

*Notes on a biotite-cyanite-cordierite-rock from the Upper Satlej Valley,
N.W. Himalayas.*

By Lieut.-General C. A. McMAHON, V.P.G.S.

[Read June 23rd, 1896.]

SOME years ago I found in the bed of the Satlej at Wangtu, in the N.W. Himalayas, about 80 miles, as the crow flies, north-east of Simla, a boulder of the rock described in the following pages. It is composed of biotite, cyanite and cordierite, with apatite and rutile as accessory minerals.

The specimen has a specific gravity of 2.92. Its structure is holocrystalline, and its minerals show no trace of parallelism in their orientation. It is, I think, a product of contact metamorphism.

I have not come across the above rock *in situ*, but the Upper Satlej at and above Wangtu is a region of intense granitic eruption and cyanite and other contact-metamorphic minerals, are to be found there in great abundance.¹

Thin slices having been studied under the microscope, the following remarks are offered on the rock and its component minerals.

BIOTITE.

The biotite is quite black when viewed macroscopically, but in thin slices and in transmitted light it exhibits strong pleochroism, (c) being dark green, (b) green, and (a) greenish yellow. The scheme of absorption is $a > b > c$.

The whole of the colouring matter and the bases are removed from the biotite on heating in nitric acid, and the solution thus obtained reacts for iron, magnesia and lime. The residue consists of amorphous silica which is completely soluble in a solution of caustic potash. The interesting point is that this amorphous silica, after yielding its bases to hot nitric acid, preserves the cohesion, the hexagonal shape, and the pronounced lamination of biotite. Whilst completely retaining the

¹ Some fine specimens of cyanite found in granitoid gneiss a mile or two above Wangtu were exhibited when the paper was read.

characteristic form and lamination of biotite, however, it loses the whole of the optical properties of that mineral and acquires those of amorphous silica. After treatment with acid it has no action on polarised light, and its refraction falls from that proper to biotite, to that proper to amorphous silica. The indices of refraction for biotite are n_g 1.606, n_p 1.562; but I find from actual observation that the refractive index of the siliceous residue of the biotite is higher than 1.374, and lower than 1.437; the mean of these figures being 1.405.

The above facts are, I think, suggestive. They not only show that the optical properties of biotite depend on the bases present—a conclusion arrived at by other observers in the case of some other minerals—but they also appear to throw some light on the constitution of the biotite molecule, and suggest that the bases are linked to the silica in such a way that their atoms may be replaced by water, or its constituents, without the molecule being broken up. That the loss of the bases did not break down the molecule, seems to me clear from the fact that though the optical and other physical properties of biotite were changed, the hydrated siliceous residue retained the form of biotite as perfectly as ever. Had the biotite molecule been broken up, we should have got pulverulent or flocculent silica, but the form of biotite would, it seems to me, have been lost.

Biotite is now so fully recognised as a product of contact metamorphism that no remarks on this subject seem necessary. I would only say, in passing, that I have seen several interesting cases in the Satej Valley of the production of biotite by the contact action of granite on basic rocks of igneous origin. I place on the table a hand specimen in illustration of this statement. One half of the specimen consists of brown biotite, and the other half of a fine-grained diorite or epidiorite.

CYANITE.

The cyanite seen in the Wangtu rock is white in reflected, and colourless in transmitted light. It is in blade-like prisms with irregular terminations and somewhat corroded sides. The longitudinal and transverse cleavages are usually well developed. Sometimes the former become very pronounced and the mineral passes into sillimanite. Sometimes the cyanite frays out into sillimanite needles, or needles of this mineral are seen in its immediate vicinity; the passage of the one mineral into the other is never, however, absolutely complete, for though it loses its oblique and puts on straight extinction, the major axis remains at right angles to the length of the prism instead of becoming parallel to it, which is the normal position for sillimanite.

Cyanite is, as is now well known, a recognised product of contact metamorphism arising from the vicinity of granite, and its abundance in the zone of contact-metamorphism in the south-eastern Highlands of Scotland, has been described by Mr. G. Barrow in his able paper published in the forty-ninth volume of the *Quarterly Journal of the Geological Society* (p. 330).

CORDIERITE.

Cordierite in this rock was the last mineral to crystallise. It is uniformly allotriomorphic and it does not present any suggestion of crystallographic form or of cleavage. Its refractive index I found to be above 1.538 and below 1.547, which would do for quartz, andesine, oligoclase or cordierite. Its double refraction did not serve to distinguish it, and in specific gravity the above minerals come near each other. Its behaviour in converging polarised light showed that it was not quartz. All doubt, however, as to the identification of the mineral in the Wangtu rock has been removed by Mr. G. T. Prior, F.G.S., Mineralogical Department of the British Museum, to whom I am much indebted for the determination of this mineral. He succeeded in isolating and analysing minute fragments, which yielded magnesia and the other constituents of cordierite, and exhibited a delicate but appreciable dichroism under the microscope.

ACCESSORY MINERALS.

The specimen contains apatite, mostly in granules, though nests of micro-prisms occur here and there. The granules are soluble in nitric acid, and the solution reacts for phosphoric acid with ammonium molybdate, and for lime with sulphuric acid. The optical properties of the granules are those of apatite.

Numerous small crystals of rutile are also to be found in very thin slices. They occur most frequently in the biotite; less so in the cordierite, and more rarely in the cyanite. They are sausage-shaped, or in stumpy crystals with rounded angles. I have only observed one or two cases in which the rutile assumes the needle shape. Most of the crystals of rutile polarise brilliantly.

No magnetite is to be seen, but now and then there is a little ferric oxide stain.

GENERAL REMARKS.

One of the questions which arise in connection with this rock is its probable origin. What kind of rock was it before it was metamorphosed?

A cyanite-gneiss has been described by Mr. Barrow, in his interesting

paper before referred to, the crystalline structure of which the author attributes to the contact action of granite, intensified by the great depth below the surface at which that action took place. "The sedimentary origin," the author writes, "of the group of rocks last described" [those of the staurolite zone] "will probably be admitted without question, but in the case of the more highly altered rocks" [this apparently includes the cyanite zone] "it is not so clear." The author appears, however, to incline to the view¹ that the rocks of the sillimanite and cyanite zones are also of sedimentary origin.

There are some points of resemblance and some points of difference between Mr. Barrow's cyanite-bearing gneisses and the rock above described. The former are foliated but the latter possesses a perfect granitic structure. The Scotch rocks contain muscovite, feldspar, free quartz, garnet, chlorite, iron ores and tourmaline, none of which are present in the Wangtu rock, whilst the latter contains cordierite, apatite and rutile, absent from the Scotch rocks. Biotite and cyanite are common to and abundant in both.

The high specific gravity of the Wangtu rocks, coupled with the absence of free silica, and the presence of apatite, are points which seem to bear on the question of origin. Apatite is characteristic of some rocks of igneous origin, and free silica is a characteristic constituent of aqueous sediments.

I framed an estimate by taking the minerals contained in the Wangtu specimen in such proportions as would give a rock with a sp. gr. of 2.92, and calculated the chemical contents from the formulæ of these minerals. The result came near the composition of augite. Until the Wangtu rock is found *in situ*, however, nothing definite can be affirmed regarding it, but I think the probabilities of the case are in favour of its being a contact-metamorphic rock of original igneous origin.

Mr. Barrow, in the paper already referred to, called attention to the fact recorded by Dana in the last edition of the *System of Mineralogy*, that cyanite is, at a temperature of 1320°-1380° C., converted into sillimanite. I have shown that the commencement of this change had been set up in the Wangtu rock. We may, therefore assume that the latter was heated until it reached a temperature of about 1320° C. If so, the heat to which the rock was raised was sufficiently high to have completely fused a basic rock of igneous origin. The melting point of diabase is said² to be between 1100° C. and 1170° C., and that of ordinary

¹ *i. c.* p. 351.

² Lord Kelvin quoting Carl Barus, *Nature*, Vol. LI. p. 439.

basalt 815° C.¹ The minerals of which the Wangtu rock is composed therefore, probably resulted from the fusion of the original rock from which it was derived, and from the rearrangement of its component silica and bases.

Looking at the rock from this point of view, its microscopical examination presents some points of interest. The first stage in the formation of the metamorphosed rock seems to have been the crystallising out of the contact minerals, and subsequently when the heat reached its maximum the last formed and more acid mineral, cordierite, began to corrode, and eat into the more basic minerals.

This corrosion and partial re-solution may be traced in the illustration (Plate III. Figs. 1-5). The action of the cordierite on the biotite is rather remarkable, the majority of the biotite crystals being fringed with tags of half dissolved mica. A question naturally arises whether these tags are portions of the biotite in process of re-solution, or whether they represent a re-deposition of mineral matter previously held in solution in the cordierite. I do not think the latter is the true explanation for the newly deposited mineral—especially if it were biotite, deposited on biotite—would surely have been deposited in a layer on the previously formed mineral and not in the form of a fringe of tags depending from the edges of the biotite leaves. Moreover the faces of these leaves often exhibit a series of vermicular marks resembling microscopic worm burrows, which seem to be due to the corrosive action of the comparatively acid mineral on the basic biotite suspended in it.

These tags have a high refractive index, the major axis is at right angles to their length, many of them are distinctly dichroic, and biotite is the only mineral they are attached to.

The study of this, and other crystalline rocks, has led me to the conclusion that a double action may be set up in such rocks when subjected to thermal action under pressure, and more or less completely fused. There is first a constructive action in the crystallising out of minerals, and this may in some cases be succeeded by a destructive action in the corrosion, and partial re-solution, of some or all of these minerals, by the comparatively acid mineral that plays the rôle of the base or residuum. A change of temperature, or an alteration in the melting point due to relief of pressure, seems sufficient in some cases to bring this about. This double action is often to be seen in granites.

¹ Professor Sollas relying on Dr. Joly, *Nature*, Vol. LI. p. 534.