Notes on the Wollastonite rock-mass, and its associated minerals, of the Santa Fé Mine, State of Chiapas, Mexico.

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THE geological features of the immediate neighbourhood of the Santa Fé Mine, which is situated about nine leagues nearly due east of the departmental town of Pichucalco, have been partially described by the author in a paper[1] recently read before the Institution of Mining and Metallurgy. The key to the position, from the point of view alike of mineralogical and of economic interest, is found in a dome-shaped mass of wollastonite in a nearly pure condition, the horizontal section of which, at the lowest level where it has been sufficiently explored to determine its shape, takes the form of an irregular ellipse about 400 yards long by 160 yards wide. With the exception of the ore-bodies, which are developed on the outskirts of this mass and close to the contacts with other rocks, the whole mass is of nearly uniform composition, consisting of the mineral wollastonite in a nearly pure condition and very coarsely crystallized. Towards the outskirts of the mass the pure wollastonite contains a small proportion of garnet (andradite), and passes, usually by insensible gradations, into the payable ore-bodies. These are irregular in form and distribution, and, while still consisting of wollastonite as the principal gangue mineral, contain also small proportions of garnet, quartz, calcite, semi-opal, and other non-metallic minerals; while the principal valuable metallic minerals, bornite and chalcopyrite, are accompanied by small quantities of galena, pyrites, fahlerz, enargite, &c.

Except near the edge of the mass, the massive wollastonite is not crystallized confusedly from a number of centres, but shows a parallel orientation over distances of many feet. The mineral has two well-developed cleavages approximately at right angles to each other, and the mass breaks readily into fissile rectangular blocks; the resulting structure resembles that of satin-spar, the parallel crystalline fibres often, however, reaching three or four feet in length. In colour the wollastonite is—except where stained by traces of iron and other minerals—

[1] 'Concentration and smelting, as applied to the treatment of low grade gold-copper ores at Santa Fé (Mexico).'

pure white and translucent; its lustre varies from vitreous to satiny; its hardness is 5, and its specific gravity (average of several determinations) is 2·88.

Origin of the Wollastonite mass. Although a mineral of somewhat wide distribution, wollastonite has hitherto never been known to form the sole constituent of an important rock-mass, but is generally found associated with garnet, epidote, idocrase, and other well-known products of metamorphic action upon impure limestones near their contacts with igneous rocks. In the paper referred to, however, the author adduces arguments to show that this particular mass of wollastonite is not a product of metamorphism *in situ*, but that it has been intruded in a perfectly plastic condition, and that the ore-bodies have been separated from it by magmatic segregation. The principal arguments in favour of such a supposition may be recapitulated as follows:—

1. The wollastonite is absolutely isolated from the limestone rocks of the district, the nearest outcrop of which is situated at a distance of one mile from the outskirts of the mass.

2. It is completely surrounded on all sides by granite, felsite, diabase, and other igneous rocks. The felsite and diabase are in close association with the wollastonite, and the granite surrounds them all at a short distance.

3. The mass is hump- or dome-shaped, its outer surface dipping away from the centre in all directions. The top of the dome only just reaches the present surface, and at the time of its intrusion probably fell short of reaching the then existing surface by several thousand feet. No very long lapse of time, geologically speaking, is required for the denudation of a few thousand feet of rock in a mountainous tropical region possessing an average rainfall of about 200 inches per annum.

4. At a depth of 200 feet below its highest point, mining operations have fairly well mapped out the extent and form of the mass, and have proved it to cover an area about 400 yards long by 160 yards wide, while at an horizon 100 feet deeper its unbroken character has been already proved over an area at least 200 yards long by 80 yards wide. Near the upper surface and outer edge of this mass the pure wollastonite is contaminated with other minerals, is much split up, and includes fragments of the surrounding rocks; it is near this outer contact that ore-bodies have been developed, and that evidences of fissuring and of secondary alteration are met with. Near its outer fringe, moreover, the wollastonite has been penetrated by trap dykes of an obviously later origin. Taking, however, only the central unaltered and undisturbed

core of the mass, which certainly contains over two million cubic yards of material above the deepest level at which it has been yet opened up, while it presents every indication of continuing unaltered down to unknown depths, it is noteworthy that in the thorough exploration of this very large mass of rock by a network of drivages in all directions, no variation in composition is anywhere observable between different parts of the mass nor in the relative proportions of lime and silica present, no vestige of a transition from limestone to wollastonite, and no indication of a variation in the crystalline structure, which is perfectly developed and uniform throughout.

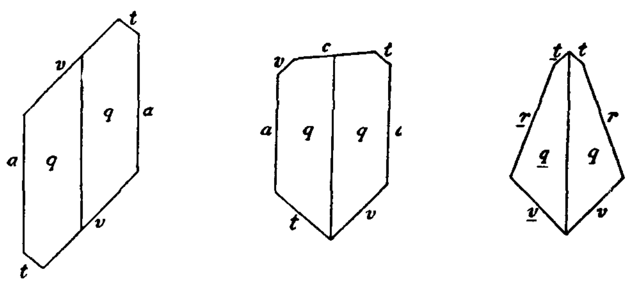
It is admittedly a unique occurrence for so large a mass of eruptive rock to be composed of practically a single mineral species, but it seems difficult to conceive that so large a mass of limestone could be gradually metamorphosed by siliceous solutions or vapours in such a way as to produce a pure anhydrous silicate of lime of absolutely definite composition and of uniformly macro-crystalline structure throughout. In portions of the rock-mass which are traversed by master-joints the crystalline fibres usually run perpendicularly to these joints, and are often strictly parallel to each other over a width of as much as fifty feet, and absolutely continuous for four to six feet from joint to joint. After long and careful study of the conditions on the spot the author is convinced that these and all the other observed facts can only be explained on the supposition of the eruptive origin of the wollastonite mass.

Crystals of Wollastonite. In cavities and open spaces near the outer edge of the wollastonite intrusion, stout tabular and prismatic crystals of wollastonite are found, varying from half an inch up to nearly a foot long, and the largest of these are almost invariably converted partially or entirely into quartz or semi-opal. The smaller crystals are always found in small cavities, which were almost completely sealed against the passage of solutions, and these have generally remained almost or quite unaltered; but the largest crystals are all found in much larger cavities, which have evidently at a later date been water channels, and most of these are almost entirely converted into silica, sometimes crypto-crystalline, sometimes amorphous. The largest and finest crystal found has been placed in the British Museum; it measures $10\frac{1}{4}$ inches long by $5\frac{1}{2}$ inches wide. Specimens of the unaltered wollastonite crystals, which are sometimes pink, though generally white, vary from $\frac{1}{2}$ inch long by $\frac{3}{8}$ in. wide, up to $2\frac{1}{4}$ in. by $1\frac{1}{4}$ in.

It is quite evident that the agency which has effected the transformation of the wollastonite into nearly pure silica is merely that of the surface waters percolating down through the mass of wollastonite and decomposing the silicate exclusively through the action of their dissolved carbonic acid. In some cases veinlets are found in the wollastonite mass full of secondary calcite or quartz, and more rarely both quartz and calcite are found crystallized side by side in the same veinlet, both evidently derived from the surrounding wollastonite by the agency of the percolating surface waters.

The following crystallographic details, determined on specimens now in the British Museum, have been supplied by Mr. L. J. Spencer:—

The large and somewhat roughly developed crystals of wollastonite from Mexico are elongated in the direction of the axis of symmetry, and the faces in this prismatic zone are deeply striated in the same direction. They are usually attached at one end, only one doubly terminated crystal being observed. There are perfect cleavages parallel to *a* (100) and *c* (001), from which fairly good measurements could be obtained, the mean of twenty-one readings being $ac = 84° 37'$. A few crystals are twinned on *a* (100), giving rise to a small salient or re-entrant angle (measured 10° 44′) between two *c* cleavages. The forms prominently developed and which could be determined with certainty are[1]:—*a* {100}, *c* {001}, *v* {101}, *t* $\{\bar{1}01\}$, *r* $\{\bar{3}01\}$, *q* {340}; these are shown in the accompanying figures. The hemihedral development of the crystal represented in the second of these figures is not due to twinning, as is the case with another crystal of very similar appearance. The third figure represents a twinned crystal.



Wollastonite crystals from Mexico.
(Orthogonal projections on the plane of symmetry.)

The plane of the optic axes coincides with the plane of symmetry, and the sign of the double refraction is negative. Through a cleavage flake parallel to *a* there emerges an optic axis outside the field of view ($\frac{1}{8}$ inch objective in oil), and through the *c* cleavage is seen, towards the edge of the field, the set of rings around the second axis. The acute bisectrix lies in the acute[2] axial angle β, and is inclined at

[1] Letters and indices as in Dana's 'System of Mineralogy,' 6th edit., 1892.

[2] Not in the obtuse axial angle, as incorrectly quoted from Des Cloizeaux by Dana and in Rosenbusch's 'Rock-making Minerals' (2nd German, and 1st–4th English, editions).

only a few degrees to the normal to t ($\bar{1}01$); through this plane the optic figure is thus seen nearly centrally. The axial angle in cedar oil was approximately measured with a stage-goniometer as $2H = 40°$.

In attempting to cut sections parallel to a plane of symmetry, the material readily broke up into fine fibres perpendicular to this plane. This almost fibrous structure of the crystals is perhaps due, not so much to the perfect cleavages, as to the presence of numerous, very fine, tubular cavities. These cavities are arranged parallel to the axis of symmetry, and are much elongated in this direction: under a high magnification some were seen to contain liquid and a bubble of gas.

Wollastonite with Bornite. In the ore-bodies near the edges of the mass, the essentially parallel development of the crystalline fibres of the wollastonite gives place to a confused network of small interpenetrating crystals, between which small crystals of bornite, chalcopyrite, and garnet have developed. This forms the ordinary concentrating ore worked in the mine, and it clearly exhibits the way in which the metallic and other impurities in the mass were eliminated during its cooling, so as to leave in the central portion nothing but pure silicate of lime. In other parts of the ore-bodies the impurities have been concentrated to a much higher degree, so as to produce masses of garnet mixed with copper minerals which are rich enough to be treated by direct smelting to regulus.

It may be remarked that the whole of the copper minerals carry precious metals, each ton of fine copper in the product of the mine containing on an average 9 ozs. gold and 160 ozs. silver.

Chalcedony containing Bornite. One small mass of this material was found forming the filling of a cavity in the wollastonite. It appears as a solidified jelly of grey semi-transparent chalcedony with minute spots of bornite.

Opal. In some places close to the outskirts of the wollastonite mass, and along lines of fissuring which run in a curved direction following the exterior of the mass, the processes of solution of lime and re-deposition of silica have gone so far as to leave nothing but a mass of semi-opal, more or less stained by iron oxide and copper carbonate, which occasionally attains a width of two or three feet.

Garnet. Like most of the garnet found all over Mexico associated with contact-zones between porphyries and limestones, this is an aluminous andradite. It is found in rhombic dodecahedral crystals embedded in the wollastonite and in small cavities. In colour it varies from olive-green to resin-yellow and reddish-brown, but crystals of the different colours vary very little in chemical composition, as shown by the following partial analyses:—

	Green.	Brown.	All colours.
Silica	36·10	36·48	36·35
Alumina	—	—	12·37
Ferric oxide ...	19·30	19·50	19·43
Lime	—	—	33·33
Magnesia ...	—	—	0·40
			101·88

The average of a number of determinations of the specific gravity gave 3·89, which is higher than one would expect from the chemical composition.

Auriferous Linnaeite. In some of the massive bornite, as well as in some of the mixed rock from the ore-bodies carrying copper minerals, but always in very close association with the bornite, grains of a brittle, steel-grey mineral are sometimes found, and these on analysis turned out to be linnaeite (the nickeliferous variety, siegenite). A number of grains of the mineral were carefully picked out under the lens so as to be free from intermingled grains of bornite, and a portion of the picked mineral submitted to analysis, with the following results:—

Sulphur	44·31	
Cobalt	29·64	
Nickel	17·15	
Iron	3·32	
Copper	5·32	
Gold	0·53	(=173 ozs. per ton)
Silver	0·13	(= 42 „)
Insoluble residue (quartz)	0·43	
	100·83	

Arsenic, antimony, bismuth, and tellurium were searched for but not found. The above figures agree closely with the formula

$$(Ni,Cu,Fe,Co)S.CoS_2.$$

The peculiarity of this mineral is in its gold and silver contents. It is often found associated with free gold, and the small specimens pulverized for analysis left, upon a screen of 120 meshes to the inch, metallic gold in amount equivalent to over 200 ozs. per ton. The author believes, however, that a portion of both the gold and silver contents occur in a chemically combined condition, replacing the other metals, since they cannot be wholly separated from the mineral by amalgamation [1], and suggests that they exist as sulphides replacing cobalt.

[1] Details of the experiments are given in Trans. Inst. Mining and Metallurgy, 1900, vol. viii, p. 304.

Enargite. This mineral is met with in parts of the ore-bodies near the present surface, where abundant evidence of secondary enrichment is forthcoming in connexion with extensive deposition of calcite and of massive bornite. It forms small, brilliant black crystals bounded by the macropinacoid *a* {100}, prism *m* {110}, and basal pinacoid *c* {001}, all of which are about equally developed. The crystals are quite short in the direction of the vertical crystallographic axis *ć*, and are not, as is usually the case in enargite, attached at one end of this axis. They are frequently arranged in stellate twinned groups of three individuals inter-crossing at approximately 60°. The crystals sometimes occur on quartz in cavities, but more generally investing masses of bornite.

Interlamination of Bornite and Galena. This peculiar occurrence, which the author believes to be unique, is very rare, only two or three specimens having been met with. The first specimen found, which was also by far the largest, was met with as a nodule in a mass of soft, decomposed, ochreous material containing garnet and quartz, which formed the outcrop of one of the ore-bodies occurring near a contact of wollastonite with felsite-porphyry. Diligent search was subsequently made for this mineral in unaltered portions of the ore-body immediately below, and was rewarded by finding several small nodules in pure unaltered wollastonite, the largest of which is about the size of a hazel-nut. The material is very rich in the precious metals, a specimen assayed containing at the rate of 14 ozs. gold and 108 ozs. silver per ton.

This peculiar interlamination reminds one of graphic granite, or of the inter-crystallization of some of the felspars. Most of all does it resemble the structure of eutectic alloys as exhibited by micro-photographs of polished surfaces under a magnifying power of several hundred diameters; in fact, except as to scale, the form and arrangement of the interlaminations are absolutely identical.

Idocrase in Crystalline Limestone.

Near the top of a limestone peak, about one and a half miles south of Santa Fé, very difficult of access and covered by dense bush, is a small outcrop of a coarsely crystallized rock, which consists largely of crystals of idocrase set in a matrix of calcite. The crystals of idocrase are stout prisms from $\frac{3}{4}$ to $1\frac{1}{4}$ inch in length, of a dark yellowish-green to leek-green colour, and almost invariably coated with scales of talc. They show the forms *m* {110} and *p* {111}, with subordinate *a* {100}.