

ART. XXXIV.—*On Serpentine Pseudomorphs, and other kinds, from the Tilly Foster Iron Mine, Putnam Co., New York*; by JAMES D. DANA. With plates VI and VII.

THE "Tilly Foster" iron mine is situated about two miles and a half to the northwest of Brewster, on the Harlem Railroad. The rocks of the region are Archæan, being part of the Highland Range, which reaches from New Jersey, across Eastern New York, nearly to the borders of Connecticut. The ore of the mine—magnetite—is distributed, according to a published report, through a band 132 feet wide; and, like that of Northern New York and other Archæan regions, it constitutes a bed conformable to the stratification.

The special mineralogical interest of the locality was first ascertained by Professor O. D. Allen, of the Sheffield Scientific School of Yale College, and the collections made by him have been the source of many of the facts which are here detailed. Prof. Allen has given me further aid in the research by his chemical examinations. Prof. Brush too has kindly placed the specimens in his cabinet before me for study. I have also visited the region and thus added to the number and variety of the specimens under examination. The analyses and descriptions of some of the minerals of the mine by Mr. E. S. Breidenbaugh, in a paper published, in 1873, in the sixth volume of this Journal (p. 207), have given me additional assistance.

#### I. GEOLOGICAL STRUCTURE OF THE REGION.

1. *Archæan rocks*.—The Archæan rocks of the region are mostly different varieties of syenite and syenyitic gneiss, from black to white in color, and, as usual in Archæan formations, they are often in abrupt alternations, so as to make broad bands, riband-like, of black and white, with black blotchings; and the lines of bedding are much contorted. The syenyitic gneiss varies to a granular hornblende rock, containing little feldspar; also to a whitish granulyte-like rock, but little schistose, consisting of quartz and orthoclase, with a very sparse sprinkling of hornblende; also to a hornblendic gneiss, in which both hornblende and biotite (or a black mica) are present: also to a

true gneiss, but only sparingly. The feldspar of the rocks is generally whitish, though sometimes flesh-red; and, judging from the absence of striæ on either cleavage surface, it is orthoclase. Whitish mica (muscovite) is of rare occurrence. Minute zircons may often be found by searching in the syenyctic rock with a lens.

The rocks are generally very durable; but at the railroad cut in the village of Brewster, both the syenyctic gneiss and the included hornblende rock are crumbling to a depth, in some places, of three or four feet, and this disaggregation appears to be in rapid progress.

2. *Ore-bed.*—The magnetite of the ore bed is more or less mixed with chondrodite. In a portion of it, the magnetite greatly predominates, and the ore passes for massive magnetite. But through the larger part the chondrodite constitutes half or more of the mass, while much of the outer portion of the bed is correctly described as chondrodite containing, along with some other minerals, disseminated grains of magnetite. Massive chondrodite is the chief constituent of the refuse from the mine, and may be had there by the ton.

The chondroditic rock and ore often contain disseminated chlorite; less generally, dark green or greenish-black hornblende and grayish or brownish-gray enstatite; occasionally, disseminated white dolomite and brownish-black biotite; while orthoclase is not found, except in the enclosing syenite. Molybdenite is occasionally met with, and rarely apatite. A little pyrrhotite and chalcopyrite occur with some of the ore, and still less frequently pyrite.

A small part of the rock is dolomite, with disseminated grains or crystals of chondrodite and occasional grains of magnetite.

3. *Veins in the ore-bed.*—In small veins or nests in the ore-bed, the various minerals occur well crystallized. The chondrodite, chlorite, and magnetite are often in excellent crystals, and with these occasionally apatite; and in some cases cavities were bristled with slender prisms of enstatite. The dolomite is present in simple rhombohedrons, some of them two or three inches across. This mineral usually overlies the other crystals mentioned, but crystals of chondrodite are sometimes isolated in the chlorite and also in crystals of dolomite; and magnetite occurs in these minerals and also in crystals of chondrodite.

Some veins, half an inch to three inches in width, consist mainly of coarsely crystallized chlorite, and others are filled with enstatite in long fibrous masses. Still others consist mainly of dolomite; but this dolomite is a filling, covering beautiful crystallizations of chondrodite, chlorite and magnetite implanted on the walls of the little veins: yet the same dolomite often contains isolated crystals of chondrodite, magnetite or chlorite.

The filling is occasionally dolomite and brucite together; and rarely splendid crystals of chondrodite occur isolated in the latter.

The crystallization of the chondrodite and of other minerals of the bed is now under investigation by Mr. E. S. Dana, and nothing therefore need be added here.

In the wall-rock of the bed there are occasional small veins containing crystals of hornblende and magnetite, and sometimes plates of biotite. The magnetite of these veins is octahedral, with even, polished faces, while that of the ore-bed is dodecahedral, with usually convex and striated faces.

The above species appear to have been crystallized in the fissures they occupied at the time of the crystallization or the metamorphism of the rock. The crystallized chlorite, according to an analysis by Mr. Breidenbaugh (loc. cit.), is the species ripidolite; but it is not certain that all the granular chlorite of the ore-bed is of the same species. The color of the ripidolite is generally deep green, rarely reddish.

4. *Minerals of later origin, resulting from alterations of the older minerals, or in other ways.*—Besides these, there is another series of minerals that are manifestly of later origin.

The ore-bed is jointed in various directions. The part containing little chondrodite is mostly solid, with few fractures; but the larger part which contains much chondrodite, along with that which consists mainly of this brittle mineral, is broken throughout to fragments, and so extremely so that the pieces are often smaller than the hand. A great mass of the purer iron ore is in some places in the midst of the more chondroditic; and then the former looks like rock enveloped in a fragmentary deposit arranged more or less concentrically about it. The joints, like those of the Archæan rocks of that vicinity, show that the region has been subjected to disturbing forces; but the extraordinary amount of fracturing is a consequence of the exceeding brittleness of the chondrodite.

The fracturing opened the rocks to movements of water, or moisture in some form, and was the occasion also of such movements and of much chemical action therefrom.

The fragments, large and small, down to those an inch or less in size, are generally coated with a white or greenish *serpentine*, which often looks like a varnish over the surface, and again is an inch or more thick.\* They all feel soapy to the fingers on

\* Mr. Breidenbaugh found for the composition of the *white serpentine* (this Journ., vi, 209)  $\text{SiO}_2$  42.28,  $\text{Al}_2\text{O}_3$  0.86,  $\text{FeO}$  2.57,  $\text{MgO}$  40.29,  $\text{CaO}$  1.35,  $\text{K}_2\text{O}$  trace,  $\text{Na}_2\text{O}$  0.48,  $\text{H}_2\text{O}$  12.52 = 100.35, giving the oxygen ratio for the protoxides silica and water 3.1 : 4.03 : 2, that of serpentine being 3 : 4 : 2.

He obtained for the *biotite*,  $\text{SiO}_2$  40.08,  $\text{Al}_2\text{O}_3$  14.21,  $\text{Fe}_2\text{O}_3$  11.51,  $\text{MgO}$  22.03,  $\text{Na}_2\text{O}$  0.22,  $\text{K}_2\text{O}$  9.73,  $\text{H}_2\text{O}$  1.69,  $\text{Fl}$  trace = 99.47; for the constituents of the *ripidolite*,  $\text{SiO}_2$  32.33,  $\text{Al}_2\text{O}_3$  14.56,  $\text{FeO}$  5.29,  $\text{MgO}$  33.74,  $\text{CaO}$  1.04,  $\text{K}_2\text{O}$  0.87,

AM. JOUR. SCI.—THIRD SERIES, VOL. VIII, NO. 47.—NOV., 1874.

account of it. The great piles of refuse rock that are heaped up near the railroad leading from the mine are, in the main, piles of chondrodite masses thus coated or varnished with serpentine. Over the most of them the serpentine is white, a kind that looks much like meerschaum.

The serpentine also penetrates the masses, and from many of them a fragment of chondrodite as large as a filbert cannot be obtained that has not films of serpentine in or about it. It also fills the cavities in the old veins that were partly filled with crystallizations of chondrodite, chlorite, magnetite and dolomite, so that the crystals of these minerals are buried under it; or it penetrates the veins where there were no distinct cavities.

Besides serpentine, there is sometimes also a coating of *brucite* (hydrate of magnesia), and occasionally this mineral is in large crystallizations. *Fluorite* is another of the secondary incrusting minerals, although not common; it is sometimes in pink massive forms, and occasionally in small amethystine cubes.

In addition, the ore bed abounds in *pseudomorphous minerals*. Crystallizations of chlorite, enstatite, chondrodite, dolomite, apatite and other kinds occur converted into serpentine of various colors. The universal serpentinization of masses and crystals conveys the impression that the rock along all the multitudinous fissures, and, to a large extent, through the interior of solid portions, had been subjected to long digestion in heated magnesian waters.

There are also other kinds of pseudomorphs, indicating great corroding and recomposing power in the waters, as described beyond.

Further, there are species of still later origin. Implanted in the serpentine sometimes occur polished cubes and cubo-pyritohedrons of pyrite; and in seams in the serpentine, the mineral pyrrhotite, another sulphide of iron. There are also, on some of the surfaces of blocks, occasional small groups of crystals of aragonite, or thin crusts of hydromagnesite.

## II. THE PSEUDOMORPHS AND THEIR TEACHINGS.

The pseudomorphs which have been thus far observed are of five groups: *first* (A), those consisting of *serpentine*, or of *serpentine and dolomite* combined; *second* (B), those consisting of *bru-*

$\text{Na}_2\text{O}$  0.54,  $\text{H}_2\text{O}$  12.02 = 100.39. Whether all of the chlorite is of the species *ripidolite* is not ascertained.

The *enstatite* afforded him  $\text{SiO}_2$  54.17,  $\text{Al}_2\text{O}_3$  3.30,  $\text{FeO}$  9.94,  $\text{MnO}$  0.24,  $\text{MgO}$  31.99,  $\text{CaO}$  0.99,  $\text{K}_2\text{O}$  0.16,  $\text{Na}_2\text{O}$  0.32, ignition 0.13 = 101.24. He analyzed a massive, faintly fibrous kind. It occurs also long fibrous, and radiated fibrous, the fibers easily separating;  $G. = 3.29$ .

A brown *chondrodite* gave him  $\text{SiO}_2$  35.42,  $\text{FeO}$  5.72,  $\text{MgO}$  54.22,  $\text{Fl}$  9.00 = 104.36; equivalent of oxygen replaced by fluorine, 3.79.

The *dolomite* gave Mr. C. A. Burt (*loc. cit.*, p. 213)  $\text{CO}_2$  47.01,  $\text{FeO}$  0.70,  $\text{MnO}$  0.39,  $\text{MgO}$  20.79,  $\text{CaO}$  30.14 = 99.03, making the ratio of carbonate of lime to carbonate of magnesia nearly 1 : 1.

cite; *third* (C), those consisting of *magnetite*; *fourth* (D), those consisting of *pyrrhotite*; *fifth* (E), those consisting of *dolomite*.

A. *Consisting of Serpentine*.—Of these there are eleven kinds, 1. Cubic, *after an unknown mineral*. 2. Hexagonal prisms, probably *after calcite*. 3. Hexagonal prisms, probably *after apatite*. 4. Plates, clusters of divergent folia, and masses, *after chlorite* (part, or all, *ripidolite*). 5. Masses and crystals, *after chondrodite*. 6. Prismatic and massive forms, *after enstatite*. 7. Crystalline massive forms, *after hornblende*. 8. Foliaceous to massive forms, *after biotite*. 9. Rhombohedral, *after dolomite*. 10. Massive, *after brucite*. 11. Rectangular tables or plates, *after an unknown mineral*.

B. *Consisting of Brucite* (hydrate of magnesia).—12. Foliated forms, *after dolomite*.

C. *Consisting of Magnetite*.—13. Rhombohedrons, *after dolomite*. 14. *After chondrodite* and other minerals.

D. *Consisting of Pyrrhotite*.—15. Plates *after serpentine* (that of No. 11).

E. *Consisting of Dolomite*.—16. Pseudomorphs, *after crystals of chondrodite*.

A. SERPENTINE, OR SERPENTINE-AND-DOLOMITE, PSEUDOMORPHS.

1. *Cubic Pseudomorphs*.

The cubic pseudomorphs—the rarest of those at the mine—often form part of the same specimen with the hexagonal of the second kind above enumerated; and they are shown together in figure 1, plate VI; and fig. 2 is a view of part of the opposite side of the same specimen.

The present form of the specimen is owing to the removal of a portion of the original mass. The bottom layer has usually the cubes with the cubic axis at right angles to the surface beneath; but, above this, the mass conforms mostly to one position, some one of the original crystals having dominated over the rest. This latter fact is well shown in fig. 2.

1. *Composition*.—The pseudomorphs consist either of serpentine, or of serpentine and dolomite combined; and in the latter kind there are all proportions, from those purely serpentine to those that are largely dolomitic.

The serpentine of these pseudomorphs has usually a pale green color, though in some specimens olive-green. According to an analysis by Professor Allen, its composition, after expelling 2.09 per cent of hygroscopic moisture, is

Silica	Magnesia	Water	Fe <sub>2</sub> O <sub>3</sub> , Al <sub>2</sub> O <sub>3</sub>
41.87	42.43	13.40	2.30 = 100

and, accordingly, it is the common kind.

The dolomite of these compound pseudomorphs is white and translucent, like ordinary crystalline dolomite. Owing to the

difficulty of separating it entirely from the serpentine, only a qualitative analysis has been made of it by Professor Allen; and this indicated the presence of carbonic acid, magnesia, and lime, and left no reason to doubt its identity with the ordinary dolomite of the mine and of other parts of the specimens.

2. *Structure*.—The structure is the same for the pseudomorphs consisting of both serpentine and dolomite, as for those of serpentine alone. A description of the former, which is of greater interest, will, therefore, suffice for both.

These compound pseudomorphs usually constitute easily-cleavable masses, two or three inches through. The two minerals are united in one crystallized mass, not by intimate mixture, but by side-by-side juxtapositions of independent rectangular blocks or layers of each, all fitted together like parts of a simple crystal.

The *cleavage is cubic* and exceedingly perfect, without the slightest distinction for the two combined minerals, the rectangular blocks (which are always bounded by the cleavage surfaces) separating easily, even more so than those of a crystallized mass of galenite.

Figures 3, 4, plate VI, illustrate this singular tessellated combination, the serpentine being the green portion and the dolomite the white. To appreciate the remarkable delicacy of the tessellation it must be noted that the specimen here figured (taken from the large pseudomorphous mass of fig. 2) is but a third of an inch broad, the view being enlarged five times lineally. In order that the blocking of the serpentine in the dolomite may be better apprehended, the top of the specimen represented in fig. 3 is given separately in fig. 4. Some of the rectangular serpentine spots in these figures are wholly isolated in the dolomite areas; but this isolation is superficial only, for there is internal connection with the other serpentine portions.

Figure 5 affords another illustration of this tessellated structure. It represents a side of a thin plate (a fragment from a large mass) about two-thirds of an inch square and an eighth of an inch thick. The upper, and under, and middle portions are serpentine, and between lie enclosed blocks or layers of dolomite. The lines over the surfaces in the figures represent lines of cleavage, but only those that were externally very distinct.

3. *Origin of the Pseudomorphs*.—This combination of two so distinct minerals, one a hydrous silicate and the other a carbonate, in a common crystalline mass, having one system of cleavage, is proof that, for one or both, the form is pseudomorphous. That both are so, is made manifest by the structure of the minerals.

In the first place, the *serpentine* shows itself to be pseudomorphous by the fact that the cleavage is not *true* cleavage, but

merely a jointed structure; for the smaller blocks afforded by it have no cleavage within, but instead, a wax-like, massive structure; and the uncleavable plates are sometimes quite thick. In true crystals every smallest grain has the cleavage structure as truly as the entire crystal, cleavage belonging to all possible planes in its direction; and, therefore, absence of the cleavage in any part indicates absence of crystalline structure. In some parts of the specimens the cubic cleavage-lines are distinct, *without any cleavage whatever*, the blocks that seemed to be marked out being all solidly united into an uncleavable mass.

It is evident, from the above, that this is not serpentine crystallizing in cubic forms, and, therefore, a new mineral species. It is simply *common serpentine*, which has somehow become possessed of a form foreign to it.

Secondly, the cubic cleavages of the *dolomite* are only joints or divisional planes in rectangular directions. The demonstration of this is found not only in the failure of the cubic cleavage in the interior of the blocks or slices of it, but also *in the existence in the same of the rhombohedral cleavage of ordinary dolomite in all its perfection*. The oblique lines *d, d, d*, on figure 4 are due to the existence of this cleavage; and in the blocks the cleavage may be obtained indefinitely, precisely as in common crystallized dolomite. Again, portions of one of the masses have sometimes no cleavage but the rhombohedral.

The dolomite is, therefore, *ordinary rhombohedral dolomite*.

Here, then, dolomite and serpentine have together received cubic divisional planes in some way independent of their own powers of crystallization. They have derived it, moreover, from the alteration of one and the same crystallized mineral.

What the original mineral was is not taught us by any thing now occurring at the iron mine. It must have had, not only easy rectangular cleavages, but an open cleavage structure, that is, cleavage-joints, such as exist in galenite; for these cleavage-joints are the divisional planes or joints that are retained in the pseudomorph.

As crystallized galenite (sulphide of lead) has cubic cleavages and also cleavage-joints, it is a question whether this was not the original mineral in the case of this pseudomorph. But the change of a sulphide of lead to dolomite or serpentine, or its removal and the concurrent substitution of these minerals, is hardly supposable.

Anhydrite (anhydrous sulphate of lime), although orthorhombic, has easy rectangular cleavages in three directions and its masses have generally rectangular fractures throughout, following planes of cleavage; so that it possibly might sometimes give cubic jointing to its pseudomorphs. Moreover, the mineral is occasionally found in veins of ore, as in the Hartz and

at Fahlun in Sweden. But the crystalline masses of this orthorhombic mineral are made up usually of tabular cleavable masses, and never have the perfect cubic regularity of divisional planes found in these pseudomorphs.

Common salt has at times the cubically-jointed structure required for producing such pseudomorphs. But its presence in an iron ore bed is improbable; and, if present, it could hardly undergo a change to dolomite or serpentine and retain its cleavage structure, on account of its easy solubility.

Fluorite (fluor spar) occurs in masses made up of cubes; but strictly and only cubes; and its cleavage is octahedral.

I can make no other suggestions as to the original mineral. This much is certain, that the species was isometric in crystallization, and had easy cubic cleavage; and its crystallized masses had numerous cleavage-joints.

Whatever the mineral, it underwent two kinds of pseudomorphic changes. We note, *first*, that the two changes could not have gone on together; for two so different minerals could not have been simultaneously formed in the same crystalline mass from the same chemical solution. *Secondly*, that the dolomite must have been formed before the serpentine portion; for the serpentine blocks or plates have the faces perfectly smooth and polished, while those of dolomite, while very even, always appear faintly eroded, as seen under a lens.

Was *part* of the *original* crystalline mass first changed to dolomite, and the rest subsequently to serpentine? Or, was the whole mass first changed to dolomite, and afterward a part of it changed to serpentine?

The last supposition seems to be the most reasonable. The change from the original cubical mineral to dolomite must have gone forward through infiltration along the open cleavage-joints, and thus these cubic cleavage planes were imparted to it. The change of part of the dolomite (or of the whole in some cases) to serpentine took place subsequently, by the same general method, and so the dolomite gave the latter its borrowed cubic cleavage-joints.

Further, this change of the dolomite took place by rectangular blocks, one such rectangular plate or block being changed alike throughout, when another adjoining, separated only by planes of the cubic cleavage, remained unaffected. This pseudomorphism by blocks seems at first improbable; yet the specimens prove it to be a fact, and other examples of it are given beyond, showing that it is a common method.

The question comes up: Could the chemical change from dolomite to serpentine have gone forward through an alkaline solution of silica, the magnesia having been derived

from the dolomite; or through a solution of a magnesia-silicate, that is, of serpentine itself? The former supposition can not be true. For if a block of dolomite had been changed to serpentine in that way, it would have been changed also in density, and therefore in size; and the difference in size would have been apparent by displacements throughout the pseudomorphous mass. The fact is, all parts are fitted together as exactly as if the whole were of one mineral. It follows then, if the serpentine has displaced dolomite (instead of the original cubic mineral), that the material introduced in solution to effect the change was not silica, but a magnesia-silicate. It follows also that the same magnesia waters had the power of dissolving, and so removing the dolomite; and that the infiltrating magnesia-silicate took the place of the dolomite as the removal went on; it thus being a case of substitution and not of alteration.

If the *first* of the above suppositions is true, there was no change of dolomite to serpentine, but only of the original cubic mineral to each dolomite and serpentine—part to one, and then the rest to the other; and both must have been cases of substitution or removal, in order that the blocks should fit together with the exactness characterizing the pseudomorphs.

## 2. *Hexagonal prisms, probably after Calcite.*

The hexagonal prisms here referred to are terminated in three rough rhombohedral planes (fig. 1, plate VI); and, as nearly as I can ascertain, the angle between the latter planes is that of calcite. The prisms, several of which occur together in groups, are half an inch to two-thirds in diameter, and one of those examined is two inches in length. They consist mainly of serpentine, but contain a little dolomite. These large prisms have a thick coating of serpentine, which externally is smoothly rounded and shining. In figure 1, two of the prisms of a group are shown partly denuded of the coating, while a third has still the coat on. This coat is a tenth to a sixth of an inch through, and is transversely semi-columnar in structure.

Beneath this coating there is usually some incrusting white dolomite, granular-crystalline in structure; and the base of one crystal is mainly dolomite, with some small pieces of magnetite.

The original mineral of these prisms was probably calcite (carbonate of calcium), as the form is a common one of that species. It is possible that dolomite may occur under such a form; but so large and long prisms of dolomite trihedrally terminated have never been observed. Since the dolomite that is now in the pseudomorphs is an aggregation of crystalline grains instead of having the cleavage of a simple crystal, it is not part of the original mineral.

3. *Hexagonal prisms, probably after Apatite.*

These prisms occur imbedded in the cubic serpentine. They are slender, being less than a line in diameter. By measurement, they are regular hexagonal prisms; and as apatite is one of the occurring minerals of the mine, they are probably pseudomorphs after that species.

*Relations of the Cubic to the Hexagonal Pseudomorphs, and to the associated Minerals.*

(1.) In the specimen, a portion of which is represented in fig. 1, the cubical portion *rests upon* the coating of the rhombohedral portion; and over a large part of the specimen the former is easily separated, and leaves exposed the shining surface of the latter. Only in a small part are the two soldered together. The prismatic pseudomorph in view has been exposed by such a removal.

It is thus demonstrated that the group of large hexagonal prisms preceded the existence of the cubical portion. We hence discover that the following was the order of events.

1. The crystallization of a group of hexagonal prisms, probably of calcite.

2. The change of these crystals to serpentine and partly to dolomite.

3. The incrusting of these prisms, after this change, by serpentine, making a coating over the whole, as shown in figure 1.

4. The deposition, over this coating, of a cubic mineral whose masses had many cubic cleavage-joints.

5. The change of the cubic mineral to dolomite, by infiltration along the open cleavage joints, and hence with a retention of many cubic cleavage surfaces.

6. The change of part of the dolomite, thus cubic in cleavage surfaces, to serpentine, through the infiltration along the cleavage-joints of a solution of magnesia-silicate, the alteration affecting entire rectangular blocks or plates of the dolomite, but leaving throughout adjoining blocks or plates unaffected.

While proving here that there were an earlier and a later era of pseudomorphism, it is not proved that the successive eras may not have been comprised within a single epoch of pseudomorphism. They may have been successive events in a single month or year.

(2.) With regard to the relations of the pseudomorphs to the associated minerals, we note:

In an olive-green specimen of the cubic serpentine there are imbedded tabular crystals of chlorite (ripidolite), and also large dodecahedral crystals of magnetite. Along with these minerals occur the pseudomorphs after apatite.

This association proves either that the crystals of chlorite and magnetite were formed at the time the original cubic min-

eral was deposited: or that they were made during the change of the cubic mineral to serpentine. The former may have been the fact; and yet there is no trace of alteration in the chlorite crystals to show that they have passed through a time of serpentine deposition.

#### 4. *Pseudomorphs after Chlorite.*

The change of the crystallizations of ripidolite to serpentine, in specimens from this locality, was early observed, in all its stages, by Professor Allen. Mr. Breidenbaugh, in his account of the white serpentine, remarks that there is a gradual shading in the color of the ripidolite from bright green to pure white, and "in its texture from the foliation and transparency of the unchanged mineral to the compactness and opacity of the serpentine." Specimens are common. Some are crystals, white and pearly, retaining the form of the ripidolite; others, aggregations of whitish folia, from fissures half an inch to three inches in width; others, white, grayish or greenish divergent fibrous masses, either large divergent groups, or stellated aggregations; and others are structureless white or greenish serpentine.

Many of the specimens illustrate the progress of the change from chlorite to serpentine. The surface of a half-changed crystal is often marked with green and white, as represented in figures 6 and 7, plate VI; showing that, in the change, the cleavage-joints were a barrier to its progress; portions of the chlorite bounded by cleavage lines remaining still green, while other portions outside and beneath are wholly changed, on the principle illustrated in the cubic pseudomorphs. The green plates in the figure have the angles  $60^\circ$  and  $120^\circ$ , and perfectly even sides.

When the change to serpentine is complete, there is often one or more of the outer folia on one side or another of the mass that still has some of the color of the chlorite and removes all doubt as to the origin of the foliated mass. But from these there are gradations to other varieties, in which the foliaceous or radiated structure is wholly lost.

The massive crystalline-granular chlorite of the ore-bed also occurs changed to serpentine; some of it retaining the granular structure, and other portions destitute of it. The color is often dark olive-green, while that of the crystals and foliated masses is white or pale green. This fact suggests that this massive chlorite may be another species containing more iron. Breidenbaugh found in a massive chlorite of the mine 9.62 per cent of protoxide of iron, while the ripidolite crystal afforded only 5.29 per cent; but his analysis leaves some doubt as to the nature of the former species.

(To be continued.)

Fig. 1.

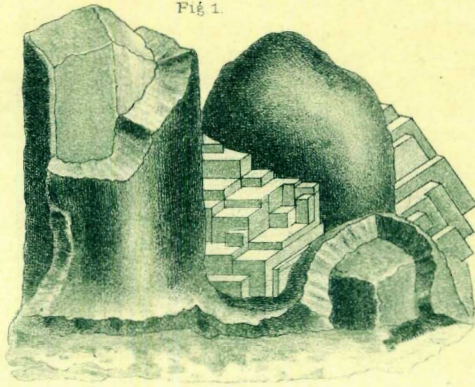


Fig. 2.

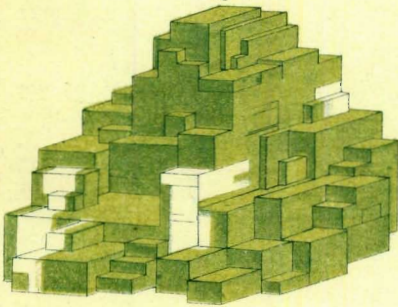


Fig. 4.

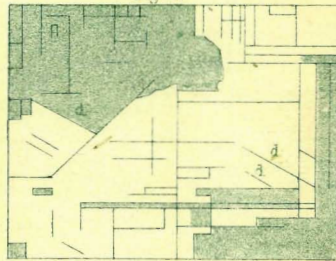


Fig. 3.

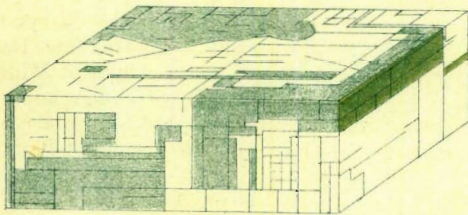


Fig. 5.



Fig. 6.

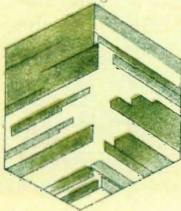
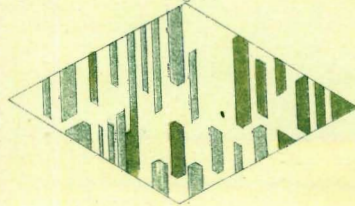


Fig. 7.



Fund. Geol. Soc. London, Nov. 1881, 105

SERPENTINE PSEUDOMORPHS

Fig 8



Fig 9

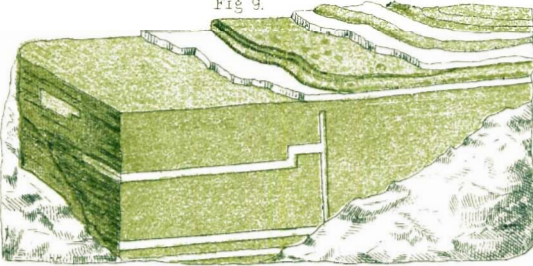


Fig 12



Fig 13



Fig 11

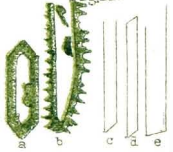


Fig 10



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