creek its breadth is from 12 to 15 feet. On the western shore it can be seen, but the section is unsatisactory, and is represented largely by *débris*. A large quarry has been opened in this rock adjoining the main road, about a third of a mile north-west of Mawgan, and from thence it continues in a south-westerly course to Roskymmer, near which place a small quarry has been opened. It is a coarse-grained biotite elvan, hading to the south-east, with abundant phenocrysts of quartz and smaller turbid felspars. Bleached and weathered biotite is more abundant than usual in rocks of this class. The matrix is micropoikilitic to micro-granitic, with graphic halos around the quartzes. This rock, as seen in the quarry north-west of Mawgan, has a parallel structure and looks slightly sheared, with the biotites orientated, but under the microscope this structure is not very apparent (4640).

In the belt between Mawgan Cross and Nantirret there are four dykes of fine-grained porphyritic felsite (5551 and 5557) that closely resemble the aplite of Tresevern lying within the Carnmenellis granite in the map to the north, and described in the Memoir on that area[1]. The first of these, situated immediately south of Mawgan Church, where it has been quarried, dips S.S.E., and was briefly described by Mr. R. Thomas[2]. To the south of Rosevear two parallel dykes on either side of the valley have also been quarried, both of which hade about 45° S.E. A similar dyke of pinkish colour has been quarried at Nantirret, while further south-west in the vicinity of Sowanna another outcrop can be traced by the *débris* in the soil.

The smaller group of elvans in the north-west corner of the Sheet is much more restricted. A dyke crosses about a quarter of a mile south-east of Sithney, having a north-east and south-west trend. At Sithney another elvan has been drawn on the old map, but its existence could not be demonstrated during the recent survey. As it has been shown, however, as the continuation of another dyke that occurs farther to the south-west near Trelissick, it may be present beneath the soil, or the dyke may have been

[1] 'Geology of Falmouth, &c.' (*Mem. Geol. Surv.*), 1906, p. 72.
[2] *Trans. Roy. Geol. Soc. Corn.*, vol. vi., 1843, p. 109.

unduly prolonged on the old map, as was frequently the case. The dyke near Trelissick, which has been referred to above, runs north-east and south-west along the lower end of the tributary valley, which passes to the west of Sithney, and is apparently only a few feet thick. It is one of the fine-textured felsitic type without porphyritic crystals, and carries much pyrites.

Close to this dyke another occurs to the north-west, probably 5 or 6 yards in width, and containing porphyritic felspars up to an inch in size. On the western side of the main valley leading to Porthleven a similar dyke has been quarried, which is doubtless a continuation of the same elvan, but thrown to the north-east by the great cross course that follows the line of the valley; the texture is coarse, with large quartz grains very abundant, and porphyritic felspars that reach an inch in length. It is of a dark grey colour where fresh, and of a reddish hue on its external surface where more decomposed.

A small elvan dipping to the north is seen at Wheal Fortune[1], which underground has a most irregular behaviour, and often swells to a considerable size. Another elvan occurs in the valley a quarter of a mile south of Trelissick, pursuing a south-west course. On the old map it has been drawn inside the Godolphin granite, but whether it really cuts that mass the evidence is now insufficient to show. To the south of Trelissick it is exposed amongst mining excavations, where it is crossed transversely by a lode carrying copper pyrites. Only one side of the dyke can be seen, but it must be several yards wide. It dips at a low angle to the south-east, and contains quartz, tourmaline, and porphyritic felspars up to an inch in size. It was formerly quarried close to the roadside to the south of Penbro.

[1] $\frac{1}{3}$ mile N.W. of Trelissick.

CHAPTER XX.

METAMORPHIC AUREOLES OF THE GRANITES.

The killas that flanks the Carboniferous granites has been considerably altered by the heat and vapours given off by those plutonic intrusions during the slow process of their consolidation. As the southern edge of the Carnmenellis granite skirts the northern border of the Sheet for a distance of six miles there is an extensive aureole of metamorphism immediately adjacent to that mass. Although the Godolphin granite is represented by a very small area at Breage, its aureole of contact alteration is considerable, being over three miles in length.

These metamorphic aureoles exhibit great variation in their width, which is largely controlled by the angle at which the granite plunges beneath the surface, as also in a less important degree by the duration of the period of cooling. As regards the respective aureoles encircling the Carnmenellis and Godolphin granites, it is seen that the former considerably exceeds the latter. Whereas the Carnmenellis granite occupies an area approximating to about sixty square miles, the smaller mass of Godolphin has a superficial extent of about five square miles. The finer texture of the latter points to its more rapid cooling, while the more restricted aureole of metamorphism follows from the same cause.

These individual aureoles, however, themselves exhibit variation in breadth, and, moreover, the degree of metamorphism, notwithstanding a general decrease from the granite margin outwards, is by no means uniform in this respect. While this may to some extent be accounted for by the diverse chemical composition of the killas, it cannot be doubted that the structural features of the latter must likewise have contributed to this result. The sediments were folded, fractured and cleaved prior to the irruption of the granite. Moreover, as the compression to which they owe their deformation has taken place at depths sufficiently shallow to lie well within the zone of fracture, the folds are rarely of great amplitude, as relief from strain has readily been afforded by actual disruption. As a result the killas has been so extensively fissured as to resemble a gigantic breccia, the irregular rock segments into which it has been divided being bounded by fracture planes with such slight displacement that the continuity of the general dip has not been seriously affected. This brecciation often results in the development of crush breccias.

As a consequence of these mechanical changes the killas is on the large scale singularly incohesive, but the intrusion of the granite has to some extent restored its solidity; the contact alteration being comparable to a process of rock-welding, so that within the metamorphic aureole the strata are more massive than beyond it. The heterogeneous condition of the killas, due to these structural changes alone, must have played an important part in controlling the chemical changes set up during the cooling of the granite.

Before proceeding to indicate the course and behaviour of the metamorphic aureoles flanking the granites, it is necessary to point out that their outer limits representing a feeble and gradually diminishing metamorphism cannot be fixed with any attempt at precision. Moreover, owing to the fluctuating thickness of the killas that overlies the granite due partly doubtless to the uneven subterranean contour of the latter and partly possibly to later crustal disturbances, the metamorphic belt may include killas in which no alteration can be detected. In the same way small outliers of knotted slate may occasionally be seen beyond the limits of the main belt of alteration, but sufficiently close to associate them with the two granite masses with which we are dealing. In other words, the upper limits of the metamorphic aureole are marked by undulations that do not always reach the present ground surface.

The aureole flanking the southern edge of the Carnmenellis granite that lies within this Sheet forms a belt ever widening towards the west, so that while in the east its breadth is about half a mile, in the Helston district it attains a width of at least two miles. This belt of metamorphism lies within the Mylor Series, except for a small tract in the vicinity of Gweek, where it has extended into the adjacent Falmouth group. The metamorphic belt associated with the Godolphin granite is only about a third of a mile broad along the north-eastern flank of that granite which lies in the adjacent Sheet to the west. After reaching Breage, however, the granite margin suddenly swings round in a south-south-west direction until it reaches the coast. The metamorphic belt, however, does not share in this acute bend of the granite but sweeps round more gently, its margin gradually receding, so that the aureole at Breage is fully half a mile in breadth, widening gradually until at Tregew it is three-quarters of a mile, and finally sweeps round to the south-east through Porthleven to Loe Bar.

The increasing belt of metamorphism following the diversion of the granite margin at Breage is doubtless due to the fact that on this side the granite plunges at a more gentle angle beneath the killas, and it is probable that it again comes to the surface further to the south-east beneath the sea opposite Porthleven. Not only is this inferred from the course of the metamorphic belt, but where the granite reaches the coast it sends extensive veins into the killas in a south-easterly direction as seen at Tremearne Cliff where they were mapped by Mr. Wilkinson[1]. This metamorphic belt flanking the Godolphin granite is also confined to the Mylor Series, except for a slight tract at Loe Bar, where it has continued into the Falmouth group. While the coast section from Tremearne Cliff to Loe Bar crosses the aureole obliquely, the shores of Polwheveral Creek afford a continuous section

[1] 'Geology of the Land's End District' (*Mem. Geol. Surv.*), 1907, p. 49, and 'Geological Report on Devon, Cornwall and West Somerset,' by Sir H. T. de la Beche, 1839, p. 166.

cutting directly across the entire metamorphic belt, and the whole phenomena may be studied within the distance of about half a mile from the granite margin.

Throughout the contact zone the dominant feature is the development of spots or knots forming 'spotted slates' or *knotenschiefer*, which are especially marked in the argillaceous members of the killas. This peculiar aggregation of material that characterises the earlier stages of thermal metamorphism is, so far as the outer portion of the aureole is concerned, the sole product of alteration. It is, however, also strongly developed among the more highly modified products of the inner zone.

As the rocks are mainly argillaceous, the contact minerals formed are chiefly aluminous silicates, the most characteristic of which are andalusite, muscovite and biotite. These minerals pervade the inner zone, andalusite occurring in the belt immediately next to the granite, while secondary white mica and biotite extend to greater distances from the intrusion, the biotite perhaps having a wider range than the muscovite. Both micas, however, closely aggregated, occur usually in tiny scales, the biotite being of the reddish-brown colour characteristic of contact altered rocks. Pyroxene and epidote likewise occur as secondary minerals in the contact zone within the greenstones. The knots exhibit various shapes and sometimes represent andalusite in an imperfect state of crystallisation, but often consist of aggregates of mica and quartz. Tourmaline, in this area, is rare in the metamorphic belt. As the killas is frequently divided by shear planes that impart the structure of a schist, the access of mineralisation due to contact metamorphism has produced occasionally good mica schists.

Microscopic Characters of the Metamorphic Zone.—As in the area to the north the microscopic characters of the metamorphic belt flanking the Carnmenellis granite have already been rather fully described[1], it will be unnecessary to repeat the evidence in this Memoir as regards that part of the aureole that lies within this Sheet as it presents no new features of interest. A specimen of knotted andalusite slate obtained from Treviades at about a hundred yards distant from the granite junction is seen under the microscope to consist principally of quartz, biotite and muscovite. The quartz forms strongly marked parallel bands running along the foliation, and the biotite is of a deep brown colour and is partly weathered into chlorite and limonite. Andalusite is abundant although the crystals are not large but tend rather to form aggregates of small grains; it is sometimes pleochroic but mainly colourless, and contains comparatively few enclosures, the most common being small grains of magnetite and cavities. Knotting is not pronounced even in the hand specimen (3435).

Another specimen from Polwheveral at about 135 yards from the granite margin shows on the surface pale divergent sheaf-like masses resembling those of the *garbenschiefer*. Under the microscope is seen a mass of biotite, muscovite, quartz, andalusite with a small amount of tourmaline, magnetite and chlorite. The andalusite is often full of biotite but never resembles chiastolite in the arrangement of its enclosures. The foliation is rude and imperfect (3437).

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[1] 'Geology of Falmouth, &c.' (*Mem. Geol. Surv.*), 1906, pp. 82–86.

CHAPTER XXI

MICA TRAPS.

General Description and Lithological Characters.—The mica traps of West Cornwall were treated by the earlier writers as members of either the Elvan or Trap groups. De la Beche refers to them among the latter, while Messrs. A. K. Barnett and J. A. Phillips include them with the former. Mr. J. H. Collins[1] was apparently the first who gave a detailed account of these rocks as a group, but he states that their recognition was originally established by the researches of Mr. A. K. Barnett.

In this area they are apparently confined to the minettes, the two principal minerals being orthoclase felspar and biotite, with quartz, apatite, and carbonates as the more important accessories. Augite or pseudomorphs after that mineral have rarely been recognised, in such cases the rock falling under the category of augite minettes. Owing to their advanced weathering the nature of the felspars is not always determinable, so that kersantites may be represented. They occur as small irregular sills and bear a marked resemblance to the lamprophyres that are so commonly distributed throughout the schists of the Scottish Highlands, except that in Cornwall they are more decomposed in common with the killas that encloses them, a distinction that is evidently due to the absence of glaciation in the south-west of England. As pointed out by Dr. Teall[2], these rocks are similar in composition, state of preservation, geological age, and mode of occurrence to the lamprophyres of Gümbel, that occur as small dykes, generally running north and south, in the Palæozoic strata of the Fichtelgebirge, Thüringer Wald and Voigtland, that are intruded in strata as high as the Culm Measures. In the south of Scotland and the north of England they penetrate Lower Palæozoic strata, and in the Scottish Highlands they appear to have undoubted affinities with the dyke phases of the Newer Granites, which cannot be younger than the Lower Old Red Sandstone.

In Cornwall they are considered by Mr. Collins[3] to have preceded the granites that are apparently of late Carboniferous age, and to have been injected "about the close of the Devonian period." While the fractured condition of the mica traps and the evidence they bear of having shared in the stresses to a much greater degree than is exhibited by the elvans, lends some support to Mr. Collins's conclusions, their petrological affinities with the Permian volcanic rocks of Devonshire suggests that they may be referable to this later epoch.

As the minettes do not occur within the granite aureole their relative age with the granite cannot be decided as is the case with the greenstones and elvans. The mica traps show no granulitsation, but in some instances the micas have been distorted. The biotite is occasionally bleached and has sometimes been replaced

[1] J. H. Collins, 'The Geological Age of Central and West Cornwall,' *Journ. Roy. Inst. Corn.*, vol. viii., 1884, p. 190.

[2] 'British Petrography,' 1888, p. 351. [3] *Journ. Roy. Inst. Corn.*, vol. 13, p. 203.

by chlorite. They present a rusty brown aspect in the field and are generally highly decomposed. They occur as dykes and sills traceable only for short distances in the killas, on which they have effected a limited amount of contact alteration, indurating the marginal slates for about 6 or 9 inches. They occasionally display spheroidal and fluxion structures, and quartzose and felspathic inclusions, and they moreover vary considerably in texture; the biotite, however, retains its normal dimensions notwithstanding the variable texture of the rock, and this, taken in conjunction with the occasional distortion of that mineral, points to its having crystallised at an early stage. As will be seen later, they share in the minor dislocations that have heaved the slates.

Distribution and Field Relations.—The mica traps of this area lie in the southern portion of a belt of country extending from the vicinity of Truro to the basin of the Helford River, through which tract these rocks are sporadically distributed. Those which occur in the northern area have been described in the memoir on the Falmouth Sheet[1]. The dykes of that belt that lie within this Sheet occur on the coast at Mawnan and The Gew, on either side of the entrance to the Helford River, on the northern margin of that creek, west of Helford Passage, and on the southern shore north-west of Helford, and on either side of Frenchman's Creek[2]. Beyond the Helford River the only example of this class of rock is seen on the coast at Men-aver Beach west of Nare Point.

The dykes that are exposed on the cliffs to the east and south-east of Mawnan afford the best opportunities for the study of their mutual relations with the killas amongst which they occur, the cliffs forming a strike section of sandy and argillaceous killas dipping seaward while the mica trap lying as a sill between the beds is frequently exposed. Owing to the folding and disturbed nature of the killas the sill presents a somewhat irregular aspect, having been intruded after the general plication of the area so that it is sometimes represented by lenticles, due to the cliff face having cut the junction of the two rocks, as pointed out by De la Beche, and figured by him in his Report[3]. Not only is it clear that the dyke is posterior to the folding, but the evidence is conclusive that it is also later than the dominant quartz veining of the killas. On the other hand some of the small faults that abound in the killas are posterior to the sill, which they traverse and sometimes heave. The mica trap varies from four to six feet in thickness, and the northern exposure is fresher and more massive than that south of Mawnan. Its average dip is about 40° or 50° to the south-east. It contains inclusions of quartz and felspar some of which are two or three inches in length and are often well rounded, as is so common a feature of inclusions in the lamprophyres. The dyke encloses thin seams of slate and contains fragments of the same material. It is of medium texture with biotite and felspar standing out clearly to the naked eye, but the margin shows chilled edges of finer material. These sills strike about north-east and south-west. Under the microscope (3560) it is seen to be a decomposed minette containing a

[1] 'Geology of Falmouth, &c.' (*Mem. Geol. Surv.*), 1906, pp. 74–80.
[2] A branch of the Helford River leading to Frenchman's Pill.
[3] 'Report on the Geology of Cornwall,' 1839, p. 94.

yellow brown biotite with darker borders, in all stages of decomposition. The felspar is mainly orthoclase but is also much decomposed, and there are pseudomorphs in calcite and quartz which may be after augite.

Inland these sills are seldom seen on account of their small size and want of continuity, and there are doubtless many lying below the soil that have not been detected. One apparently traverses the churchyard at Mawnan as evidenced by the *débris*, but this is the only locality within the area of this Sheet where these sills have been met with beyond the coast during the progress of the survey.

On the north shore of the Helford River, about a quarter of a mile west of the coastguard station, there is a decomposing mica trap about 15 to 20 feet in breadth whose relations to the slate are very irregular as if intruded between folded strata, the cleavage, however, of the latter appears to be truncated by the dyke. It seems to crop out again on the south shore, due north of Kestle, still following a north-east and south-west direction. It varies in width from 10 feet downwards, and thin bands of slate are enclosed within the sill. It contains quartz inclusions and exhibits spheroidal weathering, and has been intruded along the bedding of the slate subsequent to the isoclinal folding of the latter. Further to the south-west a sill about 10 feet thick occurs on either coast of the creek leading to Frenchman's Pill which, judging by its direction and general character, is related to the intrusion just described. A specimen from the Helford rock, where very fresh, shows under the microscope (4639) large biotites with a pleochroism from pale straw yellow to dark reddish brown; they have a general parallel arrangement due to fluxion and are often bent and distorted. They are darker on their borders and exhibit good crystalline forms, but the larger crystals in cross section have zig-zag edges. This mineral is nearly uniaxial; greenish brown hornblende appears also in clusters of small idiomorphic crystals which may be after some other ferro-magnesian. The felspar is mostly orthoclase (probably with some soda) and is turbid and reddened by weathering but still preserves its polarisation characters. Apatite in hexagonal needles is very abundant and forms groups of crystals in parallel growth. Magnetite occurs in small octahedra, while chlorite, calcite, pyrite, and a little quartz (perhaps secondary) are the remaining ingredients.

An irregular sill of the same type is seen on the coast at The Gew at the southern entrance to the Helford River. This intrusion is eight feet at its thickest and generally only about four feet. It branches and tails out. It contains inclusions of quartz some of which are rounded while others are angular; there are also included fragments of slate. It exhibits spheroidal weathering and the slates on its immediate margin have been indurated and subsequently brecciated. While all the dykes hitherto described are intrusive into the Portscatho Series (Ordovician), the remaining example of this rock met with in the area pierces the Devonian conglomerate. It is seen on the beach at Caermenow—adjoining the road leading to Penare—trending about north-north-east and south-south-west. It is of the usual brownish colour, very decomposed, and with spheroidal weathering, while its width is probably about six feet.

CHAPTER XXII.

TERTIARY ROCKS.

Eocene.

The composition of the beach-shingle at Gunwalloe is so peculiar as to point to the proximity of some Tertiary deposit[1]. The shingle is perfectly rounded, and in appearance is unlike anything one would expect to find in Cornwall. The coarser beach pebbles proved to consist largely (about 70 per cent. by weight) of Chalk-flint and Greensand-chert, only 30 per cent. being Palæozoic at the spot where it was examined. A large quantity of the fine shingle, examined by Mr. Clement Reid, yielded:—

	Per cent.
Chalk-flint	86·0
Greensand-chert	2·0
Quartz	9·0
Grit	2·5
Serpentine	0·5
	100·0

The absence of Chalk-flints from the Pliocene gravels seemed at first to suggest that the Gunwalloe gravel might be derived from some deposit of glacial origin. A study of certain angular flint gravels found at Ludgvan in Mount's Bay shows however that the Gunwalloe beach is derived from the neighbourhood of Ludgvan, and a close examination suggests that these large unworn flints come from an outlier of Eocene or Oligocene river-gravel, such as occurs on the east side of Dartmoor, extending in long tongues into Dorset.

There is no reason to suppose that any Eocene outlier still exists within the area here described; but such an outlier may well be found beneath the sea in Mount's Bay.

Pliocene.

No sedimentary rocks of Upper Palæozoic or of Secondary age are known to occur within the limits of this Sheet, but resting on the gabbro of Crousa Common there is a patch of gravels that may with reasonable probability be ascribed to the early part of the Pliocene period. As the main road to St. Keverne passes over Crousa Downs, and the gravels have been dug for many years as material for mending roads their occurrence at this spot has long been known. De la Beche mentioned them in 1839[2], and states that "this patch of gravel is perfectly isolated, occupies

[1] C. Reid, 'On the Probable Occurrence of an Eocene Outlier off the Cornish Coast,' *Quart. Journ. Geol. Soc.*, vol. lx., 1904, p. 113.

[2] 'Report on the Geology of Cornwall, Devon and W. Somerset' (*Mem. Geol. Surv.*), 1839, p. 396

an area of about half a square mile, at a height of about 360 feet above the level of the sea, and resembles no other accumulation of superficial detritus within considerable distances." In 1843 the Rev. E. Budge[1] described the pits that were being worked at that time and considered that the gravel was of 'diluvial' origin.

The Crousa Common gravels occupy an area of rather more than a third of a square mile; the surface is covered with gorse, heather and pine woods, but differs so markedly from that of the surrounding gabbro that the boundaries of the area are easily ascertained. The gravels yield a light, dry, and rather barren soil, which is exceedingly thin and contains quartz pebbles in great abundance, while the gabbro is covered with great residual blocks of grey rock set free by the weathering of the subjacent mass. At the margins of the outcrop there is a mixture of quartz pebbles and gabbro *débris*.

Many pits have been opened in the gravels, but only one of them is worked at present. It lies on the south side of the St. Keverne road near the east end of the outcrop; the working faces are about ten feet deep and show only gravels with stones mostly two or three inches in diameter, but sometimes eight or ten inches. Mixed with the gravel there is a small amount of sand and whitish clay, but these do not form well-defined strata. The bottom of the deposit is not exposed at present, though it probably rests on a clay derived from the gabbro beneath, as in wet weather the pits are full of water.

When the vertical section of the gravel in the face of the pit is viewed from a short distance it exhibits remarkable curvature or contortions, as if the deposit had been folded. The folds are very irregular and about eight feet deep. In the lowest portion of the deposit a horizontal stratification is sometimes clearly seen; hence these contortions are restricted to the upper part of the mass, and Mr. Clement Reid, on seeing them, suggested that they were due to irregular sub-soil movements in periods of intense frost followed by sudden thaws, such as might have happened about the close of the Glacial period.

The old pits, which are quite numerous, are often overgrown with gorse, so that little information is to be obtained from them. No fossils are to be found in the pits at present, nor are there any records of the occurrence of fossils in these beds. One large pit in a wood on the north side of the St. Keverne road is full of water, but in this pit it can be seen that the base of the deposit contains blocks of gabbro several feet in diameter.

The stones in the gravel are nearly always vein quartz such as occurs as veins in the killas north of the Lizard boundary. They are seldom well rounded though never angular; most of them have little pits and protuberances, and resemble potatoes in shape. In this respect they are similar to the quartz pebbles in the gravels at Polcrebo, in the Sheet to the north of this one, that were described by Mr. Tyack[2] and Mr. Hill[3]. No granite

[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. vi., 1843, p. 91.
[2] *Trans. Roy. Geol. Soc. Cornwall*, vol. ix., 1875, p. 175.
[3] 'Geology of Falmouth and Camborne' (*Mem. Geol. Surv.*), 1906, p. 88.

occurs in the gravel, and gabbro blocks are only seen at its base, but here and there a few small fragments of quartz-tourmaline rocks may be found, such as occur in veins in the country around the granite. From these facts we infer that the materials must have been transported from some distance, as they are all of foreign origin and only the hardest and most durable rocks are represented. If similar gravels once covered the whole area from Polcrebo, which is miles north of Helston, to Crousa Downs a vast amount of killas must have been removed by denudation to furnish so much vein-quartz.

The gravels rest on the highest part of the Downs at an elevation of 365 feet. They once covered a much more extensive area, for traces of them are observable on Goonhilly Downs between the Dry Tree and Traboe Cross, but they occur only on the present watershed of the country and have no relation to the existing river system. No signs of old river valleys can be found to explain their occurrence at these elevations. The similar gravels at Polcrebo have been ascribed to the Pliocene, and Mr. Clement Reid, after a visit to Crousa Down, was satisfied from their relations to the Pliocene platform of the Lizard that the Crousa Common deposits also belong to that epoch. At St. Erth in the Land's End area[1] there are well-known Pliocene deposits that have yielded many fossils; they are assigned to the lowest part of that formation; and at St. Agnes[2], in the Newquay Sheet, other deposits of sand and gravel occur on the surface of the rock platform that is so characteristic a feature of western Cornwall, and are believed also to be of Pliocene age. The Crousa Common gravels are accordingly one of the scattered patches which are all that remain to testify to the former existence of a wide-spread deposit of marine sediments on the lower grounds of the county. Much of these deposits may have consisted of sands and clays that were more readily washed away than the gravels by rain, or by the waves of the sea, as the land emerged after subsidence.

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[1] C. Reid, 'Pliocene Deposits of Britain' (*Mem. Geol. Surv.*), 1890, p. 59. 'Geology of the Land's End District' (*Mem. Geol. Surv.*), 1907, p. 71.

[2] 'The Geology of the Country near Newquay' (*Mem. Geol. Surv.*), 1906, p. 62.

CHAPTER XXIII.

PLEISTOCENE AND RECENT DEPOSITS.

Raised Beaches and 'Head.'

In all probability the excavation of the valley system dates from the post-Pliocene uplift, and has continued from thence to the present day, but during that interval there have been marked oscillations involving changes in the mutual boundary of land and sea. Thus the raised beaches of Cornwall that are of Pleistocene age were formed when the relative level of land and sea differed little from that of the present time, and after a submergence of the valleys which allowed the tidal waters to occupy the estuaries at least to the extent which prevails to-day. After the epoch of the raised beaches there was another uplift of the land which at the close of the Glacial period must have stood fully 50 feet higher than at present. During that epoch, although Cornwall lay to the south of the great *mer de glace* beneath which the greater part of Britain was buried, its proximity to that ice field entailed rigorous climatic conditions. The higher ground was covered by snow, and the soil cap on the barren slopes deeply frozen, so that summer thaws, acting on a frozen surface unchecked by vegetation, induced an extensive slipping of the subsoil to lower levels, which, creeping seaward, ultimately found repose on the Pleistocene beach platform. This abnormal formation, often rudely stratified, is known as 'head.' Concomitant with this great surface creep over the body of the land, the valleys were swept out and deepened by the torrential conditions that then prevailed, so that all trace of the Pleistocene beach along the valleys that previously formed tidal estuaries has been obliterated. Finally the uplifted land surface again began to sink, and the valley floors, once more occupied by alluvium and covered with vegetation, were again buried beneath the waves, as is so clearly testified by the evidence of the submarine forests. Moreover, that final submergence has resulted in a most remarkable approximation in level between the modern shore line and that of the Pleistocene sea.

While the denudation of the land surface, therefore, has been continuous since its uprise from beneath the Pliocene sea, the erosion on the coast line from the action of the waves has been checked by the subsequent upheaval of the land that was gradually extending its frontiers, and this crustal oscillation has so far neutralised the effects of marine erosion that this part of the Cornish platform, terminating in the Lizard peninsula, has practically retained intact its seaward frontier of the Pleistocene age.

A fuller account of the post-Pliocene history of south-west Cornwall has been presented in the Memoir on the adjoining region to the north[1], where the sequence of events can be more satisfactorily studied. We will now proceed to give a brief account of these phenomena in this district, the evidence of which is mainly confined to the coastal tracts.

[1] 'Geology of Falmouth,' &c. (*Mem. Geol. Surv.*), 1906, pp. 90-103

Raised Beach covered with Head at Nelly's Cove, Porthallow.

Eastern Tract Southward to Porthallow.

Between the northern margin of the map and Sowan's Hole[1] there is a well-marked rock platform, varying from 5 or 6 feet to 12 feet above high-water mark, supporting a deposit of conglomerate and gravel about a couple of feet thick, the latter beds being capped by a narrow ledge of 'head' with a maximum thickness of about 20 feet. The beach deposit is mainly composed of quartz pebbles, and is at times cemented by oxide of iron. The Pleistocene beach is not present on the promontory of Rosemullion but to the south of that headland it again lines the coast for about half a mile as far as Mawnan and is capped by a similar deposit of 'head,' and the surface of the latter is broken by landslips. As already remarked the extensive sweeping out of the valleys in the Glacial period has removed the raised beaches from the estuaries, but to the west of the Helford River and reckoning its mouth as marked by Toll Point on the north and The Gew on the south, there are two small relics of the raised beach in the vicinities of Durgan and Padgagarrack Cove[2] on either side of the estuary which have evidently owed their preservation to the sudden widening of the valley just to the west of those localities. At The Gew just beyond the mouth of the estuary there is a small deposit of 'head' overlying the raised beach platform, and at Dennis Head just to the north of the entrance to Gillan Creek there is a small relic of the raised beach resting on a rock platform between 12 and 15 feet above high-water mark. Boulders up to 3 feet in size derived from the Portscatho sandstone occupy the base of the deposit, which is overlain by 5 or 6 feet of sand and gravel and capped by a protective covering of 'head.'

On the southern shore just beyond the entrance to Gillan Creek a most conspicuous platform of 'head' reposing on the raised beach lines the bay extending to Nare Point. The cliffs of 'head' reach a height of about 20 feet and overlie the raised beach which is a few feet above high-water mark. Along the coast for a distance of a third of a mile south of Nare Head this old platform is frequently seen, sometimes capped by gravel and sand, or directly overlain by 'head,' and at heights varying from 5 or 6 feet to 12 feet above high-water mark. Between Nare Point and Porthallow the rocky platform of the raised beach is well displayed forming a narrow ledge often only a few feet above high-water mark. The beach deposit, however, is not always present although frequently exposed, and sometimes encloses large boulders of quartzite, and doubtless many of the similar blocks that line this shore have been washed out of the Pleistocene beach. To the north of Nelly's Cove the raised beach is sufficiently compact to form the roof of a modern cave and was figured by De la Beche. In Nelly's Cove there is an excellent section of the raised beach overlain by head (Plate XIV.) which was likewise depicted by him[3]. He also called attention to the occurrence of flints in the raised beaches[4], a feature which also marks the modern shores.

Western Tract Southward to Polurrian Cove.

The western seaboard lying within the limits of this Sheet is not so extensively lined by the Pleistocene beach. Not only is the coast of Mount's Bay exposed to the force of the Atlantic breakers, but the situation of the Pleistocene platform below high-water mark has brought them still further within the destructive influence of wave action. Whereas on the east coast the Pleistocene rock platform is raised from 5 to 15 feet above the modern shelf, there are only one or two instances on the western seaboard within the limits of this map of that ancient ledge above high-water mark, and the evidence is clear that the modern beach is occupying the Pleistocene shelf, and the few traces of the older deposit that yet remain are doomed to disappear within a comparatively short time.

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[1] $\frac{1}{4}$ mile W.N.W. of Rosemullion Head.

[2] Immediately W. of Bosahan Cove.

[3] 'Report on Cornwall, Devon and West Somerset,' 1839, p. 431.

[4] 'Report on Cornwall, Devon and West Somerset' 1839, p. 429.

On the foreshore to the west of Porthleven there are relics of the Pleistocene beach in a small cave at Pargodonnel Rocks and at the head of a small gully closely adjacent. The cave is filled at high water and the small patch of cemented gravel cannot long withstand the tidal scour. In the small opening to the north some tiny patches of gravel are still adhering to the rocky sides, but mainly in small hollows in the walls which have hitherto afforded them protection. The tidal platform, moreover, is strewn with erratics which have evidently been washed out of the ancient beach; one of these, known as the Giants' Rock, is of about 50 tons weight (Plate XV.). This huge block is composed of microcline gneiss of a type unknown in Britain, and differs also from the gneiss forming the Eddystone Rock. Although its surfaces are polished its edges are not rounded and its shape has not been materially modified since it was stranded by ice on the Pleistocene beach. Smaller blocks are lying in the cave and gully, the largest of which are about 5 or 6 feet in length, consisting of quartz, granite, gabbro and quartzite, some of the latter being of a metamorphic type unknown in Cornwall. These boulders, however, unlike the Giant Rock which stands alone on the rocky foreshore, have been rounded and drifted into their present position by the force of the breakers. On the foreshore to the south-east of Porthleven Harbour similar rounded erratics are seen and many more are concealed beneath the beach shingle.

Three small patches of 'head' occur on the coast between Wheal Penrose[1] and Wheal Rose, and just beyond the latter there is a ledge about 20 feet in length of the Pleistocene beach consisting of sand and gravel with embedded blocks of killas about 6 feet in length. Between Loe Bar and Gunwalloe Fishing Cove there are similar relics of the Pleistocene beach at the foot of the cliffs about high-water mark, while on the south side of that cove the old beach is overlain by 'head.' As was noted by De la Beche the materials of the Pleistocene beach in this locality are firmly cemented together by black oxide of iron and in some cases by oxide of manganese[2]. The powerful cementing properties of iron oxide are well illustrated in this locality where an old iron chain that lies on the modern beach has caused the gravel in its vicinity to be as firmly cemented as the adjacent Pleistocene deposit.

The coast from Porthleven to Gunwalloe Fishing Cove is lined by shingle largely composed of chalk - flints with subordinate chert pebbles probably derived from the Greensand. So extensive is this deposit that it has formed a bar fronting Loe Pool and has converted what was originally a tidal estuary into a fresh water lake. That this abnormal shingle deposit did not occupy this position in Pleistocene times is shown by the composition of the older beaches immediately contiguous, in which flints, although present, are rare. The derivation of this shingle is unknown, but from its great extent and the large proportion of flints it probably represents the destruction of a deposit lying not far distant below the waters of Mount's Bay. Mr. Barrow has described an outlier of sub-angular gravel of similar composition in the Scilly Isles at St. Martins[3].

The Lizard District.

Within the Lizard District raised beaches are principally confined to the eastern shores, where they form an almost continuous fringe to the coast line, though in many places they have been removed by the sea. On the west side of the peninsula they occur only at a few spots far apart, because the more active erosion that is going on in that quarter has almost completely swept them away. It we are to judge of their age by their elevation above the present sea-level, they are not all strictly coeval. The majority

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[1] $\frac{1}{3}$ mile S.E. of Porthleven Harbour.

[2] *Op. cit.*, p. 430.

[3] 'Geology of the Isles of Scilly' (*Mem. Geol. Surv.*), 1906, p. 24.

Glacial Boulder on the Beach at Porthleven.

of them are only a few feet above high-water mark, but others are found at altitudes of 25 to 35 feet. The highest are presumably the oldest, because they are least perfectly preserved; their gravels have either been entirely removed and only the bare rock-platform left, or if preserved they are firmly cemented together. The lowest beaches have their gravels and sands in an incoherent condition.

Starting on the east coast at Porthallow Cove we find small patches of the raised beach below the cliffs a few hundred yards east of the hamlet. They are only a few feet above sea-level, but the old platform and the gravels that cover it are still visible. Between Pencra Head and Porthoustock the raised beach occurs in many places but is being removed in course of the quarrying operations that are carried on there. The deposits are often very sandy with gravels at their base. In Porthoustock Cove the raised beach is seen a few yards west of the pier on the north shore, and there are traces of the platform on the south side. On Porthoustock Point there is a well-known raised beach at a place that has been marked on the one-inch Ordnance map for many years. It rests on a platform of gabbro which is covered by a few feet of gravels. The beaches are not seen on Manacle Point, but to the south of this they can be followed along the shores of Godrevy Cove where they blend with, or are covered by the recent alluvium in the centre of the valley. They are often buried under a small amount of 'head' which, as usual on the gabbro, is of a rather stiff and clayey character.

About Dean Point the raised beach is less conspicuous and near Poleries it is obscured by a storm beach of coarse gravel, but at Lowland Point we meet with the largest spread of raised beach in the peninsula. It covers many acres and consists of rather fine yellow or buff clays, often sandy, and gravelly at the base. The beach platform of gabbro is almost at the level of present high water in spring tides. On the landward side the beach is often covered by large blocks of gabbro which have tumbled down from the old cliff which overlooks the raised beach as a line of grey crags masked by the growth of ivy and other plants. This beach, which is one of the finest in Cornwall, was described in 1842 by the Rev E. Budge.[1]

From Lowland Point to Coverack patches of raised beach are frequent though interrupted often by bare gabbro crags. Their altitude varies, but some of them are 15 feet above high-water mark. The north-west part of Coverack village is built upon a raised beach of sand and gravel resting upon a platform of serpentine and gabbro about 6 feet above high-water mark. The rocks that underlie the beach are much decomposed. The beaches at Coverack have been described by Mr. Ussher in his work on the post-Tertiary geology of Cornwall[2].

In Perprean Cove the raised beach forms an almost uninterrupted border to the cliffs; it is covered by 'head' which is slipping downwards, and its breadth is so small that it can hardly be represented on the one-inch maps. The rock-platform is only a few feet above high-water mark. Chynhalls Point has raised beach at its eastern end, and very well marked on its southern side below the Headlands Hotel. From there to the Black Head the raised beach deposits and the rock platform beneath them are constantly in evidence, though much reduced by the action of the sea. In the old rock-platform the black dykes have often been eroded to form gullies exactly as in the modern beach.

Between the Black Head and the Lizard Point the raised beaches are seldom seen, but at Beagles Point and the mouth of the stream to the west of it there are remains of the rock ledge, and thin gravel and sand deposits in several places. About 400 yards west of Poldowrian (on the east side of Compass Cove) there is a beach platform 12 feet above high-water mark covered with 'head' full of angular stones.

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[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. vi, p. 59.
[2] W. A. E. Ussher, 'The Post-Tertiary Geology of Cornwall,' 1879, p. 18.

In Kennack Cove mere traces of raised beach are to be found in one or two situations. They appear as thin stratified sands and gravels on the south face of the serpentine cliff south of Carn Kennack (20 feet above high-water mark); and in the centre of the west cove rounded beach stones lie among the *débris* on the top of the banded gneisses only 2 or 3 feet above the highest level of spring tides. On the west side of the cove, just south of the gate, scraps of gravel with rounded stones rest on the top of the serpentine cliff at an elevation of 16 feet.

Although there may be a trace of the raised beach platform in Cadgwith Cove, nothing more is seen on the east coast that can be definitely ascribed to this series.

On the west coast by far the most interesting raised beach is that which forms a well-marked rock-platform on Mullion Island, 75 feet above mean tide level. As seen from the shore at Mullion Cove the island presents a remarkable outline as the eastern end is perfectly flat while the western point rises to an elevation of a hundred feet or more. Probably at one time the raised beach formed a shelf all round the island, surrounding a central elevation, but the sea has attacked and removed all the western part of the platform. The Pliocene plateau has always a higher altitude than this and in the Lizard district no isolated rocks rise above it; hence this feature must be of later origin. In the Land's End district Mr. Clement Reid[1] has found at Penlee, south of Newlyn, a raised beach, 65 feet above Ordnance datum, still covered with marine gravels, but on Mullion Island no relic of the beach deposits has been left. In the Scilly Isles Mr. Barrow and Mr. Reid[2] discovered patches of erratics probably deposited by coast ice at a time when the sea stood 200 feet higher than at the present day.

No further signs of raised beach are met with along this coast till we reach Kynance where Mr. Clement Reid has recognised the platform on the west side of the cove at an elevation of 10 feet above high-water mark as showing traces of marine erosion. At Caerthilian Cove (south of Pentreath Beach) remains of raised beach deposits may be seen on the south side of the streamlet and are only a few feet above high tides; on the north side of the cove the rock platform is quite obvious.

A very interesting patch of raised beach was pointed out to us by Dr. Teall on the south side of the Lizard Point just north of the Bumble Rock. It is about 25 feet above high-water mark and is the highest raised beach on the shores of the Lizard peninsula. Nothing is left but a mere scrap of gravels rather firmly cemented together in a little niche on the face of the cliff. It faces directly south and is not easily found as it is concealed by a projecting angle of the cliff. This beach has much of the appearance of the one that was discovered by Mr. Reid at Penlee, though it occurs at a lower elevation.

There is exceedingly little of the unstratified surface material known as 'head' in the Lizard district. As a rule it is to be seen only on the cliffs and has no extension inland. Often the raised beach is covered with 20 or 30 feet of a stony loam that has apparently slipped down into its present position. The evidence would lead to the conclusion that if the 'head' is not contemporaneous with the raised beach it is of slightly later origin. The best exposures are in the cove south of Coverack, where 'head' mantles the face of the cliffs. This material is always of local origin, and the numerous blocks of rock in it are angular and unworn. South of Chynhalls Point there is a narrow fringe of 'head' along the serpentine cliffs, and the finer clay seems to be rapidly washed out, as the surface of the deposit is covered with projecting rocks that closely resemble a scree; evidently under present conditions the 'head' is slowly wasting away.

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[1] 'The Geology of the Land's End District' (*Mem. Geol. Surv.*), 1907, Pl. IV.
[2] 'The Geology of the Isles of Scilly' (*Mem. Geol. Surv.*), 1906, p. 21.

Submerged Forests.

These forest beds which occupy the lower portions of the ancient valleys were submerged in the last subsidence of the land already alluded to, and their sites now lie buried beneath later deposits. So far as this area is concerned their presence has only been detected at two localities. The Rev. Canon Rogers[1] observed the remains of a submarine forest a little above low water mark at Porthleven, with stumps of oaks and willows in the position of growth, and we are informed by Mr. Trezise that a similar deposit was exposed many years ago opposite the entrance to the valley at Gillan Cove, near Flushing.

Alluvium.

The principal deposits of alluvium are those which line the valley floors at Helston, Porthleven, and Gunwalloe, while the streams which empty into the Helford River have deposited narrow bands of alluvium in the valleys which they water. These deposits, however, are mainly confined to fine silt and mud, and only material of this nature is laid down by the streams in the tidal estuary of the Helford River. The extent to which that estuary is being silted up has not been investigated, but as regards the Fal basin in the Sheet to the north, there are more available data, to which the reader is referred[2]. That the alluvial deposits of the Loe Valley are creeping seaward is seen by a comparison of the map published in 1813 with that of 1887, where in that period of 74 years the mouth of the valley has advanced about 200 yards.

Blown Sand.

These æolian deposits are rare in this region, but The Towans at Gunwalloe occupy a tract of about 200 acres, which reaches a maximum height of 174 feet, and forms excellent golf links that are the means of attracting visitors to the district. A small patch of blown sand skirts the slope on the south-eastern side of the entrance to The Loe Pool. In the Lizard district the only area of blown sand is in the centre of Kennack Cove, and its extent is not more than a few acres.

Coast Erosion.

Although this peninsula forms the extreme southern limit of Britain and is exposed to the full force of the Atlantic breakers, the rocks are sufficiently massive to withstand the action of the waves, and coastal erosion is a slow process. This action is retarded, moreover, by the genial climate of the region, so that severe frosts which tend to widen the jointed surfaces are rare, and play but an insignificant part in rock disintegration.

As mentioned earlier, owing to oscillation of the land, the modern coast-line closely corresponds to that of the Pleistocene

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[1] *Trans. Roy. Geol. Soc. Corn.*, vol. iv., p. 482.

[2] 'Geology of Falmouth,' &c. (*Mem. Geol. Surv.*), 1906, pp. 100–103.

period, some of the Raised Beach and 'Head' deposits of that epoch still fringing the shores, and it is in those situations only that the coast-line is showing any perceptible recession.

The Lizard group, which occupies the southern part of the peninsula is composed of more resistant rocks than the cleaved strata of the killas to the north, and their degradation by wave-action has been consequently slower. This is clearly brought out by their junctions at Porthallow and Polurrian, where the Lizard group projects seaward on either coast beyond the killas tract, in the former locality for about half a mile, and in the latter for nearly triple that distance. The greater extension on the western side is due to increased erosion from that shore being directly exposed to the Atlantic. Thus on the east coast considerable tracts of 'head' still remain, as on either side of Rosemullion Head, and to the west of Nare Point; whereas on the western side these deposits have been entirely washed away, save for the few insignificant patches fronting Porthleven Sands.

The influence of resistant strata on coast erosion is likewise marked by the smooth shore line on either side of Loe Bar, where comparatively soft strata of the Falmouth and Mylor groups are enclosed between the Breage granite and massive Devonian sandstone, the former making the headland of Trewavas, and the latter projecting as a promontory to Pedngwinian.

The Lizard cliffs are wasting slowly and at unequal rates. The serpentine is, on the whole, a soft rock and does not well resist the attack of the waves; hence the cliffs are lofty, for they are eaten back to the level of the plateau. The joints in the serpentine are few and the cliff scenery is often very bold and rugged. At the base, on the west coast at least, there is seldom a beach of rolled stones, but fairly deep water may often be found close in to the rocks. The coarse hornblende schist of Predannack seems to withstand the waves better than the serpentine to north and south of it, but the Lizard mica schists and green schists are much less resistant.

On the east side of the Lizard the gabbro, though it weathers more readily than the serpentine on the surface of the downs, is a harder and tougher rock and is better adapted to resist the encroachment of the sea. A good instance of this is the promontory of Carrick Luz, where the great dyke of gabbro projects beyond the serpentine. On the west side of Kennack the banded gneisses are receding rapidly owing to their abundant joints affording planes of weakness in which water and frost can operate to disintegrate the rock mass; after every winter the fallen rock cumbers the base of the cliffs in many places though it is soon washed away by the waves.

Landslips.—Landslips are occasionally seen on the shore margins, and in such cases are hastening erosion. They are very conspicuous on the platform of 'head' to the south of Rosemullion Head, and on the bare cliffs between Mawnan and Toll Point, in both localities the seaward dip of the strata having contributed to their production. To the west of Porthleven, however, between Methleigh Beacon and the margin of the map, extensive landslips occur transverse to the strike of the strata which have given rise to vertical cliffs.

Where dykes of gabbro, epidiorite or gneiss occur in the serpentine they act as channels for water, and landslides are frequent. Looking west from Carrick Luz, for example, we see the whole face of the cliffs covered with screes of broken rock that have been loosened by the action of frost and percolating water in the numerous fissures occupied by intrusive dykes.

The sea also readily tunnels along fault planes and dykes, giving rise to caves. Examples of these are found at Mullion, Kynance, Cadgwith and other places and are well known to visitors to the Lizard.

Often the roof of large caves has collapsed and great circular depressions are produced; these are especially common where there are dykes or veins of the banded gneisses in the serpentine. Some of them are more than a hundred yards in diameter and resemble great quarries as they are filled with broken rock, often in enormous pieces. They form one of the characteristic features of the serpentine cliffs and the best examples are Lawarnick Pit (west of Kynance), Holestrow and Kildown Cove. The Devil's Frying Pan is a similar pit from which the broken rock has been washed out by the sea. The Lion's Den, on the west side of Housel Bay, is of especial interest as being a cauldron formed by the collapse of the roof of a cave during comparatively recent times. The subsidence took place in 1847 and was described by the Rev. C. A. Johns[1]. "On the night of Febuary 19th, 1847, without having shown any previous symptom of insecurity, a portion of turf, in shape an irregular ellipse, about 120 feet in circumference, suddenly subsided to the depth of 30 or 40 feet. The appearance presented next morning was that of a pit with precipitous sides and an overhanging edge of turf, the bottom being level and composed of loose stones and earth. It was known that the base of the neighbouring cliff was pierced by a cave (the Daw's Hugo), which extended in the direction of the new cavity, and as the outer edge of the latter was only 56 feet from the cliff, it was natural to suppose that the roof of the cave had fallen in. Since that time all the material in the pit has been washed out and the sea now ebbs and flows in it with every tide."

Most of the coves are situated at the mouths of the streams and are, partly at least, due to the submergence of the lower parts of the old land valleys. As instances we may adduce the coves at Porthallow, Porthoustock, Church Cove and Mullion Cove. The cove at Kynance has originated partly through the existence of an old land valley that has been attacked on its western side by the encroaching sea, but the rock pinnacles and numerous islets have been separated from the land by the sea taking advantage of lines of fault and brecciation and of dykes of intrusive gneiss that were comparatively easily removed.

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[1] *Quart. Journ. Geol. Soc.*, vol. iv., 1848, p. 193.

CHAPTER XXIV.

FAULTS.

In the area to the north of the Lizard group the killas is crowded with small faults and thrusts as described in the chapters dealing with the tectonics of the Palæozoic strata. Scarcely any, however, are of sufficient importance to show on the one-inch map. The more important marginal faults of Polurrian and Porthallow, together with the few transverse faults that are met with on the boundary of the Veryan and Lizard Groups have already been described.

The intense brecciation that prevails among the Palæozoic rocks to the north of the Lizard boundary is a local characteristic, and stops abruptly when we pass that line. The Lizard hornblende schists, at Porthallow and Polurrian for example, except for a distance of a few yards from the marginal faults, are in a fairly massive state. Among the Lizard rocks, though faults are very numerous, there are few breccias or crush conglomerates.

The Lizard faults may be grouped into two series, the minor and the major. As the rocks are all crystalline and metamorphic and their thickness is not known there is nothing to show what is the actual magnitude of the displacements, but we may consider those faults which can be mapped across country for one or several miles as major faults, while the minor faults are visible only in the coast sections and cannot be followed inland. The major faults very often form the boundaries of certain groups of Lizard rocks for considerable distances.

The minor faults are by far the most numerous. Professor Bonney[1] remarked in 1883 that "faults abound in the Lizard district; they may be noted in almost every cove, inlet, or sea chasm (of which they are probably the cause). The generally uniform character of the rock makes it extremely difficult to estimate the amount of vertical displacement; but, as a rule, I believe it to be slight." These small faults often cut the intrusive dykes and can be proved to have a throw of only a few feet. Many are vertical, others inclined; some are nearly horizontal, and, while the majority are clean cut, there are others which are bordered by zones of schistose character (tremolite schists, gabbro schists, &c.) due to movement of the rock faces on one another. No doubt these small faults belong to more than one period of movement and some of them are of comparatively recent origin. It is certain, however, that many of them are of great age, being in fact contemporaneous with the intrusion of the plutonic rocks. We have already described a case at Kennack where a gabbro dyke was faulted before an epidiorite dyke cut it; another instance of the same thing is seen in the cove west of Poldowrian, and Dr. Teall[2] has described a faulted junction of serpentine and gabbro a little north of Pen Voose (between The Balk and The

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[1] *Quart. Journ. Geol. Soc.*, vol. 39, 1883, p. 3. [2] *Geol. Mag.*, 1887, p. 487.

Chair) that was probably undergoing movement at the time when the gabbro was consolidating. In the banded gneisses there are often small step faults that displace the banding for an inch or two, yet are firmly welded together, and probably were produced while the rock was still hot. The irregular course and frequent disruption of the veins of gabbro schist in all parts of the serpentine have already been described in a previous chapter.

The major faults may be divided into five groups.

I. The east-and-west faults ; pre-Devonian.
II. The north-east faults : post-Carboniferous.
III. The east-and-west faults ; (post-Carboniferous ?).
IV. The north-west faults ; pre-Devonian.
V. The north-west faults ; post-Carboniferous.

I. *The pre-Devonian east-and-west faults.*—The thrust that forms the southern boundary of the serpentine is perhaps the only representative of the dislocations that attended the late Silurian or Caledonian movements that so profoundly affected the structure of the Veryan and other Palæozoic rocks on the north of the Lizard boundary. It has a nearly east-and-west course, somewhat convex to the south, and both at Pentreath and the Balk the hade of the fault plane is to the north at about 40°. The low hade renders it probable that this is a thrust by which the serpentine has been forced southward over the schists, and as the direction of movement was from the north it corresponds with the pre-Devonian or Caledonian stresses in the south-west of Cornwall (p. 31). This fault belongs accordingly to the epoch at which the Ordovician killas was crumpled and broken up before the Devonian conglomerate was laid down on its denuded surface.

There is a good deal of brecciation of the rocks on both sides of this thrust plane and the breccias are veined with carbonates and reddened by hæmatite. In several parts of the Lizard district there are narrow belts of breccia, principally in the serpentine; these have an east-and-west trend, and where there are slip-planes they often dip to the north. It is in every way likely that they belong to the same epoch of movement as the fault we have described, though there is no evidence to prove that they have a considerable displacement. Breccias of this kind are seen in several places on Pentreath Beach to the north of the boundary thrust and parallel to it. Between Enys Head and Poltesco there are several brecciated belts of serpentine, much decomposed and reddened with hæmatite, running in a westerly direction. Similar crush-belts are seen in the serpentine cliff below Carn Kennack, and they are well-marked also in the cliffs about Beagles Point and near the Black Head; in that district they seem to be the source of the copper that was once mined by means of shafts on the cliffs. On the west coast there is a breccia at Gew Graze that may also belong to this group.

II. *The north-east post-Carboniferous faults.*—In the neighbourhood of Mullion there are two important faults having a north-eastern direction; one of them forms the boundary of the hornblende schist at Polurrian and the other separates the serpentine from the schists at Mullion Cove (Porth Mellin). In both cases they are well exposed in section in the cliffs and the fault planes hade to the south-east at about 40°. The Mullion Cove fault at a place half-a-mile inland from the coast contains a lenticle of black killas, between walls of schist and serpentine, and Mr. Hill considers that this rock may be the Devonian slate. In that case the dislocation is post-Devonian, and as the direction of movement in the late-Carboniferous (Armorican) movements was from south to north, we conclude that this is a thrust by which the serpentine has over-ridden the hornblende schists to the north of it. The Polurrian fault has the same strike and hade and may belong to the same group. Both of these faults enter the serpentine and die out or cannot be traced further, the one after a course of three miles, the other in a mile or so.

III. *The east-and-west post-Carboniferous (?) thrusts.*—The dislocations that emerge to the coast-line at Porthoustock and Porthallow have so exactly the same trend that they are presumably sister faults like the two above described. The Porthallow fault has a southern hade where it is exposed in the cliff at the south side of the cove, but the other fault is not seen in section and its hade is not known. If these be thrusts they must have originated under pressures acting from the south and are presumably connected with the post-Carboniferous or Armorican movements. It may be remarked that the Devonian and Carboniferous rocks of the country to the north of this Sheet are often traversed by faults having this direction, and to regard the Lizard boundary line as a post-Carboniferous thrust is a possible explanation of the absence of fragments of Lizard rocks in the Devonian conglomerate. The presence also of a great lenticle of the Treleague quartzite in the southern fault line is quite in accordance with the interpretation of this structure as a thrust plane. The fault plane at Porthallow hades to the south at an angle of 45°.

IV. *The north-west faults (older group).*—A very large number of faults in the Lizard have a north-west trend, though none of them appears to be so powerful or persistent as those above described. There seem to be two groups of these faults, one being of much greater age than the other.

About the Lizard Point there are many north-west faults exposed in the cliffs. They are parallel with the general strike of the schists and the largest of them forms the boundary between the mica schists and the hornblende schists, running north-west from the Lighthouses. None of these faults can be proved to cut or shift the southern boundary thrust of the serpentine; hence they are possibly older than the pre-Devonian movements. It is a noteworthy fact that many of the small displacements that shifted the gabbro dykes before the epidiorite dykes were injected have a north-west or north course, and it seems certain that many of these faults belong to the time before the great basic and acid intrusions had been brought to an end. We may recall also the prevalent north-west trend of the black dykes, which proves that the older rocks were traversed by numerous fissures running in that direction. Many of the black dykes were intruded along lines of fault.

V. *The north-west faults* (*post-Carboniferous*).—In the Carboniferous and Devonian rocks of the west of England the east-and-west mineral lodes are often shifted by north-west dislocations, some of which are of considerable magnitude. Among the north-west faults of the Lizard area there are many that are evidently much later than the injection of the plutonic and intrusive rocks, because they displace the gneisses which are the youngest of them, and these may belong to this epoch of faulting. In this group we may place the fault that cuts the gneisses in Cadgwith Cove and some of the small faults that shift the Lizard boundary line. Many other north-west faults are visible in the cliff sections south of Cadgwith, at the Devil's Frying Pan, for instance, and south of Polbarrow. A north-west fault runs up the Kynance valley, separating the bastite serpentine from the tremolite serpentine and passes between the Lion Rock and the Yellow Carn (Fig. 5). There is also an important fault of this group on the north side of Predannack, separating the serpentine from the hornblende schist. Very little evidence is available as to the age of many of the north-west faults in that quarter. Another important dislocation that has a north-west direction starts in the serpentine at Traboe and crossing the Lizard boundary separates the pillow lavas from the hornblende schists in the neighbourhood of Relowas.

In discussing the nature of the Lizard boundary we stated that its zig-zag or irregular course could be resolved into segments each having the direction of one of the principal fault systems that characterise the district to the south. From Porthallow to Belossack the course is westward, and though sinuous is by no means so irregular as that of many great thrusts; this portion might belong to either the Armorican or the Caledonian east-and-west dislocations, or might be due to both of these in different places since there has been repeated thrusting of the soft killas against the metamorphic rocks. The evidence of the Devonian conglomerates may be adduced in support of the hypothesis that the Lizard rocks were not in their present position before Lower Devonian times. At Relowas the boundary is displaced by a north-west fault, and a smaller displacement having the same direction occurs at Trevassack.

From Belossack to Polglase the direction is south-west, corresponding with the Polurrian and Mullion Cove faults. At Belossack the pillow-lavas may be truncated by a continuation of this displacement but at Polglase no evidence of it was found; strike faults however in such a country may easily elude observation. From Polglase to Bochym the margin has a south-east direction, like many faults within the Lizard, but if this be a fault along its whole course it must be older than the Polurrian fault which is not displaced by it. In the stream south-east of Bochym the junction of the hornblende schists with the dark killas is seen and is clearly a fault that brings hornblende schist and black slate, two rocks in an entirely different state of metamorphism, in contact with one another.

CHAPTER XXV.

ECONOMIC GEOLOGY.

SOILS AND AGRICULTURE.

Northern District.—Although subject to much variation the area between the northern margin of the map and the boundary of the Lizard group is very fertile and almost entirely laid under cultivation. The extreme north of the Sheet, however, occupied by the granite, although almost wholly cultivated has a colder soil than in the killas areas to the south and the crops are more backward. The killas divisions furnish generally a rich soil, except in situations where natural drainage is difficult and clay is readily formed. Moreover, the various greenstones which occur in association with the killas materially contribute to the richness of the soil, and these bands have been taken advantage of where in a soft and decomposed condition and spread on the killas tracts to increase their fertility. The belt of country between Helston and Porthleven in which the greenstones are particularly abundant is very fertile and in a high state of cultivation.

The killas soils, however, are often materially impoverished by the large amount of quartz *débris* with which they are associated, and some tracts are out of cultivation, while others have only recently been reclaimed from the wastes. The belt of country extending westward from Polwheveral to Boskenwyn Downs and Gweek Downs illustrates these conditions, much of it being out of cultivation and covered with gorse and heath. This comparatively sterile belt runs to the south of Helston Downs and extends to the west coast between Carminow Creek and Berepper, but is not so sterile as to the east of Gweek and is almost entirely under cultivation, notwithstanding that it is in many places thickly covered with quartz *débris*, which is particularly conspicuous to the north of Tangies. Beyond this belt there is a large tract in which clay is abundant in the area enclosed by Treloskan, Tregiddle and Millewarn. Clay land is also frequent in the vicinity of the quartzites which have checked the flow of the waters percolating the strata, as is exemplified by the soils to the north-west of Trevaddra.

In the eastern tract, which is protected from the winds by the hollow of the Helford basin, woodlands are abundant. Trees, however, do not flourish in the same luxuriance in the western region, although the proximity to the sea does not affect their growth in sheltered situations as in the valley of the Loe and especially at Penrose. On the high ground, however, in the centre of the peninsula the maritime pine flourishes as can be seen by the plantations to the south of Trelowarren.

Lizard District.—About one-half of the Lizard area is under cultivation at the present time, the remainder being left in its original state of thorny and heather-covered downs which are used only as rough pasturage for the cattle in summer. The evidence of old enclosures and of ruined cottages shows that at some period there must have been a far larger extent of land under the plough and through the influence of agricultural depression there has been a marked shrinkage of the cultivated areas. Recently, however, a certain amount of reclaiming has been done and the best of the waste land is being again taken into cultivation. As this part of Cornwall has never been subjected to glaciation by an ice sheet and as there is very little alluvium in the shallow valleys, the soils are all sedentary or local in their origin and have the closest possible association with the underlying rocks, from which they have been derived by the ordinary processes of disintegration and weathering. The serpentine practically always yields poor stiff land, while the adjacent hornblende schist is rich and fertile. In many places the margin between the cultivated and uncultivated ground follows very exactly the boundary of the serpentine. This is especially striking along that tract of country which stretches from Mullion Cove to Traboe; the hornblende schist in that part is nearly all cultivated but the arable land stops at the edge of the serpentine or extends beyond it for only a few hundred yards. The only outcrops of hornblende schist and gneiss in the Lizard which are not under permanent pasture or under crop are the small outlying patches that lie in the heart of the serpentine on Goonhilly Down.

According to the four lithological types of rock which have an important development in this area there are four classes of soils each possessing distinctive features. These rock types are the hornblende schists, the gneisses, the gabbro and the serpentine. Mixed soils are also found in places where two or more of these rocks are dovetailed into one another or form a complex; around Ruan Minor, for instance, the gneisses have been intruded into the serpentine in such quantity that they greatly modify the character of the soil; but each of these rocks has, as a rule, its own area of distribution and underlies considerable stretches of ground where the soils have been entirely derived from the decomposition of one class of rock.

The hornblende schists yield the best soils in the Lizard peninsula; some of them in fact are so good that it may be doubted whether better soils of sedentary origin are to be found anywhere in Cornwall[1]. To the north of the serpentine, from Mullion by Newtown to Porthallow there is a rich agricultural country situated on rocks of this class. The hornblende schists are deeply rotted and in many places it is impossible to find exposures of hard rock. They decompose into a fine soft brown loam, which sometimes contains small angular pebbles of yellow epidote, the remains of the epidosite veins and bands that occur in the schists. The upper layers of this loam, which have their ferruginous minerals in a state of thorough oxidation, change to a bright red colour, which in early spring before the crops have started vigorous growth is a well-marked characteristic of the

[1] De la Beche (Report on the Geology of Cornwall, Devon and West Somerset, 1839, p. 474) gives some striking illustrations of the high fertility of the soils on the Lizard hornblende schists, and quotes Borlase in support of this.

fields throughout the hornblende schist country. In former years this loam was much used as a marl or top-dressing for the fields and very large old marl-pits are to be found on many of the farms; some of them are 20 feet deep, but really fresh rock is not exposed in them.

This practice of 'marling' the cultivated land has now fallen into disuse, as artificial manures have proved a cheaper and more satisfactory method of fertilizing the soil, but the great size of some of the old pits around Mullion, Traboe and Tregarne indicates that it was actively carried on probably for hundreds of years. In many of them orchards are planted and trees are standing which are of considerable size. On soils derived from hornblende schist the fine rotted rock of these pits cannot have been of much value as a top-dressing; though when mixed with manure in the farmyards it possibly assisted in retaining the soluble nitrogenous matters which might otherwise have been washed out during the wet winters. On serpentine soils, of course, such a compost would do much good.

The fine dark red soils which are typical of the hornblende schist country are developed in greatest perfection where the underlying rocks are of the fine silky compact type of hornblende schists. The admixture of mica schists and granulites with these rocks in certain districts does not appear to affect the character of the soil greatly; this may be well seen in the rich valleys to the south and west of Porthallow. The reason is probably that these rocks are usually felspathic in composition; moreover, they never occupy considerable areas alone, but are always intermingled with chloritic and hornblendic schists. On the other hand the coarse rough hornblende schists (Traboe schists) yield a distinctly inferior soil; the patches of schist enclosed in the north of the serpentine are of this kind. The elevated situation may to some extent explain the sterility of the soil, but it may be pointed out that at Roskruge the hornblende schists are cultivated at the same altitude (350 feet) and give excellent crops. These coarse-grained schists weather more slowly than the fine-grained. They yield a rougher and more stony soil which is often encumbered with large residual blocks, resembling those found on the area occupied by the gabbro; outcrops of bare rock also occur on these schists but never on the finer-grained hornblende schists.

The soils which are derived from the granite and gneiss may be described as yellow sandy loams; they have not a very wide extension in the Lizard Peninsula, being restricted in the main to two areas, that of Erisey (north of Ruan Minor) and Gwendreath, on Kennack Bay. On both of these farms there is much red gneissose granite, deeply weathered, and near the farmhouses there are large disused marl pits. On Gwendreath the granite is so decomposed that the rabbits burrow in it freely. The sandy nature and rather coarse texture of the soil, which is due to the quartz grains in the original granite, make it light, porous and well drained; in fact in dry summers the crops may suffer from lack of moisture. Near the top of Goonhilly Down there is a rather large patch of granite gneiss which is left waste; its soil is very thin and stony because the decomposed fine earth has been washed away by the rains.

The banded gneisses of the Kennack gneiss group resemble the granite gneiss a good deal in the nature of the soils which cover them, but they hardly merit a special description seeing that they never cover large areas but occur only in small fringes on the edges of the granite outcrops or as local intrusions into the serpentine. On the east side of the Lizard road there is a district which includes Grade, Cadgwith, Ruan Minor and Kuggar, which consists essentially of serpentine penetrated by very numerous intrusions of banded gneiss, granite and gabbro. Most of this district is cultivated, and the land is of fairly good quality, though varying much in accordance with the nature of the rock it rests upon. Over this country the slow-weathering serpentine stands out in many small rocky knolls, and a casual observer would conclude that there was little else than serpentine underneath the soil. The coast sections prove, however, that there is great abundance of gneiss and granite, and in places also a fair amount of gabbro in the serpentine. This is confirmed by examintion of the *débris* in the fields which often consists in large part of these rocks. On the slopes of the Ruan valley above Cadgwith red gneiss and striped gneisses can be seen in several places, and this is also true of the Poltesco valley. In this tract of country the fertility of the soil changes from field to field; in one place there may be barren serpentine covered with a thin stiff clay, while close at hand a rich sandy loam may mark the site of a small patch of gneiss. As we pass westwards the abundance of intrusive rocks in the serpentine decreases, and the cultivated land gradually gives place to heathery down. To the west of the Lizard road the serpentine prevails to such an extent that the area of cultivated ground becomes very small.

The gabbro differs from the hornblende schist and the gneisses in this respect that a smaller part of its total area is under cultivation. This amounts to rather more than one-half, and lies mostly on the east side of the outcrop, around St. Keverne and Coverack. On the gabbro there is some very excellent land and much also that is very poor and barren. The traveller passing along the road to these villages cannot fail to be impressed by the large area of down covered with enormous grey blocks of gabbro which he traverses in crossing Crousa Downs. Some of this land affords fairly good pasture and probably none of it is so poor as the serpentine country, but it is not worth cultivating at the present time and is left in a state of nature. The stony barren character of the soil seems to be due mainly to the removal by the rains of the finer particles of earth. Where this process has not gone on to the same extent the gabbro soil may be very good. Around St. Keverne and Lanarth, for example, there are many good farms on the gabbro. Here also are numerous and large 'marl pits' in which it can be seen that the country rock is rotted to great depths and changed to a stiff yellow clay, in which many rounded and sub-angular lumps of gabbro may be found, from a few inches up to several feet in diameter. That this material is gabbro rotted *in situ* is proved by the occurrence in it of dark vertical bands which are the remains of the greenstone or epidiorite dykes, and these often are fresher and more coherent than the surrounding gabbro. Where the gabbro was coarse-grained the shapes of the original felspar and diallage crystals can still be made out in the 'marl.' Near Lanarth there are pits in this material which must be nearly 20 feet deep, and all the farms which stand upon the gabbro have similar pits though usually not so large. When the fine earth is washed away by the rain the large blocks remain and their abundance is to some extent a measure of the amount of soil which has been removed during the lapse of time.

The gabbro soil is stiffer and more clayey than that which is formed from the hornblende schist. It is not quite so well suited for corn, as in wet seasons the crops are so heavy that they are apt to lie down after rains, but in dry seasons the best of the gabbro land yields surprising crops. For the same reason most of the gabbro is in pasture; it gives great crops of grass and is very valuable for feeding stock, especially as the winters are so open in this part of England. The presence of the large gabbro blocks, 'greystones,' as they are called locally, is not so detrimental as might have been supposed, except when they are so deeply buried in the soil that only a few inches of them project; then they may damage the plough, but when they are fully exposed the farmer ploughs round them and they do no harm. Vast numbers of these blocks have been broken up and used for mending the rough stone walls which separate the fields, but even on the old farms which lie between Coverack and St. Keverne it is by no means uncommon to see dozens of these huge stones in the midst of flourishing fields of corn[1].

The soil which rests upon the serpentine is of exceedingly poor quality and is in large measure left uncultivated. The principal downs in the Lizard area, those of Kynance, Predannack and Goonhilly are situated on serpentine, and the only plants which seem to thrive upon these moors are the Cornish heath and one or two species of gorse. The barrenness of the serpentine soil is due to certain well defined causes which are both chemical and physical; in all parts of Britain and the rest of the world where serpentine rocks occur the soils which cover them are noted for their sterility.

The source of this sterility is certainly the abundance of magnesia in these soils. "Kearney and Cameron in America have shown that salts of magnesia possess, even in solutions of great dilution, a toxic action on plant roots, which is much diminished if salts of calcium be present at the same time. Loew at the same time has indicated that a comparative excess of magnesium over calcium in certain soils results in sterility. With this may be correlated the fact that the soils resting upon the serpentine, which is a compound containing magnesia, are notoriously poor[2]." The absence or great scarcity of the alkalies (potash and soda) from the serpentine must also be of considerable importance, and the rock is also poor in phosphate, which is one of the most valuable ingredients of soil for the growth of plants. From these facts we can understand that the common practice in the Lizard area of

[1] Dr. Paris, writing about this part of Cornwall in 1818 remarks 'The lands between the church of this parish (St. Keverne) and Coverack Cove, constitute one of the most extraordinary districts in the Kingdom, presenting a rare combination of rudeness and fertility ; gigantic boulders, and fragments of syenite, lie scattered in all directions, and yet, in point of luxuriant fruitfulness, this country may be denominated the Garden of Cornwall.' (*Trans. Roy. Corn. Geol. Soc.*, vol. i., 1818, p. 189).

[2] A. D. Hall, 'The Soil,' p. 222 (1903).

dressing the serpentine fields with shell sand from the beaches and decayed seaweed is a good one, for the shell sand provides lime, while the seaweed is a source of alkalies, both of which are much needed by these soils.

The physical character of the soil is also unfavourable. The serpentine decomposes slowly, and the layer of soil and sub-soil is very thin, usually not over a foot or two in thickness, and often less than this. On the gabbros, schists and gneisses the sub-soil may be 20 feet deep. The olivine of the original rock yields, when completely decomposed, a fine rusty yellow or brown clay in which grains of some of the other minerals, such as bastite, tremolite and chromite, are embedded. These ochreous clays are impermeable to water, and after wet weather the fields and downs on the serpentine are often water-logged; hence these soils, even when improved by drainage and long cultivation, are cold, stiff and late. Moreover, the abundant iron oxides they contain are partly dissolved from the superficial layers and sink downwards, but are again precipitated in the deeper layers of the soil forming an 'iron pan' which still further prevents the downward passage of water and deteriorates the quality of the land.

By far the greater portion of the serpentine is left waste at the present time, though a good deal of it has been enclosed and may have been cultivated at some former period. There are a few farms near Ruan Major and on the east side of the peninsula around Arrowan and Treleaver that are situated almost entirely on the serpentine; many other farms consist principally of serpentine land, but the soil is improved by the presence of dykes and sills of granite, gneiss or gabbro. The wet soils of the serpentine and of the gabbro have proved unsuitable for sheep-farming; but, where the serpentine is carefully treated, root crops and grass sometimes do moderately well.

Water Supply.

The killas which makes up the geology of the greater part of the northern area is extensively fissured, and retains sufficient water for the needs of the district, although in periods of drought the springs which supply the villages occasionally fail, but in these cases water is generally to be obtained either from the deeper wells or from the streams which are sufficiently numerous to tide over the short intervals in which water is scarce.

As there are no great centres of population in the Lizard and St. Keverne districts, the need for a large water supply is not felt, and it would be difficult to obtain, as many of the houses and farms stand on the top of the platform, while the streams flow in valleys at a somewhat lower level, so that a gravitation scheme could not be carried out satisfactorily. Most of the farms have wells which vary in depth from 20 to 40 feet or more, and yield satisfactory supplies of water when they are protected from surface contamination. On the serpentine wells are few, and attempts to obtain water by sinking are not always successful, apparently because this rock has few joints and fissures, and accordingly does not carry much water; but where there are masses of gneiss or gabbro in the serpentine these are more decomposed and porous, and serve as channels along which the underground waters circulate. Many of the houses, especially in Lizard Town, are provided with large rain-water tanks which meet all the needs of the inhabitants and yield supplies that are perfectly safe. The water from wells in the serpentine is somewhat hard, but there is no evidence that the presence of magnesian salts in it is at all detrimental to health.

Building Stones and Road Stones.

Northern District.—The profusion of igneous rocks in the district affords a great variety of excellent building stone, but at present it is only raised to meet local requirements. The small granite tract at Breage does not appear to have been quarried within the limits of this map, but quarries have been opened on the southern portion of the Carnmenellis mass at Polglase, Boswidjack[1], and Constantine. The Cornish granite industry, which until recent years was in a flourishing condition, is now suffering severely from the importation of Norwegian and Swedish granite, which is less expensive to dress and can be placed on the home market at a price with which the native stone cannot compete. Notwithstanding, therefore, the vast granite resources in Cornwall alone and the excellence of the stone, the prospects of the native industry are far from bright, in spite of the fact that its immense durability has been amply proved by the condition of the stone after enduring many centuries of exposure to the weather in churches and other ancient stuctures.

A noteworthy feature of the Cornish granite is its wide system of jointing which admits of the extraction of blocks ranging up to 3,000 tons, far exceeding the largest stones ever used in building. The following table illustrates the crushing strength of the Constantine granite, as determined by Mr. David Kirkaldy in 1904 for Messrs. John Freeman & Co., Penryn:—

Locality.	Dimensions.	Base Area.	Crushed.		
			Stress.	Per sq. in.	Per sq. ft.
	Inches.	Sq. ins.	Lbs.	Lbs.	Tons.
Tresahoe ...	3·92 × 3·96 × 3·95	15·64	314,200	29,090	1,292·0
	4·00 × 3·98 × 3·97	15·80	335,700	21,247	1,366·4
	3·98 × 3·98 × 3·98	15·84	269,500	17,014	1,094·1
	Mean ...	15·76	306,467	19,450	1,250·8

Although the crushing tests are valuable guides to the strength of a rock, it must be recollected that such results obtained shortly

[1] ¼ mile N.N.E. of Melenzeth.

after the block has been hewn from the quarry may undergo considerable modification after a long period of strain. It is evident that the ability of a rock to maintain its strength under exposure to atmospheric conditions over a protracted period must be of first importance in selecting stone for dock and harbour works, bridges and lighthouses, and it is this quality of resistance to weathering, in which the Cornish granite has stood the test of time, that commends its use for the erection of such national structures as are outlined above.

In the selection of building stones in this district the most suitable rock lying nearest at hand has been utilised. Thus while the villages of Constantine and Breage are built of granite, the town of Helston has been largely built of greenstone. In the latter locality, however, the greenstone band that has been used is a decomposing variety that has evidently commended itself by the ease with which it can be dressed, while the more durable seams have been neglected, although being in great demand as macadam. The elvans have also been used for building and constitute an excellent stone, especially the band near Rosevear, whereas the serpentine, on the other hand, although largely used, conduces to damp. The greenstones are much wrought, especially in the neighbourhood of Helston, and large quarries have been opened on the pillow lava at Tregidden.

The quartzite is frequently used for road metal, and the loose blocks ploughed up in the soil have yielded the principal supply, but quarries have also been opened on this rock at Tregadjack and to the south of Manaccan. The hornblende schist of Manaccan has also been wrought, especially at Tregonwell, Carplight and to the south-east of Withan, although the rock is frequently in the condition of a crush breccia. One of the best examples of a crush breccia broken for road metal is in the large quarry adjoining the roadside near Carn, where the rock is made up chiefly of a fine-grained quartose sandstone, and notwithstanding its closely brecciated condition, it is so compact as to form a satisfactory macadam. Quarries of the more massive bands in the killas are common throughout the district, but this rock has been mainly used for buildings and hedges. The Devonian conglomerates and sandstones have also been frequently quarried, and the latter often produces an excellent building stone, being more compact than the normal sandy bands in the Ordovician killas. Besides being wrought for building stone and macadam, the greenstones of the area, when in a decomposed condition, have frequently been raised for spreading over the land, and in this state are locally known as 'marl.'

Lizard District.—The principal building stone over the whole of this area is the serpentine, and many quarries have been opened in the downs and are worked extensively for this rock. It has many advantages to recommend it, for it can be obtained in blocks of considerable size and is so soft that it can be easily trimmed and squared; moreover it is very durable. The most obvious objection is its sombre dark green colour, which may be avoided by rough casting or cementing the walls, and is often relieved by the use of the pale grey granites from the Constantine district for lintels, sills, and corners. Some of the churches and more important buildings have been erected with granite or elvan imported from the country lying to the north. The opinion is widely current in the Lizard district that walls built of serpentine are rarely waterproof, but it is not easy to make certain how far this is due to defective mortar, and in any case the absence of shelter during the winter storms renders it very difficult to secure dry walls for the dwelling houses. The hornblende schists are as a whole too fissile to yield blocks suitable for the better class of buildings, while the gabbro is very tough and difficult to split and dress. The large blocks of the latter rock which are scattered through the downs and fields around St. Keverne and Coverack are shattered with dynamite, and the fragments are much used locally for rough buildings and for repairing the dry stone walls and hedges that separate the fields. Recently an attempt has been made to utilise the waste broken stone of the road-stone works near Porthoustock as a building material by mixing it with cement, and this makes excellent walls. The roofing materials are always imported.

All the principal varieties of rock which occur within the Lizard district have been more or less used for mending the roads. The least satisfactory is probably the serpentine, which is too soft to withstand heavy traffic and is at present employed only on some of the minor roads. In recent years the increase of motor traffic has led to a search for the best and most lasting types of road stones, and some of the Lizard rocks have proved to be of very high quality for this purpose. The granites and banded gneisses are used only in a few places, but pits have been opened for road metal in these rocks at Kuggar, north-west of Trerise, and on the east side of the Lizard road near Ponson Joppa. The dark green hornblendic varieties wear more rapidly than the harder pink felspathic rocks; consequently the road surface becomes uneven and is apt to break up after a spell of drought.

The dark hornblende schists and epidotic hornblende schists which surround the serpentine contain many tough rather massive bands, which make road stones of the highest quality, and experience has shown the advisability of employing them on those roads which are exposed to the heavy motor traffic that now passes along all the principal highways of this district. There are four or five pits from which the main supplies are drawn by the road authorities, viz., Church Cove, Carn Barrow (south of Cadgwith), Mullion Cove (a little east of Porth Mellin), and Lower Relowas (about a mile south-west of St. Martin's). In 1909 small quarries were opened also in the hornblende schists which occur in the downs about half a mile west of Traboe, and the rock obtained was comparatively coarse—not fissile—and very tough; in fact, it had all the qualities of a first-class road stone. The rocks of this type are not only durable but bind well, and under ordinary conditions the road surface is smooth and stands heavy rain very well indeed.

In the vicinity of Coverack and St. Keverne the roads are often mended with gabbro or the dark greenstone (epidiorite), dykes which are common in that district. The principal source of supply seems to be the great blocks that are strewn over Crousa Down. These rocks are apparently more tough and not less durable than the hornblende schists, and they last well, but they wear less evenly and yield a rougher road surface. The gravels of the Pliocene series that occur on Crousa Down have been much employed for road metal, and are still to some extent, but they have little to recommend them. The quartz pebbles are too varied in size and often too large; consequently the gravel will hardly ever produce a well bound, coherent, firm surface which is suitable for fast traffic. The quartzite also is brittle, and when the pebbles are loose they are readily pulverised by the wheels of loaded carts and waggons passing along the roads.

The Road Stone Trade in the St. Keverne District.

In recent years the village of Porthoustock has become the centre of a considerable industry in the preparation of materials for road metal. The principal quarries are situated along the cliffs to the north and south of Porthoustock Cove, and the choice of this locality has been determined not only by the presence of rocks which are admirably adapted for road metal but also by the necessity of finding a sheltered coast where piers can be erected at which ships may lie in safety. The road metal prepared in these quarries is not used locally, but is all sent by ship to other parts of Cornwall and to the rest of England. Each of the companies engaged in this industry has accordingly built a pier or jetty at which small ships can be loaded. The broken stone is brought along overhead tramways in small wheeled trucks each holding about half a ton, and may be stored till required in large bunkers, either on the pier or near the crushers as is most convenient.

In 1908 four firms were working the quarries between Porthallow and Coverack, and together they gave employment to nearly 200 men. About half a mile east of Porthallow there is a small quarry in coarse hornblende schist; as there is no mechanical crusher at this quarry the rock raised is either hand broken or is shipped in lumps which are broken at the place where they are to be used on the roads.

Further south the cliffs from Porthkerris Cove to Porthoustock are occupied by a long range of important quarries which are under the management of the St. Keverne Stone Company, one of the largest firms in the macadam trade in Cornwall. The amount of overburden in the quarries is sometimes considerable, but diminishes as the working face is carried backwards into the cliffs. It consists of 'head' and sandy raised-beach deposits. The rocks are banded hornblende schists, some fine grained, others relatively coarse; they contain also epidotic bands and a few thin streaks of pink or grey granitic gneiss. The stone sent to the crushers is carefully selected and the soft, decomposed, or slaty bands rejected. This quarry has two installations of engines and crushing plant, and loading is done at a pier on the north side of Porthoustock Cove.

Rosenython quarry is situated on the south side of the cove, and is worked in gabbro which is cut by a large number of dykes of fine compact dark green epidiorite. From an examination of the working faces and of the heaps of crushed stone it is clear that these two rocks are mixed in about equal proportions in the road metal sent out. The epidiorite is the harder rock of the two, but the gabbro, though somewhat decomposed, is exceedingly tough. This quarry is in the hands of the West of England Road Metal Company, and the workings extend eastwards along the cliffs to Porthoustock point.

About a mile further south there is a quarry with a large pier for shipping the stone at Dean Point; the rock in this locality is almost entirely gabbro, sometimes very coarse and pegmatitic and intersected by few of the dark fine epidiorites. It is very massive and exceedingly tough. The company which works this quarry is registered as the Dean Coverack Stone Company.

Attrition tests of some of the roadstones exported at Porthoustock have been made by Mr. E. J. Lovegrove with the following results.[1]

No. of test.	No. of Slide.	Chips.		Dust.		Average.
		Dry.	Wet.	Dry.	Wet.	
313	E 4931	0	·0	3·42	5·81	4·61
606	E 6027	0	3·47	4·20	6·35	5·27
607	E 6028	0	·88	7·57	10·65	9·11
608	E 6029	0	·0	6·79	6·79	6·79

313. Epidiorite occurring as dykes in the gabbro of Rosenython quarry.

606, 607, 608. Hornblende schists from the St. Keverne Road Stone Company's quarries on the north side of Porthoustock.

These tests show that as roadstones the rocks possess great durability and resistance to wear, the epidiorite being distinctly tougher than the schists, but no tests have been made of the gabbro that occurs on the south side of Porthoustock Cove.

The Serpentine Industry in the Lizard.

Large quantities of serpentine are cut and polished for ornamental purposes in the Lizard district. The industry is centered in Lizard Town, but at Mullion, Ruan Minor, and Coverack there are also workshops and the stone is exported to serpentine workers in other parts of Cornwall. At the present time about sixty men are employed in quarrying or in polishing serpentine, but many of them spend part of their time at the pilchard fishing or in agricultural work. There are no large firms in this trade, but in all cases the work is done by one or two men in small workshops or in the cottages. The machinery used is of the simplest character as the stone is turned on rough lathes, first with iron tools, then with emery powder or emery cloth, and is finished with powdered rouge. About thirty years ago there was a serpentine factory at Poltesco, but it has been closed for many years. The remains of the machinery for sawing and dressing the stone may still be seen, and it is clear that large slabs were polished for panels, mantelpieces, columns, &c. Power was obtained from a water wheel, and most of the stone was quarried at Kildown Point, though supplies were also drawn from other localities. When the works were closed down the workmen were scattered among the different hamlets in the district and some went to other parts of Cornwall, where they still carry on the trade.

The principal objects manufactured are small vases, inkstands, paper weights, candlesticks, napkin rings, tobacco jars, and bowls, which usually do not exceed a foot in size. More elaborate ornamental articles such as Cornish fonts, clock cases and carved vases are also produced, and a fine set of these may be seen in

[1] E. J. Lovegrove, J. S. Flett and J. A. Howe, 'Attrition tests of Road-making Stones,' London, 1906.

the Museum of Practical Geology, where also there are beautifully finished columns which were turned out at the old Poltesco factory, but the principal demand is for small objects costing a few shillings, which are purchased by visitors and tourists. Since the factory was closed very little serpentine has been worked in the Lizard for architectural purposes. The reason for this is not very clear, for the stone can be got in large blocks if carefully quarried, as may be seen clearly from the masses which are lying in the quarry at Kildown; it is as easily cut as marble and readily takes a fine polish. In London façades of polished Lizard serpentine are occasionally seen, and as they must have stood for forty or fifty years and are still in good condition it is clear that the rock lasts well and preserves its polish. To some extent, no doubt, the neglect of the Lizard serpentine for architecture may be due to its brittleness and the frequency with which flaws and veins develop in the stone. The colours also are dark, even sombre in some varieties; while the polished granites, both British and Norwegian, have usually not only a more attractive colour but also greater hardness; and the Italian, Greek, and Irish marbles offer a greater choice of colours and more variety of banded, veined, and brecciated patterns.

For the manufacture of small ornamental articles, however, the Lizard serpentine is excellent. There are inexhaustible supplies of material in pieces of suitable size, and there is an endless variety of colours, many of which are exceedingly beautiful. The most popular stones are those which have a dark green base blotched, veined, or streaked with red; others have a dark red matrix spotted with green and yellow, or with light red; pale green, banded kinds are also used and some have a network of yellow veins in a green matrix. Quite the most valued of all are brecciated kinds with a matrix of milky white steatite (pseudophite) in which lie many small richly coloured angular fragments of green and red serpentine.

The ornamental serpentine is nearly all obtained by quarrying. Occasionally suitable blocks are found along the shores or in the cliffs, and the rich 'steatite' breccias which are the rarest and most valuable are picked up in veins in the cliffs at such places as Gew Graze and near Pedn Boar (or the Black Head). Some of the quarries are of considerable size and have been worked for many years; there are also many small pits from which little stone has been taken. In the large quarries it is clear that the oxidation which has produced the varied tints of the rock is not immediately connected with exposure to the atmosphere, since the stone obtained in depth continues to be of good appearance; but elsewhere there is a marked change in the rock as the quarry deepens, especially when the serpentine has been bleached in colour near the surface by percolating rain. That direct exposure to the atmosphere changes the character of the rock is also proved by the occurrence of blocks which have grey or greenish surfaces while the interior is dark green.

The stone is raised by quarrymen who are employed by the serpentine workers, but in some cases the workman himself does the quarrying. Before it is removed from the quarry the rock is trimmed with small hammers to a convenient size; at the same time it is proved whether the material has cracks or flaws which will make it likely to break on the lathe. Much care is exercised in this respect and accidents very rarely happen during the turning of the stone. Although beauty and variety of colour are the prime requisites they are not the only ones. Uniform softness and the absence of hard lumps is very desirable; consequently most of the favourite kinds of serpentine have their enstatite completely converted into bastite. The pale yellow chromite serpentines are employed a good deal, especially when they are crossed by many veins, but the chromite (known to the workmen as 'iron') is difficult to polish and breaks down into a hard angular powder which scratches the stone. Probably for the same reason the tremolite serpentine is hardly used at all; but that rock also has this disadvantage that it rarely shows much variety of colour.

The fine dunite serpentine of Porthallow has sometimes been polished, and near Parc Bean (Predannack) there are small pits in the fine serpentine of that locality. The tremolite serpentine obtained in quarries a short distance to the west of Traboe, has been used, but not often; it is not only hard but also fissile because it is well banded. With these exceptions all the quarries are in the bastite serpentine, which alone appears to combine all the properties desired by the workmen. The presence of the large bastite crystals is advantageous, because they lend variety to the rock and produce shining spots when the light falls on their polished surfaces. Moreover they are usually different in colour from the matrix and the veins which intersect it; being originally less rich in iron they tend when decomposed to be paler green, red, or yellow than the rest of the rock. In the blotched serpentines the spots are often derived from this peculiarity of the enstatite.

One of the best known quarries is that at The Balk, near Landewednack Church, which yields a dark green rock with red spots and veins, and a grey-green, sometimes apple-green rock. The old quarry is now less wrought than formerly, but another has been opened along side of it, and on the slopes of the valley a few hundred yards to the west there are several smaller pits all yielding ornamental stone. At Trethewas (locally called Trevas) north of Lizard Town there are also well known quarries which yield several varieties of serpentine. Kildown quarry, on the cliff a little north of Cadgwith, produces dark red and green stones, much used in former times in the Poltesco factory. At Brugan, south of Ruan Minor, there is a quarry by the roadside in a very handsome dark serpentine. One of the largest quarries in the whole district stands on Carn Kennack less than half a mile north of the centre of Kennack Bay; the rock of this quarry is dark red, with irregular blotches ranging from light red to nearly black. It is one of the favourite stones at the present time. Many small quarries are worked in the serpentine along the west side of Gwendreath valley, and below high water mark in the rocks known as the Caerverracks in Kennack Sands there is a quarry which produces a very striking dark red stone. The eastern district, around Coverack and the Black Head does not contain many quarries, though Pedn Boar has long been known as the principal source of serpentine veined with steatite[1], and there is a quarry on the cliffs west of Poldowrian. In the Mullion district several pits yield useful stones and at Ruan Major there is a large old quarry, now disused (known as Long Alley), while a new quarry was opened in 1908 at Hervan on the Lizard road. It would be impossible to enumerate all the smaller pits which have been wrought, some of them only for a single season, but enough has been said to show that over the whole area of the bastite serpentine ornamental rocks have been found, and there is no reason to suspect that there will ever be any dearth of beautiful varieties of this rock in the Lizard district.

Mining.

Northern District.—With the exception of the attempt now being made to restart Wheal Anna Maria[2] there are no mines at work in the district. The available information regarding the mines, few as they are, is very meagre.

Silver-lead has been yielded in some quantity in the region between Helston and Porthleven, while iron ore has been obtained in the parish of Constantine. Ores of tin and copper have not been produced in quantity, and with the exception of Henwood's account of Wheal Trewavas little can be said about them.

Joseph Carne writing in 1818 stated that the mines of Wheal Rose and Wheal Pool were worked for lead as far back as the middle of the 16th century, at which time the lead ore was not separated from the silver it contained[3].

About 1740 the mine was doing well and yielded considerable profit to the adventurers. After this the mines appear to have been stopped, for in 1790 Wheal Pool is stated to have been again set to work and a smelting and testing works erected for the extraction of silver, but as the venture was not a success the mine was again stopped. The lead ore from Wheal Pool contained from 30 to 40 ounces of silver per ton, while the lead ore from Wheal Rose, which was treated at the Wheal Pool works, contained 60 ounces to the ton.

Writing in 1871 Mr. Stephens[4] states that the mine was worked as far back as the Roman occupation. In 1871 the Wheal Rose sett was 850 fathoms long from north to south and 300 fathoms in width and comprised six lead lodes.

Shafts were sunk to the 64 fathom level and the silver lead ore extracted was sold for £100,000, on an average of £20 to £26 per ton. It appears to have been the miners' opinion that the main lode is that which is known as Wolf's cross course in Wheal Vor, and which yielded copper ore in Godolphin Bridge Mine. The ores consisted of galena, with phosphate of lead, carbonate of iron and quartz. Small vugs containing phosphate and arseniate

[1] H. S. Boase, 'Contributions Towards a Knowledge of the Geology of Cornwall.' *Trans. Roy. Geol. Soc. Cornwall*, vol. iv., 1831, p. 335.

[2] At the head of Porthnavas Creek. Work on this mine has since been abandoned.

[3] 'On the Discovery of Silver in the Mines of Cornwall.' *Trans. Roy. Geol. Soc. Corn.*, vol. i., 1818, p. 118.

See also W. Borlase, 'Natural History of Cornwall,' 1758, p. 210.

[4] 'Mineral Phenomena of Wheal Rose' (Hugh Stephens). *39th Annual Report Corn. Roy. Poly. Soc.*, 1871, p. 77

of iron were found, while phosphate also occurred in parallel cracks in the country rock. The gossan consisted of brown hæmatite which contained in places rich silver-lead. At the 54 fathom level an east and west cross course headed the lode.

Among the mines which have yielded tin and copper ores may be mentioned Wheal Anna Maria, which was being reopened at the time Mr. Hill visited the district, and Wheal Trewavas described by Henwood. Of the former the work is not sufficiently advanced to enable an examination of the mine to be made[1], while of the latter the following description is from Henwood's account[2].

There are four lodes consisting mainly of quartzose veinstone with spots of copper and iron pyrites, and worked to about the 68 fathom level.

The South Lode of Trewavas Mine has a bearing of W. 40° N., and varies in underlie from vertical to 12° south-west, and in width from 1 to 6 feet.

The veinstone down to the 68 fathom level is mainly quartz and chlorite, containing copper and iron pyrites dispersed through it, and drusy cavities lined with cupreous minerals. In the neighbourhood of the lode the country rock is traversed by veins consisting of schorl and iron and copper pyrites. The other lodes, varying from 6 inches to 4 feet in width, have a bearing of W. 25° N., and contain but little ore.

The only iron lodes of which information is available are those of the Brogden Iron Mine in the Parish of Constantine[3]. Captain Noble remarks that the mine was leased by Messrs. Brogden and Sons in 1868. The lode upon which work was commenced has a bearing of E. 5° S. and an underlie of 15° to the south, the width varying from 6 inches to 6 feet. The ore is brown hæmatite, stated to contain 52 per cent. of iron. It is somewhat quartzose and is traversed by fissures containing clay. Another lode on the south which at its nearest point to the former is 4 feet distant, has a bearing of E. 25° S. and a width of from 1½ to 6 feet.

Of the less important metalliferous minerals the occurrence of ilmenite (gregorite or menaccanite) sands at Lanarth and Tregonwell Mill in St. Keverne and Manaccan Parishes, is of importance to the collector[4]. The occurrence of this mineral has also been noted by J. Garby[5] in diallage at Gwendra in Coverack.

Although gold has been found from time to time in minute quantities in the neighbourhood of Helford River, no deposits worth working have yet been discovered. It occurs in various ways, but mainly in minute spangles associated with detrital ilmenite (menaccanite or "black sand") in the Manaccan River and its tributaries, and at Nare Point[6]. The traces of gold in breccias, conglomerates, raised beaches and veins, as recorded by William Hambley[7], F. J. Stephens[8], and Arthur Dean[9], need not here be referred to in detail, as they are not likely to become of economic importance.

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[1] Work on this mine is now abandoned.

[2] W. J. Henwood, *Trans. Roy. Geol. Soc. Corn.*, vol. v., 1848.

[3] George Noble, 'Remarks on Mineral Veins in the Parish of Constantine.' *39th Ann. Rep. Roy. Corn. Poly. Soc.*, 1871.

[4] J. A. Paris, *Trans. Roy. Geol. Soc. Cornwall*, vol. i., 1818, p. 227.

[5] 'Catalogue of Minerals found in Cornwall,' *Trans. Roy. Geol. Soc. Cornwall*, vol. vii., 1848, p. 71.

[6] William Hambley, 'The Conglomerates of Cornwall and the Banket of South Africa.' *65th Ann. Rep. Roy. Corn. Poly. Soc.*, for 1896, p. 97.

[7] *Op. cit.*

[8] 'Recent Discoveries of Gold in West Cornwall,' *Trans. Roy. Geol. Soc. Cornwall*, vol. xii., 1899.

[9] 'Gold in Cornwall,' *Rep. Miners' Assoc. Cornwall*, 1865.

The following index gives the positions of the mines in this sheet. The Roman numerals indicate the numbers of the 6-inch and 25-inch maps issued by the Ordnance Survey. The letters indicate the quarter sheets of the 6-inch maps, while the figures are the numbers by which the 25-inch maps are designated.

Breage, *Parish of.*
  Fortune, Wheal. LXXV., NE. 8.
  Rib, Wheal. LXXV., SE. 12.

Constantine, *Parish of.*
  Anna Maria Mine. LXXVII., NW. 6.
  Brogden Iron Mine. LXXVII., NW. 5.

Mullion, *Parish of.*
  Fenwick, Wheal (copper). LXXX., SW. 14.

Sithney, *Parish of.*
  Penrose, Wheal. LXXVI., SW. 13.
  Rose, Wheal. LXXVI., SW. 13.
  Saturn, Wheal. LXXVI., SW. 9.
  Unity, Wheal. LXXVI., S.W. 13.

Wendron, *Parish of.*
  Treworlis and Tremenheere Mine. LXXVI., NW. 6.
  Pool, Wheal. LXXVI., SW. 9.

Lizard District.—There is a history of mining for metals in the Lizard District which extends back for more than a hundred years, but at no period does it seem to have been attended with real success, and it has long since been completely discontinued. In many places along the cliffs there are traces of old trial workings which are so small that they can have been nothing but the work of prospectors on the search for possible ore deposits. Most of them have been opened in the red or brown clays and breccias which occupy many of the lines of crush and faulting. Several headings may be seen in the cliff at the south-west corner of Porthoustock Cove; they have been driven along small faults. In the valley about half a mile above the village of Porthoustock there are the remains of shafts which have been sunk, according to the evidence of the stones left on the burrows at the mouth of the shafts, in reddened breccias that mark the position of the fault between the gabbro and the schists. It is said that iron ore was principally obtained, and that on assay it proved to contain silver. At Church Cove there are several headings of the same kind in the cliffs on the south side of the cove, and at Pen Olver, on the east side of the headland, remains of old workings may also be seen. Similar traces of mining operations are visible in the small cove south of Porth Mellin (Mullion Cove), and possibly these communicate with the Wheal Unity Copper Mine, which stands nearly half a mile to the south-east of this spot. In Polurrian Cove the fault which marks the boundary of the Lizard rocks was once the site of a mine, traces of which may still be seen. It is believed that the principal product was red iron ore. We may be certain that this list by no means exhausts the number of unsuccessful minor trials for metalliferous ores in the district.

Operations on a larger scale, involving the expenditure of considerable amounts of capital, have been carried on at three different localities. In each case copper was the metal sought for, and on the burrows of these old mines fragments of native copper, malachite and chrysocolla may still be obtained. The country rock is serpentine, and copper in small quantities seems to be widely disseminated in this rock in the Lizard. In Lizard Town, for example, where the signal gun for the lifeboat is placed in the centre of the village, there is a small quarry where particles of native copper may be found in the dark green bastite serpentine. When the site of the Headlands Hotel at Coverack was being prepared for building operations, several blocks of copper were found in the serpentine rock. Near Mullion, also, at more than one place native copper may be found in veins and rough irregular masses in serpentine, and along the coast line drippings of green cupreous water are by no means uncommon in cracks in the serpentine cliffs. No similar indications have been observed in connection with any other Lizard rocks, and the conclusion seems justified that the copper ores and the serpentine have a genetic connection. There must have been, however, a secondary concentration of the copper along joints and fissures, probably through the agency of circulating water, for in all the principal mines the ores were associated with brecciated and crushed types of serpentine, such as occur along zones of displacement. Large masses of native copper were obtained about the year 1850 in the workings of the Wheal Unity Mine near Mullion; one of these masses was exhibited at the great Exhibition of 1851 and is now placed on the ground floor of the Museum of Practical Geology. The matrix of this mass of copper is a brecciated and decomposed serpentine, which leads to the conclusion that the vein was a secondary deposit along a fracture or plane of movement. The veinstone of the old mines near Downas Cove is also a brecciated serpentine with calcite, steatite, and other secondary minerals filling up the cracks. Where the copper ore occurs in particles less than an inch in size the serpentine around it is sometimes quite intact and unbroken, but this is very rare and it is not clear that even these grains are undoubtedly primary.

Although copper ores are found in many parts of the world in association with basic rocks, such as dolerite, diabase, gabbro, and basaltic amygdaloids, they are by no means common in ultrabasic masses like the serpentine of the Lizard; the copper deposits of Monte Catini, in Italy, however, occur with gabbro and lherzolite (the latter rock being very similar to some varieties of the Lizard serpentine). Weed[1] states, with regard to these mines, that "Lotti regards the deposits as magmatic segregations; but the constant association with serpentine, both in these deposits and those of Liguria and other localities in Italy, seems to indicate a concentration into workable ore bodies of copper derived from primary pyrite disseminated through the igneous rock, the concentration taking place during the process of serpentinisation." In their method of occurrence these Italian copper ores seem to present many points of resemblance to those of the Lizard.[2]

The occurrence of copper in the Lizard serpentine must have been known from a very early period. Borlase in his 'Natural History of Cornwall,' published in 1758, describes and figures "virgin copper ore" from Mullion, and says that these specimens "are the richest, most sparkling, and best naturally polished copper ore which any mine affords; some years since it was raised in the parish of Mullion in large lumps of several pounds weight, one lump of it weighing forty pounds; what heightens the beauty of this ore is this, that in most places it is enamelled with that green flaky *aerugo* which age alone gives to coins and medals, and art in vain endeavours to imitate" (p. 201). From this account we may infer that at that date some kind of workings for copper existed in the Mullion District. Between that time and the year 1818, when Majendie's[3] account of the geology of the Lizard was published, it is certain that mines had been in operation, for that author states that they had been discontinued before he visited the district. Sedgwick[4] also records that "a copper mine was opened some years since near Mullion, but soon afterwards abandoned." The mines at Downas Cove were examined by Sedgwick, and he states that they had "lately been opened." From his description it seems clear that work was actually being carried on at those mines when he was in Cornwall, and from the size of the burrows and shafts there can be no doubt that the mining operations lasted for several years.

The Mullion Mines are all situated in the valley which lies to the south-east of Mullion Cove (Porth Mellin), which is called the Ghostcroft Valley in some of the older descriptions. The shafts and ruins of the engine-houses

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[1] W. H. Weed, 'The Copper Mines of the World,' 1908, p. 102.

[2] F. J. Stephens, 'On a Supposed Resemblance between the Occurrence of Native Copper in the Lake Superior and Lizard Areas.' *Trans. Roy. Corn. Geol. Soc.*, vol. xi., 1894, p. 680, (also in *Ann. Rep. Roy. Corn. Poly. Soc.*, 1894, p. 108).

[3] Ashhurst Majendie, 'A Sketch of the Geology of the Lizard District,' *Trans. Roy. Corn. Geol. Soc.*, vol. i., 1818, p. 33.

[4] Adam Sedgwick, 'On the Physical Structure of the Lizard District,' *Trans. Camb. Phil. Soc.*, vol. i., 1822, p. 304.

belonging to one mine (Wheal Unity) can still be seen at a point about half a mile south-east of the Cove; there are two shafts now partly filled with *débris*. Whether this is the oldest mine in the district cannot be established, but it is certainly the largest, and was the last to be discontinued. About the year 1847 a good deal of copper was obtained at a mine called the Trenance Mine, situated in this valley, and probably the same as Wheal Unity. The copper was mostly native metal, though large pieces of grey copper were also found. It is stated in the *Mining Journal*[1] that in 1847 a slab of native copper was raised in this mine which measured 7 feet 6 inches in length, 2 feet in average breadth, and from 4 to 12 inches in thickness; probably this is the mass which was sent to the great Exhibition of 1851, and is now in the Museum of Practical Geology. These are the largest blocks of native copper which have been mined in England, and according to contemporary accounts there were still larger pieces in the workings, but they had to be broken up to get them to the surface. So far as we can trace there are no plans of the workings in existence, and no accurate statistics of the amount of copper which was produced.

On the south side of Goonhilly Down, about a mile north of Erisey, at a place now called "Mine Waters," there are remains of houses and shafts belonging to a mine, which, from indications obtained from the materials lying on the old burrows, was worked for copper ores. The mine is evidently a very old one, and we have not found any records as to when it was worked or what amount of ore was turned out. Although a shaft was sunk there is nothing to show that the workings were extensive.

Another group of old copper mines stands on the coast a little west of Beagles Point where shafts and burrows are still visible on the face of the cliff. Sedgwick describes the appearance of the ore obtained in the following terms[2]:—"A quantity of grey copper ore, mixed occasionally with fibres of native copper, appears, from what we could learn, to be intimately mixed with the substance of the serpentine, but neither to have that regularity of direction and of thickness, nor that continuity which indicates a true vein. We obtained some specimens of the ore, which, though of no great beauty, possess considerable interest. They are composed of noble serpentine, common serpentine, steatite, bronzite, vitreous sulphuret of copper, and carbonate of copper, all intimately blended together." The *débris* lying around the shafts at the present time answers well to Sedgwick's account of the mine; the serpentine is often much crushed and brecciated, and the fragments may be cemented by crystalline calcite, as was remarked by Rogers[3]. From the direction of the workings and the character of the veinstones it seems that the copper was found along a run of broken serpentine which lay nearly in an east-and-west direction and corresponds to the east-and-west crush belts which are frequent along the shores of this part of the Lizard.

One third of a mile to the north-east of these mines there are others on the east side of the stream which flows through the valley east of Arrowan. Two old shafts are visible and the remains of some adits and burrows. The rubbish on the spoil heaps indicates that the characters of the veinstones are essentially the same as those described by Sedgwick. None of the early writers on the geology of the Lizard mention these workings, and it is probable that after the mines on the cliff had been given up operations were transferred to this site, and were continued till the enterprise proved unsuccessful.

From the evidence available we may conclude that copper mining in the Lizard serpentine has been attempted at several periods during the last two centuries, but only intermittently and with no great success. The times of greatest activity were probably about 1820 and 1848. In De la Beche's Report[4] there is no account of mining operations anywhere in the district,

[1] *The Mining Journal*, 5th June, 1847, p. 262; *ib.*, June 19th, 1847, p. 285; *ib.*, 1849, p. 502.

[2] *Loc. cit.*

[3] John Rogers, 'On the Serpentine District of Cornwall,' *Trans. Roy. Corn. Geol. Soc.*, vol. ii., 1822, p. 421.

[4] H. T. De la Beche. 'Report on the Geology of Cornwall, Devon and West Somerset,' (*Mem. Geol. Surv.*), 1839, p. 98.

though he mentions the occurrence of native copper at Mullion, and the inference seems clear that the mines were closed down about 1839, when he made his survey. Since 1850 no attempts have been made to extract copper on a commercial scale. There is a general consensus of opinion among the geologists who have examined the Lizard copper deposits that they are too small in size and too sporadic in occurrence to encourage the belief that they will ever prove important sources of the metal.

Mining for Steatite.—Veins of steatite and talc are by no means uncommon in the serpentine and may often be observed in the cliffs around Kennack, Mullion, the Black Head, Pentreath, and to the west of Kynance. They are always small and usually discontinuous; a block of white steatite of very good quality was presented to the Museum of Practical Geology, in 1908, by Mr. A. Reynell, who found it in a vein in serpentine on the east side of Kennack Sands. This vein is from 1 foot to 2 feet wide, but can be followed for only a very short distance. Borlase, in 1758, was aware of the occurrence of talc at the Lizard, and describes several varieties of the mineral which he had obtained there.

At two places these veins of steatite have been worked commercially. Majendie, in 1818[1], states that " steatite has been raised lately from a distinctly marked vein near Mullion Church Town." No traces of any steatite mines in Mullion can now be seen, but in Predannack, about a mile and a half south of Mullion, there is an old steatite mine, called Wheal Foss, which may possibly be the one referred to by this author. It is marked on the 6-inch Ordnance Survey map (Sheet 84 NW.) as a " china-clay " mine, now disused, but from an examination of the stone left on the burrows it is clear that the mineral sought for was steatite, which is present as thin veins in a brecciated serpentine. The old mine now furnishes a water supply for a dairy. The workings cannot have been extensive, and apparently there were no shafts.

The ' soap rock ' at Gew Graze was worked at several periods about the beginning of last century as a source of steatite. Berger, who visited the Lizard in 1809, describes it in the following terms[2]: " By soap rock is meant a kind of steatite so tender that it may be cut as easily as new cheese. It is embedded in the serpentine. Its colour is a pearly white or grey with red and blue veins, and when pure it has a sort of semi-transparence. On coming out of the quarry it may be kneaded like a lump of dough, but after having been exposed to the air for some time it becomes friable, owing, no doubt, to the evaporation of the great quantity of water it contains; it possesses the soapy feel in the highest degree, and pieces of hard stone are included in it in pretty large quantity. It is used in the manufacture of porcelain for the same purpose as the kaolin, and on many accounts it might be said that the soap-rock is to serpentine what kaolin is to granite."

The ' soap rock,' as has been described in a previous chapter, is really a steatised vein of granite. The vein is 3 or 4 feet thick and nearly vertical, or has a steep dip to the south. Portions of it are very soft and highly magnesian, while other parts are nearly unaltered felspathic granite; the latter are probably the hard stones to which Berger refers. The vein, so far as can be judged from the exposures seen in the old workings, is very irregular in thickness, and the 'soap rock' occurred probably as discontinuous masses, none of which was more than a few yards in length. It was worked in an open cutting or quarry, and there are no traces of shafts or underground workings. The whole quantity obtained cannot have been large.

From an interesting note by Paris[3] we learn that "the steatite, or soap rock, near Cape Lizard, is worked by Mr. Dillwyn, of Swansea, for which he pays Lord Falmouth, the proprietor, the sum of £75 per annum. About 12 tons are annually quarried and exported." Sedgwick visited Gew Graze in 1819[4] and found that mining operations had ceased. " Unfortunately for us, the work had been abandoned before we visited the district.

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[1] *Loc. cit.*, p. 33.

[2] J. F. Berger, 'Observations on the Physical Structure of Devonshire and Cornwall.' *Trans. Geol. Soc.*, vol. i., 1811, p. 130.

[3] J. A. Paris, 'On Stones and Clays Annually Exported from Cornwall.' *Trans. Roy. Corn. Geol. Soc.*, vol. i., 1818, p. 233.

[4] J. W. Clark and T. McK. Hughes, 'The Life and Letters of Adam Sedgwick,' 1890, p. 213.

The dyke and soapy vein were so deeply covered with earth in the direction in which they had last been excavated that the value of the material would not pay for extraction[1]." From De la Beche's account[2] it is clear that mining for steatite in the Lizard was never resumed.

Chromite.—The presence of this mineral in the Lizard serpentine appears to have been first noticed by Pearce[3] in the year 1862. He obtained specimens of serpentine near Cadgwith with small black grains of chromic iron ore, which he estimated formed 1·80 per cent. of the rock. Picotite or chrome-spinel was reported in several places by Professor Bonney[4] in 1877, as the result of microscopic examination of the serpentine, and its presence was confirmed in 1890 by Mr. Howard Fox[5].

These minerals are exceedingly common in the serpentine, especially in certain bands of a pale green colour, and they weather out prominently on the surface of the rock, but they never form more than a small proportion of the whole mass. There is little probability that they will be found in masses sufficiently large and pure to be worth exploiting.

Asbestos.—In many parts of the serpentine there are narrow veins of asbestos, as has been known from an early period. Borlase[6] describes specimens which he obtained from Landewednack as having "the filaments flat, pointed, of a bright purple colour and silvery gloss, extremely small and sectile, appearing in the microscope edged with a soft down, the fibres longer and of a brighter hue, but not woolly as some samples I have from the Isle of Anglesea." Many years later Carne[7] gave an excellent account of these veins. "These may be seen in almost all the serpentine formation of the Lizard; some of them are as wide as half an inch; but their width, in general, is that of a line running in all directions. At Gew Graze some veins may be seen upwards of an inch wide. The principal veins, however, occur at Kennack Cove, about three miles north-east of the Lizard, in greenstone; here there are some so wide as 3 to 4 inches; their position is sometimes quite horizontal."

The west side of Kennack Cove is still the best locality for asbestos in the Lizard; some of the veins are 3 inches thick, and have fibres 5 inches long, but the mineral is hard, coarse, and brittle in most of the larger veins, and only the thinner ones can be teased out into a woolly mass. Of recent years even thin veins of asbestos can be worked at a profit owing to the increasing demand for this substance, but no attempt has been made to exploit the asbestos deposits of the Lizard. From what we have seen of them, it appears that the quality is not very good, though careful search might reveal the presence of varieties adapted to economic uses.

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[1] Adam Sedgwick, 'On the Physical Structure of the Lizard District in the County of Cornwall.' *Trans. Camb. Phil. Soc.*, vol. i., 1822, p. 321.

[2] *Op. cit.*, p. 511.

[3] R. Pearce, 'Note on Chrome Iron in the Serpentine of the Lizard,' *Trans. Roy. Corn. Geol. Soc.*, vol. ix., 1870, p. 99.

[4] T. G. Bonney, 'On the Serpentine and associated Rocks of the Lizard District,' *Quart. Journ. Geol. Soc.*, vol. xxiii., 1877, p. 918.

[5] Howard Fox, 'Picotite in Serpentine,' *Trans. Roy. Corn. Geol. Soc.*, vol. xi., 1890, p. 336.

[6] *Op. cit.*, p. 112.

[7] Joseph Carne, 'On the Relative Age of the Veins of Cornwall,' *Trans. Roy. Corn. Geol. Soc.*, vol. ii, 1818, 1822, p. 63.

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