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I.—*On the Microscopic Structure of Luxullianite.*—BY T. G. BONNEY, M.A., F.G.S., Fellow and late Tutor of St. John's College, Cambridge.

SO far as I am aware no account of the microscopic structure of this rare and beautiful rock has yet been published. I have, therefore, thought that a brief description of its structure and some considerations concerning the origin of tourmaline rocks may be of interest to petrologists.

Boulders of the rock, as is well known, are abundant in the vicinity of the village of Luxullian (about five miles from the town of St. Austell, Cornwall), where I collected specimens in the autumn of 1873; but I believe the rock itself has never been discovered *in situ*, though veins of different varieties of tourmaline rock are abundant in the granite of this and other districts in Cornwall, some of which occasionally rather resemble it, and the mineral frequently occurs in the granite itself, the felsite elvans, and the altered sedimentary rocks.

Luxullianite* consists of a groundmass of velvet black tourmaline (schorl), in which are embedded grains of whitish quartz, occasional small rather irregular crystals of felspar, and a number of larger and

* It will not be forgotten that a magnificent block of this rock is used for the sarcophagus of the late Duke of Wellington.

more regular crystals of the same mineral, commonly from one to two inches in length. These are evidently orthoclase, of a light-pinkish-red colour, spotted with small included crystals of schorl. On a closer examination of the ground mass, it is seen to be composed of a dense mass of minute acicular crystals of schorl, matted together like intergrowing tufts of grass, and interspersed with white quartz. The exterior of the boulders has a rather slaggy aspect. This is caused by the schorl decomposing more slowly than the felspar, and so projecting with an irregular rough surface. When the schorl decomposes it assumes a dull greenish or sometimes brownish hue. The rock is extremely tough except when decomposed, and it is thus very difficult to obtain good specimens. The slide which I am about to describe was cut for me by Mr. Cuttell from a specimen not collected by myself, but selected for that purpose because of its excellent state of preservation—I am informed that it is generally a difficult rock to prepare for the microscope.

On examining the slide by transmitted light, the rock is found to consist of a groundmass of colourless quartz, often crowded with acicular crystals of schorl,* of irregular grains of brownish tourmaline, and of crystals of orthoclase felspar. more or less decomposed. I shall describe these as far as possible separately.

The groundmass.—The quartz is generally clear and pellucid, but here and there it contains minute endomorphs. These in some cases appear to be very minute belonites, which are probably schorl, but often they seem amorphous brownish grains, just like a fine dust. The schorl occurs in acicular crystals, which are massed together in tufts; the needle-like crystals radiating from a centre, like blades of grass from a root (see fig. 1 Plate VII). In places, the more minute crystals have so intergrown as to render the slide almost opaque; but when they attain a somewhat larger size and are less crowded, the effect is singularly beautiful. The crystals, so far as I can ascertain, are hexagonal prisms tapering towards the free end; they are often about 0·03 inch long, and 0·001 inch in diameter. The crystals when cut across the prism are of a translucent indigo blue or dull greenish blue colour, when cut length-wise rather of a greenish

* For brevity I will employ this name to designate the bluish variety. This would be a more distinct black when thick than the other, which inclines to yellowish brown. As will be seen hereafter, I suspect there is a difference in the chemical composition of the two kinds.

drab or pale brownish stone colour.* As they are intersected in all directions, there are of course endless varieties of tint. With polarized light the longitudinal sections exhibit strong dichroism, changing from the above brownish to bluish green tints as the polarizer is moved through 90° : with crossed prisms the same sections exhibit great varieties of colour, from pale golden-yellow to green and pinkish-purple, changing beautifully as the polarizer is rotated. It is now seen that the quartz in which these crystals are imbedded—seemingly growing in it like herbs under water—is not only crystalline, but consists of various granules, rendered very distinct by the different colours which they assume. Yet the schorl crystals are in no way limited by the surfaces of these, but pass indifferently from granule to granule. They are, however, either arrested abruptly at the edge of one of the felspar crystals, or only penetrate it to a very slight distance.

The Brown Tourmaline.—Leaving the groundmass awhile, I pass on to this constituent. With transmitted light it is seen to form grains of irregular outline (generally considerably longer than wide, with the longer exterior boundary occasionally rectilinear, or nearly so), and of a pale golden-brown colour (see fig. 2 Plate VII). They are traversed by irregular cracks, which occasionally give indications of a very imperfect cleavage parallel to the longer sides. Minute microliths and cavities—not generally numerous—appears also not seldom to have a similar arrangement. The grains included on the present slide vary from about 0·02 to 0·2 inch in the longer diameter. With polarized light the dichroism of all is shewn to be much less strong than that of the schorl crystals. When the light is analysed the colours are not generally rich (except in the case of one grain). No trace is seen of aggregate polarization. Each grain, however, is bordered by a dense mat of schorl crystals; sometimes these are short and crowded so a simply to form a comparatively thick opaque line (fig. 2), but generally they are of the usual shape, and sprout from the edges of the larger crystals like tufts of moss growing on a stone. This comparison is justified by the fact that minute dust-like microliths and ferruginous brown veinings abound where the belonites are most most closely matted, so that the blades appear to grow from a kind of soil supported by the larger tourmaline crystal.

* We have not attempted to represent this dichroism in the figure.

The porphyritic crystals of orthoclase.—When examined microscopically these are seen to be much decomposed, being more or less clouded with a fine brown dust, and containing numerous schorl microliths, which are occasionally gathered into small tufts. With polarized and analysed light they exhibit no brilliant colours, but a dull aspect, sometimes almost opaque, sometimes rather mottled with milky white; in short, the ordinary appearance of felspars which have been affected by water. The tufts of schorl belonites, however, are almost invariably implanted in a small area of clear quartz (fig. 1) generally as nearly as possible conterminous with the ends of the schorl needles; and whenever the latter appear to have penetrated from without into the surface of the felspar crystal, the accompanying interstitial quartz seems to encroach upon and pierce into the generally linear edge of the crystal.

This microscopic study of the rock would leads us to the conclusion that the microlithic schorl results from chemical action on felspar; and I think we may regard the Luxullianite as a peculiar metamorphic form of the normal granite of the country. It is well known that tourmaline is frequently present in granite and felsites, especially in Cornwall. I have studied several of these both microscopically and in the field; and the mineral has always had the aspect of a secondary product, and seemed to be closely associated with decomposed felspar. For instance, I may refer to the veins of schorl rock so common in South-western Cornwall, which may be traced through decomposing granite till they die away in strings. From these veins we may collect specimens in every stage, from what we should call a rather decomposed granite rich in schorl to a rock which seems to consist solely of quartz and schorl. I may refer also to apparent dykes of schorl rock, or very schorlaceous granite, which I have seen W. of Mousehole; these at first sight might be taken for true intrusive dykes, but on closer examination are seen to pass, though rapidly, into the adjoining rock; as well as to the sections to be seen near the Carclaze Mine (St. Austell), where veins and nodes of schorl abound in the granite near its junction with the "killas," and the latter rock is now composed of alternating sandy and schorlaceous layers. I think no one can study this district without coming to the conclusion that the schorl is a secondary product formed from the felspathic constituents of the various rocks.

If, however, Luxullianite is an altered granite, two difficulties must be considered. The Cornish granite consists of mica, felspar, and quartz. How then do we account for (*a*) the absence of the first mineral; and (*b*) the fact that the original grains of the last (if such existed), do not seem to have offered any opposition to the formation of the schorl crystals?

(*a*). It will have been observed already that I have spoken of two varieties of tourmaline in luxullianite which differ markedly one from another; one, the brown variety, found always in grains, which (omitting some filmy specks occurring here and there among the denser part of the other kind) are of considerable size and irregular form—the other always acicular, more or less aggregated, of a bluish colour, and (as I think) more strongly dichroic. In examining the first I am struck by the general resemblance which the grains present to the ordinary forms of mica, and by the indications of cleavage already mentioned, which much more resemble that of the black mica occurring so commonly in the Cornish granites, than the very irregular structnre of tourmaline. Its mode of occurrence seems to indicate that it is not a true cleavage of the tourmaline itself, but a kind of pseudomorphic structure. I have also noticed in examining other rocks containing tourmaline that mica does not occur where it abounds, and that where the two are found together, the former appears to replace to some extent the latter.

A section from a specimen of granite collected in the quarry near the railway viaduct W. of S. Austell, gives, I think, full proof of this. The rock itself shews a fair proportion of schorl occurring much as the black mica (probably biotite) ordinarily does, and some silvery-white mica (? margarodite). Examined by transmitted light, it will be seen that much of the tourmaline (which is brown in colour) presents a resemblance to the ordinary form of mica, preserves distinct traces of the characteristic basal cleavage of that mineral, while here and there are remnants of mica not wholly altered. In some cases the bluish variety (which I have called schorl) also is seen bordering the changed biotite crystal, but here appearing to be developed from it: it is not, however, abundant, and has not the tufted arrangement.* The felspar is a good deal decomposed, but only shews occasional microliths of both varieties of tourmaline.†

* In another slide from the Mousehole rock the schorl generally borders the brown tourmaline where it is contiguous to felspar crystals.

† I am aware that the opinions above expressed differ from those of Dr. Senft (*Die Krystalliinische Felsengemengtheile, &c.*, p. 505), who regards mica as an alteration product of tourmaline, and gives a section which appears to favour his

(*b*). The acicular schorl passes from grain to grain of the quartz. On any hypothesis this seems rather strange, but on that of the former mineral being a secondary product it is very perplexing. It would be a most exceptional thing for a slice of average Cornish granite nearly ¾ inch in diameter not to contain some free quartz; and if this one did so contain it, how are we to explain its easy penetration by the schorl. There is one small grain evidently not a secondary product, free from schorl, but this, it is important to note, is completely enclosed in one of the larger crystals of felspar. Hence, I conclude that the more probable hypothesis is that the chemical agents which produced the schorl rendered the quartz sufficiently plastic to yield easily to the crystalline forces.* Hydrofluoric acid will gelatinize quartz, and we must not forget that fluorine is generally present in tourmaline.

The very variable composition of the latter mineral would lead us to anticipate that it would, under certain circumstances, be present as a decomposition product of more than one mineral, and its presence as above described seems to accord with our expectations. We observe on consulting a table of analyses of tourmaline, such as is given by Dana (Mineralogy, p. 368), that magnesia is generally present, sometimes in large amounts (up to 14·89 per cent). According to De la Beche (Geology of Cornwall, p. 189) a tourmaline from Bovey, which he takes as also representing the Cornish mineral, contained 0·70 per cent. For these reasons, if we had supposed it formed from felspar alone, we should have had to consider our mineral to be a variety exceptionally poor in magnesia, and it would also have been asked what had become of the biotite, so normal a constituent of the Cornish granite. Senft, however (*op. cit.* p. 507), shews the possibility of the change of tourmaline into magnesia mica; and as it appears to me his reasoning will not only

view. Not having seen the locality, I cannot say whether his interpretation is the only one possible; and at any rate it leaves quite unanswered the difficulty of what fluid formed the tourmaline rock from either granite or quartz (the rock adjoining the veins); we must also remember that the order of chemical change in nature not seldom differs. Be this, however, as it may, I have carefully considered the question and can put no other interpretation than the above on the microscopic sections which I am now describing.

* In like way I have seen acicular crystals of secondary actinolite pierce into crystals of comparatively undecomposed felspar. This is described in a paper presented last May to the Geological Society, but not yet published.

bear reversal, but be simplified by it* (for Lithium, Boron, and Fluorine are the constituents which we should expect to be added by the agency of water), so that we need not further discuss this. Again, the formation from felspar of a tourmaline poor in magnesia by the addition of the required constituents is quite possible, as an inspection of tables of analyses will shew, by the loss of alkali, addition of iron protoxide boracic, lithic, and fluoric acid, and the disengagement of the superfluous silica. Of this last, there will obviously be a large quantity. Taking for purposes of rough calculation, the analysis given by De la Beche (*loc cit.*) SiO_2=35·20, Al_2O_3=35·50 in tourmaline; and that given by Nicol (Mineralogy, p. 110) for orthoclase, SiO_2=64·6, Al_2O_3=18·5; we shall see that in forming the former mineral from the latter (supposing the Al_2O_3 unchanged in quantity) we require very nearly 18·1 parts of the SiO_2 in the orthoclase, and so liberate about $\frac{31}{43}$ (nearly 0·72 of the whole). This then fully explains the abundance of quartz in the Luxullianite and its association with the schorl needles.

The remarkably interesting case described by Mr. Collins (p. 115), where there is considerable resemblance between the crystals figured by him and those described by me, must not be overlooked, as it points at first sight to a simultaneous formation of the quartz and tourmaline. As, however, the quartz crystal was found in a cavity in schorlaceous granite, there is no reason why its constituents should not have been dissolved from the granite by water as above.

I think then that the study of this and the other above described varieties of tourmaline bearing rocks, both in the field and microscopically, justify us in regarding them as the result of the action of water, containing the requisite substances in solution, and probably at rather a high temperature, upon granite, felsite, and certain sedimentary rocks.†

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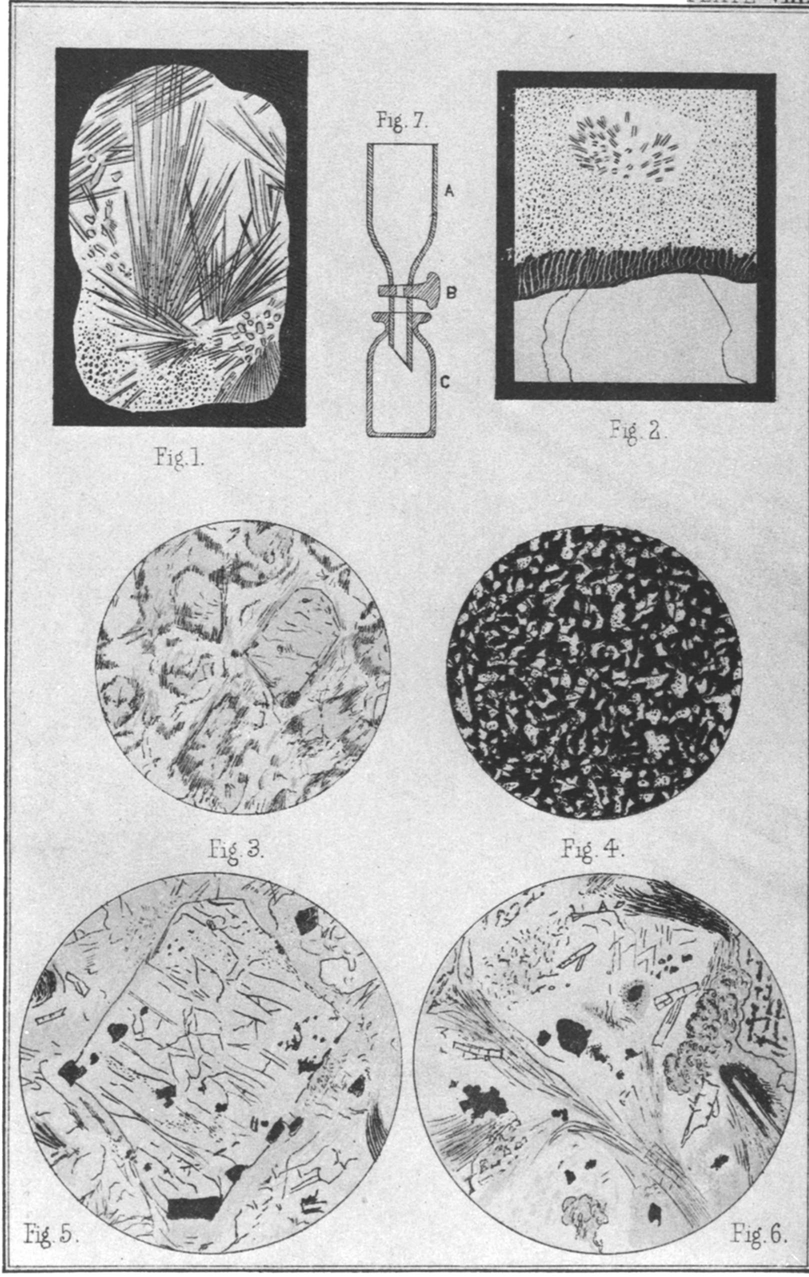
* It must also be remembered that water is a constituent of tourmaline, which favours the idea of its being a secondary product.

† Sir H. De la Beche op: cit. p. 160, regards the schorl as, at any rate in many cases, a secondary product, though he does not appear to have considered the details of the question. Since the above was written my attention has been called to a notice in the Comptes Rendus for 1864, by M. Pisani (p. 913). He regards Luxullianite as an altered granite and states that tourmaline has replaced the mica; the opinion, however, seems to be a conjecture formed on a general examination without the microscope, as the rock is said to contain very little quartz, which is hardly correct.

PLATE VIII.



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