are to be relegated to the same division as the terrestrial *tracheated* forms of the Arachnida, there is no need to offer any further evidence; but at present I deny, with other Carcinologists, that Professor Ray Lankester has proved his position, or that such an arrangement is consistent with sound zoological classification.

It is extremely interesting to record the fact that in 1881 Mr. J. F. Mansfeld communicated an account, with a woodcut, of a fine fossil *Eurypterus* found by him in the shale immediately beneath the Darlington Cannel Coal-bed, Lower Productive Coal Measures, Darlington, Pennsylvania, U.S.A. (See Amer. Phil. Soc. Proc. vol. xix. p. 152, April 1st, 1881.)

The figure I have seen, being only a sketch, and roughly executed—without scale—does not admit of accurate comparison; but so far as I am able to judge, this American *Eurypterus* must have been extremely closely related to our Eskdale species.

As it is convenient to have a name for a new form, I propose to designate this our second Scottish *Eurypterus* from the Carboniferous series as *E. scabrosus*.

Dimensions of Specimen.—Head $5\frac{3}{4}$ inches broad, by $4\frac{1}{2}$ inches in length. Length of body (including head to seventh segment) 10 inches, perfect appendage 8 inches in length, widest part at third segment of body $6\frac{1}{2}$ inches broad. Total length estimated at about 20 inches, including the telson.

EXPLANATION OF PLATE XIII.

Eurypterus scabrosus, sp. nov.

FIG. 1. Larger slab containing the head with three of the gnathopodites in place on the right side; and the 1st to the 7th somites more or less perfectly preserved. Fragments of the branchial leaves (*br.*) are seen on the left side of the head.

Prof. Huxley (who kindly looked at the original specimen) has suggested that the portion of an appendage, with a row of small tubercles along its border near the small figure 2, on the right side of the head, may possibly have been a part of a chelate appendage; but it is very obscure. Other fragments are seen on the left side of the head (near 5) similarly ornamented.

FIG. 2. A fragment of same specimen showing portions of the 8th to the 10th somites.

II.—ON THE ORIGIN OF CERTAIN BANDED GNEISSES.

By J. J. H. TEALL, M.A., F.G.S.

(PLATE XIV.)

THE term gneiss as generally used by geological writers signifies a rock of granitic composition in which a parallel structure in the arrangement of the constituents is more or less apparent. For our present purpose it is important to note that other plutonic rocks besides granite (*e.g.* diorite, gabbro, and peridotite) have their gneissose equivalents, so that, if we use the term gneiss in a structural rather than in a mineralogical sense, we may speak of diorite-gneiss, gabbro-gneiss, and so on.¹ Now the parallel structure of gneissose

¹ Roth has recently (Sitz. d. k. preuss. Akad. d. Wissen. Ueber den Zobtenit, vol. xxxii. 1887, p. 611) proposed that Leopold von Buch's term Zobtenfels should be revived under the form Zobtenite for those gabbros which are associated with crystal-line schists and are often foliated.

FIG. 1.—Granite veins in diorite, Pen Voose, the Lizard.

FIG. 2.—The "Granulitic Series," Pen Voose, the Lizard.

To illustrate Mr. J. J. H. Teall's paper on Banded Gneisses.

rocks is of two kinds. It may consist (1) of a parallel arrangement of certain constituents (*e.g.* mica plates or porphyritic feldspars), or (2) of an alternation of bands of varying chemical and mineralogical composition. It is agreed on all hands that a parallel structure of the first kind may be due either to the deformation of a mass of half-consolidated plutonic rock at the time of intrusion, in which case it is strictly analogous to the flow structure in many volcanic rocks, or to deformation produced by earth-stresses operating on the mass after consolidation. As regards the origin of the second kind of parallel structure there is no such general agreement, and many writers regard it as due to some process akin to sedimentary deposition. The object of the present paper is to show that just as the first kind of parallel structure may be and in certain cases actually is due to the plastic deformation of what may be termed homogeneous¹ plutonic masses, so the second kind of parallel structure (banded structure) may be and in certain cases actually is due to the deformation of heterogeneous plutonic masses.

In the first place let us inquire what kind of deformation is necessary in order to produce parallel banding in a heterogeneous mass. A moment's consideration will show that if any heterogeneous mass of fairly uniform dimensions in the different directions be deformed into a flat sheet or narrow ribbon, then the individual portions will be similarly deformed and the mass as a whole will show a banded structure. This was clearly realized by Mr. Poulett-Scrope in 1824, who not only explained in this way the parallel banding of the Ponza liparites, but also suggested that the similar appearances in gneiss and schist might be due to the same cause.² A very simple experiment will serve to illustrate the important fact just referred to. Take pieces of differently coloured clays (say ordinary potter's clay and clay which has been intimately mixed with the blue used by laundresses); bring them together in any way you please so as to make one lump and deform the lump into a thin sheet or narrow band by squeezing or rolling. Then fold the sheet or ribbon on itself two or three times and, if you like, repeat the process of rolling it out. In this way the most perfect parallel banding may be produced and by varying the conditions in ways which readily suggest themselves (as for example by using clays of different degrees of plasticity and inserting fresh pieces after the deformation has progressed to a certain extent) it is easy to produce many of the peculiar structures seen in banded gneisses.

It is important to note that the result will differ according as the mass is deformed into a flat sheet or narrow strip. In the former case the strain-ellipsoid will be an ellipsoid of revolution with its short axis in the direction in which the stress was applied, in the latter case the strain-ellipsoid will possess three unequal axes, the least axis lying approximately as in the former case, and the greatest axis lying at right angles to this and in the direction of

¹ Not homogeneous in the strict sense of the term, but homogeneous in the sense that the different mineralogical constituents are uniformly mixed throughout the mass.

² *Geology of the Ponza Isles*, Trans. Geol. Soc. London, 2nd ser. vol. ii. p. 228.

the length of the strip, *i.e.* in the direction of stretching. The idea of a strain ellipsoid is of course only applicable to those masses or portions of a mass which have been subjected to a uniform strain.¹ If the different coloured clays yield differently to the deforming stresses the phenomena will be highly complex.

Now before we are justified in looking favourably on the theory I am endeavouring to illustrate, it is necessary to show, (1) that banded gneisses are on the whole identical with plutonic rocks in composition, (2) that masses of plutonic rocks are often heterogeneous, and (3) that heterogeneous masses, if such exist, may be deformed in the manner required to produce banded structures.

To establish the first point it is only necessary to refer to Roth's elaborate collection of rock analyses.² No one who has studied these analyses can doubt for a moment that the banded gneisses are essentially identical with plutonic rocks so far as chemical composition is concerned. The resemblance, however, is not limited to chemical composition, it extends to mineralogical composition and in a certain sense even to structure. Each plutonic rock has its equivalent in the banded gneisses.

We pass on now to consider the second point. When large masses of plutonic rock are examined they are often found to vary considerably in composition. They frequently contain patches which differ from the main mass. These have been investigated by Mr. Phillips, so far as the granites are concerned, and have been shown by him to be in general more basic in composition than the rock in which they occur. Again, every one is familiar with the phenomena of contemporaneous or segregation veins. These appear to be in general more acid than the rock in which they occur. Sometimes two or more varieties of plutonic rocks interlace in the most intricate manner. Cases of this kind have been described by Prof. Judd³ as occurring in the Isle of Rum, where basic and ultra-basic rocks are concerned; by Messrs. Peach and Horne⁴ as occurring in the Shetland Isles, where granite and diorite are concerned; and by Herr Lossen⁵ in the Hartz, where granite (granitite) and gabbro are concerned. The last-mentioned observer states that both granitite and gabbro occur in the same dyke, and that the acid rock either surrounds or penetrates masses of the basic rock in the form of veins—the relations of the two rocks being such as to suggest that the two magmas were intruded simultaneously (or nearly so) rather than that the fluid granite-magma was injected into solid gabbro.

Diorite and granite may be seen in intimate relation in the ridge

¹ A mass is said to have been strained uniformly when every portion has been strained alike.

² Beiträge zur Petrographie, etc. Abh. d. k. preuss. Akad. d. Wissen. für 1869, 1873, 1879, and 1884.

³ On the Tertiary and older Peridotites of the West of Scotland," Q. J. G. S. vol. xli. p. 358.

⁴ The Old Red Volcanic Rocks of Shetland, Trans. Royal Soc. Edinburgh, vol. xxxii. part ii. p. 373.

⁵ On the Eruptive Rocks of the Hartz, Jah. d. preuss. Geol. Landesanstalt für 1882, p. xxi.

of crystalline rocks running E. and W. a few miles south of Haverfordwest, in Pembrokeshire, and similar rocks show similar relations in the Lizard peninsula. The last-mentioned case will shortly be described at greater length.

We have now to consider the question of deformation. No one will doubt that deformation necessary to produce banded structures in heterogeneous plutonic magmas may take place in connexion with intrusion. The only question that can arise is whether many banded gneisses have originated in this way. At present I have no definite opinion on this point. There is, however, another way in which the necessary deformation may be produced, viz. by the operation of the earth-stresses of which we have such striking evidence in mountain-regions. With reference to this mode of deformation I will content myself by referring to the work of Heim and Baltzer in the Alps, of Reusch in the Bergen peninsula, of Lehmann in the granulitic region of Saxony, and of Lapworth and the Geological Survey (Messrs. Peach and Horne) in the north-west of Scotland. It will not be doubted by any one who has studied the writings of these authors, and is at all familiar with the phenomena they describe, that large masses of country have been profoundly modified by the earth-stresses. It may be a long time before we become acquainted with the precise nature of the movements and deformations, but that they are adequate to convert a heterogeneous plutonic mass into a banded gneissic series is to say the least highly probable. It must of course be remembered that sedimentary rocks may also be involved in the movements, so that the occasional presence in a gneissic series of bands having the composition of sedimentary rocks is no proof that the whole series is of sedimentary origin.

Having by these general remarks established, as I believe, the *a priori* probability of the theory I am endeavouring to illustrate, I will now refer to what appears to me to be a case in point. In the Lizard district of Cornwall we find two or three rock-types occurring as portions of an igneous complex and as portions of a banded gneissic series. Where they exhibit the relations of igneous rocks (Fig. 1, Plate XIV.), they may be termed granite, diorite and gabbro; where they occur as portions of a banded gneissic series they possess the same specific gravity, but usually show a more or less marked parallel structure and in certain cases differ in mineralogical composition. Consider first of all the petrographical characters of the different rock-types.

Granite.—This rock never occurs in large independent masses, but only as comparatively small veins and dykes. It is found in gabbro (north of Pen Voose), serpentine (Kynance) and diorite (Pen Voose). It is present also, in a somewhat modified form, in the banded gneissic series—the “granulitic series” of Prof. Bonney.¹ The least modified rock is a fine-grained granular aggregate of quartz, felspar and dark mica. The felspar is mostly unstriated, but a striated variety also occurs. Both felspar and quartz are

¹ Quart. Journ. Geol. Soc. vol. xxxix. (1883), p. 1.

present for the most part in irregular grains. Sometimes, however, we find more or less rounded grains of quartz inclosed in the felspar, so that the quartz was not always the last mineral to form. The mica is deeply coloured. It occurs in detached scales and also in aggregates composed of several individuals. Sections parallel to the vertical axis appear a pale yellowish-brown when viewed with rays vibrating at right angles to the cleavage cracks, and opaque or a deep reddish brown when viewed with rays vibrating parallel to these cracks. The mineral is biaxial with a very small optic axial angle. It evidently contains a considerable amount of iron, for the rock in which it is abundant often assumes a deep red colour by weathering. The mica of the weathered rocks has been replaced by chlorite with which iron-oxides are associated.

The more modified rocks, and these are by far the most abundant, are characterized by the presence of a fine-grained granulitic aggregate of quartz and felspar and a more or less marked parallel structure. The granulation of the quartz and felspar is, I believe, a secondary phenomenon due to the dynamic metamorphism which has operated upon the district. It may be developed merely at the margin of the original grains, in which case we have the mortar-structure of Tornebohm¹—the relics of the original grains then lie in a fine-grained granulitic paste like stones in mortar—or it may replace entirely, or almost entirely, the original quartz and felspar. The development of white mica does not appear to be a common feature. It may, however, be observed in what I am inclined to regard as a schistose granite from Porthalla, where it occurs along the planes of schistosity. In this rock the secondary granulitic aggregate forms a large portion of the mass.

A very interesting variety of gneissose rock occurs in the serpentine near Kynance. It forms only a thin band, and is, I believe, a granitic vein which has been profoundly modified by the regional metamorphism. Sections at right angles to the foliation show a magnificent micro-flaser structure. The secondary aggregate of quartz and felspar winds in and out amongst the relics of the original grains, and possesses in some places a crypto- rather than a micro-crystalline structure. The rock does not possess any very definite schistosity and white mica is absent. It appears as if the development of white mica were connected with movement along definite planes—where the mass has been deformed in a plastic manner white mica is absent.

The specific gravity of the rocks of the granitic type lies between 2.6 and 2.7

Diorite.—This rock, like the granite, never occurs in large independent masses. It is generally veined by the granite or intimately banded with it in the gneissic series. It may also be found in the gabbro. The rocks to which I here apply the term diorite vary in composition and specific gravity. Some belong to the intermediate, others to the basic series. At the one end of the series we have a

¹ Naagra ord om granit och gneiss. Geol. Fören. i Stockholm Förhandl. 1881, pp. 166 u. 233.

rock which may be termed a mica-diorite, with a specific gravity of about 2.75; at the other end of the series we have a rock which may be termed hornblende-diorite (basic diorite, or possibly an epidiorite) with a specific gravity of 2.99; between the two extremes we find intermediate forms which may be termed mica-hornblende-diorites. The specific gravity of one of these is 2.83.

The more important minerals of the dioritic group of rocks are felspar (mostly striated in the least modified rocks), dark mica, green hornblende, sphene, iron-ores, and apatite. The felspar of the least modified rocks is often somewhat turbid, and the turbid portion frequently forms a kind of kernel in the centre of a comparatively unaltered individual. This points to an original zonal structure. Some of the diorites are porphyritic, and traces of the forms of the porphyritic crystals (felspars) are preserved even in the foliated rocks.

The mica is similar to that of the granite. It occasionally contains minute granular inclusions (probably zircon) which are surrounded by very dark borders. The sphene is a very interesting and important constituent of the diorites. It occurs in perfect crystals and also as grains. The grains in certain rocks form a border to the opaque iron-ores. This is a feature which may be observed in some of the gneissic rocks of Sutherland and the Malvern Hills. Iron-ores are comparatively rare in the mica-diorites, but they become abundant in the basic diorites. Apatite is very common in some of the mica-hornblende-diorites.

The felspars of the diorites show the same tendency to granulation as those of the granite and the individual grains in the granulitic aggregates are mostly untwinned. In the foliated diorites of the banded gneissic series striated felspar is comparatively rare.

Gabbro.—As this rock and the modifications which it undergoes when subjected to regional metamorphism were described at the last meeting of the British Association,¹ it will be unnecessary for me to enter into details on the present occasion. Suffice it to say that every gradation from a massive rock to a gabbro-schist may be observed in the district. Unaltered gabbros are, however, very rare, just as unaltered granites and diorites are rare. Since my last paper was read I have isolated the felspar and augite of the unaltered gabbro from Coverack, and Mr. Player has kindly analyzed them for me in my laboratory; the former is a somewhat basic labradorite; the latter possesses .6% of chromic oxide, and is therefore a chrome-diopside. The hornblende of the gabbro-schist from Pen Voose has also been analyzed by Mr. Player. It possesses over 10% of alumina and differs from the augite also in containing more magnesia than lime. It contains, however, decided traces of chromium. The analyses, therefore, so far as they go, point to the conclusion that the hornblende differs from the augite or diallage in composition, so that the disappearance of the pyroxene and the development of hornblende cannot be ascribed to simple paramorphism. The specific gravity of the chrome-diopside is about 3.22, that of the hornblende

¹ GEOL. MAG. Decade III, Vol. III, p. 48.

is about 3.05. With regard to the so-called saussurite, I am able to state that malacolite, felspar, and minute granules of sphene often occur as constituents. The malacolite has been isolated and analyzed by myself, so that no doubt exists as to its identification, though it often occurs only in minute grains without form or cleavages. The doubtful substance which appears white by reflected and brown by transmitted light and which is a constant feature in the Lizard saussurite has not been identified.

FIG. 3.

We have now to consider the mutual relations of the different rocks above described. At Kennack Cove and at Pen Voose, near Landewednack, granite may be seen veining diorite, often in the most intricate manner (see Fig. 1, Plate XIV.). At Pen Voose, veins of both granite and diorite occur in the gabbro, Fig. 4. The three rocks are therefore of igneous origin. They exhibit the relations of igneous rocks, and they possess the composition of igneous rocks; moreover, it is possible to find here and there portions which have escaped the influence of the dynamic metamorphism, and which show the normal structure of igneous rocks. But the same rock types occur as integral portions of a banded gneissic series in the same localities. The bands are in some places as regular as layers of sediment in a stratified rock-mass, in other places they are crumpled and contorted (Fig. 3); in others we observe "eyes" and lenticles of diorite surrounded by streaks and bands of a granitic rock (see Fig. 2, Plate XIV.)

As a rule the banded gneissic series is formed only of granitic and dioritic rocks, but we occasionally find eyes and streaks of gabbro and gabbro-schist. One large specimen, to which I wish to direct special attention, shows a crumpled band of gabbro-schist in mica-diorite.

Another mass much too large to carry away showed the appearance

represented in Fig. 5. It consisted of parallel bands and narrow lenticles of foliated gabbro, granite and diorite. Fig. 6 represents the relations of granite, diorite, and gabbro in a mass which exhibited no parallel structure. In Figs. 5 and 6 the space left clear represents granite, or at any rate a rock of granitic composition; the dotted portions represent diorite, and the portions indicated by fine

FIG. 4. Granite in Gabbro, Pen Voose. Block 6 feet long.

lines gabbro or gabbro-schist. Fig. 5 represents a mass four feet and Fig. 6 one three feet in height.

I submit, therefore, that the rocks of the Lizard District referred to in this communication, and which constitute the greater portion of Prof. Bonney's granulitic series, are of igneous origin and that the parallel structure which characterizes many of them has nothing

FIG. 5.

FIG. 6.

to do with stratification in the ordinary sense of the word, but is a consequence of the deformation to which the original rock-masses have been subjected. It is undoubtedly true, as Prof. Bonney has pointed out, that many of the rocks are largely composed of broken crystals, and may be said therefore to possess a clastic structure if we use the term clastic in its etymological sense. But this is no proof that the fragments have been deposited as such. The original minerals may have been broken during the deformation of the rock-masses. This I believe is what has actually taken place.

Geological Map of Coast near Landewednack. Scale 25 inches to the mile.
To illustrate Mr. J. J. H. Teall's paper.

The structures are of the kind for which Prof. Kjerulf¹ has proposed the term cataclastic.

I doubt whether any true clastic (epiclastic²) rocks occur in the Lizard District south of St. Keverne.

EXPLANATION OF ILLUSTRATIONS.

The map is merely intended to enable readers to form some idea of the relations of the rocks in the district especially referred to in the latter part of the paper, and to fix the exact localities from which the illustrations are taken. The actual phenomena are too complicated to be accurately represented even on the 25 inch scale. At the point marked A an "eye" of gabbro foliated at the margin and measuring about five or six feet in length may be seen in the "granulitic" series. Figs. 2 and 3 are reproductions from photographs taken at B. Fig. 5 represents a portion of the cliff face about nine feet in height; Fig. 6 another portion about four feet. The crumpling of the bands is well seen in the negative, but has not been very successfully reproduced in the figure. Fig. 1 is from a photograph taken at C, where the banded gneissic series and the gabbros are seen in juxtaposition. It represents a portion of the cliff about 8 feet in height. The line representing the boundary between the gneissic series and the gabbro should have been brought to the point C. This figure illustrates very well the manner in which the light-coloured granitic rock veins the dark-coloured diorite. It must be remembered that Figures 1, 2, and 3 represent portions of the same rock mass. If the rocks are igneous at C as seems to be proved by Figure 1, they must also be igneous at A and B. The point C is the point where a granite vein is indicated on the geological map of the district.

III.—ELEMENTS OF PRIMARY GEOLOGY.³

By T. STERRY HUNT, M.A., D.Sc., LL.D., F.R.S.

1. **U**NDER the general terms of Primary and Original, given by Werner and others, to the early crystalline rocks, have been included various mineral aggregates which may be classed under three heads: 1. The great stratiform masses of aqueous origin, essentially granitic, and formed by slow deposition at the earth's surface, which I have called Indigenous rocks. 2. Those lesser crystalline masses which were formed under similar conditions to the last, but within veins or fissures in pre-existing rocks, and may therefore be called Endogenous. 3. Rocks resembling the last in their geognostic relations, and often confounded with them, but distinguished by the fact that they have come into their present positions not by deposition from solution, but by displacement in a more or less fluid or plastic state. These Exotic or erupted masses, whether ancient or modern, are in a sense Primary, since they sustain, in one way or another, intimate relations to the more ancient rocks to which this name was first given.

¹ Grundfjeldsprofil ved Mjøsens sydende, *Nyt Magazin*, 1885, p. 215.

² Some modification in the use of the term clastic is rendered necessary by recent discoveries. I venture to suggest that it should be applied to all rocks which consist largely of mineral fragments and that we should distinguish between the three types of clastic rocks at present recognized by using the terms epiclastic, cataclastic, and pyroclastic. *Epiclastic*—Rocks formed of fragments resulting from the breaking up of older rocks occurring upon the earth's surface. *Cataclastic*—Rocks largely composed of fragments produced during the deformation of older rocks by the earth-stresses. *Pyroclastic*—Fragmental rocks of volcanic origin. The same terms may be applied to the structures which characterize the rocks in question.

³ Paper read before Geological Section, British Association, Manchester, 1887.