ON THE SERPENTINE OF MONTVILLE, NEW JERSEY.

BY GEORGE P. MERRILL.

(With Plates XXXI, XXXII.)

Being in common with petrographers in general deeply interested in the problem of the origin of serpentinous rocks, the writer took occasion, during the summer of 1887, to visit sundry localities where the rock was known to occur, and among them, that at Montville, N. J. This locality was looked forward to with especial interest, since owing to the rare beauty, purity, and compactness of the rock, as shown in numerous mineral cabinets throughout the country, and its known occurrence imbedded in a massive dolomite, it was thought that here, if anywhere, it might be found as a rock formed from aqueous sediments of chemical origin, as argued by Dr. Hunt.* The results of my examinations are given below:

As above noted, the serpentine occurs associated with a massive, coarsely crystalline dolomite, and the fine specimens to be found in the various museums are obtained during the process of quarrying this rock for burning into quicklime or for a flux in iron furnaces.

The first noticeable thing regarding the serpentine is, that while it is occasionally found in small seams and veins, its principal mode of occurrence is the form of isolated nodules from a few inches to 1 or 2 feet in diameter, or as a thin coating on large irregularly rounded or oval bowlder-like masses of all sizes up to 8 or 10 feet in diameter, and which from their crystalline texture and white or gray color seem in most instances to have been mistaken for the ordinary dolomite of the quarry.

The smaller nodules separate readily from the inclosing dolomite, and present always highly polished and often beautifully grooved and slickensided surfaces, which are covered here and there with patches of a thin foliated, somewhat fibrous, light yellowish-green mineral resembling picrolite, but which examination proves to be otherwise, as will be noted later.

The exterior of many of these nodules is strikingly like that of pebbles scarred by glacial action, and present other features such as to suggest they have been subjected to a considerable compressive force. When broken open the nodules are found, as a rule, not to consist of serpentine throughout, but to contain a core or nucleus of a white or gray mineral which, as above noted, has, on casual inspection only, been mistaken for the ordinary dolomite of the quarry. There is no

* Trans. Roy. Soc. of Canada, vol. 1, also Min. Physiology and Physiography, p. 434.

constant relationship in thickness between the serpentine and the nucleus, the coating varying from the fraction of one to several inches (rarely more than 5 or 6) in thickness. Figs. 1, 2, and 3, Pl. XXXI, are characteristic forms, the nodule shown in fig. 1 having been broken so as to leave the nucleus entire, while figs. 2 and 3 are from specimens cut through the center and polished. In fig. 1 the nucleus is about 11 inches long and 5 inches wide by 2 inches thick in its greatest dimensions, tapering down to a blunt point at the left. Larger were found, and others in which the nucleus had completely disappeared. Not the least interesting feature of the case was the discovery that these nuclei varied in color, some being gray, slightly greenish, others pure white, and that each had a coating of serpentine characteristic of itself. That surrounding the gray nuclei is deep, bright green, sometimes almost black, and scarcely translucent; that surrounding the white nuclei, on the other hand, is of a beautiful light oil yellow, almost amber color, and translucent almost to transparency. The two varieties are in most cases distinct, rarely, so far as observed, grading into one another. Both varieties show at times narrow veins of amianthus or chrysotile, though these are most abundant in the light-colored variety. On exposure to weather, after quarrying, a shrinkage takes place, so that in most cases the serpentinous crust shells off only too readily, in small fragments, and often almost as clean as the burr from a chestnut, leaving the nucleus compact and fresh, with a firm, smooth and shining surface, and with only thin patches of serpentine adhering here and there, as in fig. 1 of plate.

On examination with a pocket lens it becomes apparent that the connection between the serpentine coating and the nuclei is much closer than at first appears, the mineral of the nuclei near the point of contact assuming a faint yellowish or greenish tint. Small veins and tongues of serpentinous matter also in places project into the nuclei, as shown in figs. 2 and 3 of plate, where the light gray mineral of the nucleus shows up in strong contrast with the dark serpentine. Thin sections cut so as to include portions of both serpentine and nucleus show the latter to consist of a granular aggregate of short and stout crystals of all sizes up to 2^{mm} in diameter, colorless or slightly gray, and non-pleochroic though polarizing brilliantly in yellow, green, and violet colors. The mineral is monoclinic in crystallization, gives extinction angles on sections approximately parallel to the clinopinacoid, varying from 27° to 36°, and shows the optic axes in the plane of symmetry. Well-defined prismatic cleavages are developed, which, as seen in basal sections, cut one another at nearly right angles. A third cleavage parallel to the orthopinacoid was observed in a few instances. Polysynthetic twining is common; twin lamellæ, as shown in basal sections lying parallel with the orthopinacoid. All the above characteristics are indicative of diopside. These indications are confirmed by the analyses to be noted later. Examination of portions of the sections from the line of contact show most beautifully the direct transition of the diopside into serpentine, as illustrated in figs. 1 and 2, Pl. XXXII, engraved directly from photomicrographs by Mr. T. W. Smillie. Each crystal is bordered by a narrow fringe of parallel-lying serpentine fibers standing at right angles with the crystal itself, after the manner so well known in serpentine pseudomorphs as to need no further description. Fracture and cleavage lines have given way to irregular canals of serpentinous matter, and every gradation can be traced in a single section from the fresh diopside to pure, compact serpentine. Secondary minerals (other than serpentine) are surprisingly rare in the sections at hand. In all those from the larger masses the gray pyroxene is seen passing directly into pure serpentine without a trace of admixtures of free calcite, silica, or iron oxides, all having evidently been removed as fast as formed. (See fig. 1.) In some instances where the pyroxene occurs in nodules but a few millimeters in diameter inbedded in the dolomite the transition into serpentine is made noticeable by the formation of a reddish zone of iron oxides. Sections from the white pyroxene differ in that they still show in the form of small calcite granules the excess of lime set free during the process of transformation. (See figs. 2 and 3.) As both pyroxenes contain essentially the same percentages of CaO such differences can scarcely be expected to prove constant on further investigation. Even where the alteration is complete and no trace of the original pyroxene remains, the origin of the serpentine by hydration of some magnesian silicate is made at once apparent by such appearance as shown in fig. 4, Pl. XXXII. Here the gradual increase in bulk of two adjacent granules of the pyroxene has crowded the calcite grains lying between them into a compact bundle, while immediately beyond they spread out into broad fan shaped areas, giving rise to a pseudo fluidal structure. These evidences of expansion suggest a possible explanation of the slickensided surfaces seen on all the nodules, and which indeed are common to serpentinous rocks wherever found, and emphasize the suggestion made by Diller* and others to the effect that they are due chiefly, if not wholly, to motion generated in the mass of rock by increase in volume. Take the case of an original nodule of the pyroxene imbedded in the dolomite. As hydration goes on more space is demanded and the serpentinous matter is pushed out into every available nook and crevice. Possibly through force of expansion fractures will be formed in the inclosing rock, and as the serpentine is pushed out gradually into these spaces it comes in contact with the rough walls of the inclosing rock, and is grooved and polished in direct proportion to the amount of movement and the hardness and resistance of the material of which it is composed. The extreme compactness of the serpentine is doubtless due largely to the resistance to expansion offered by the dolomite in which it is imbedded.

* Geology of Lassen's Peak District, California. Eighth Annual Report U. S. Geological Survey, 1886-'87. MSS. notes.

Nov. 8, 1888.

Just what the amount of expansion has been can not be estimated absolutely, owing to a loss of an undeterminable amount of material. From a comparison of specific gravities of the two minerals alone it would appear that this increase was about 29 per cent. This, however, can not be considered as more than a rough approximation, since, as shown by the analyses to be noted later, there has been a loss of all the lime and presumably of a part of the silica with smaller amounts of iron oxides and alumina.* I am of course aware that as long ago as 1872, J. Lemberg† in describing the highly lustrous and slickenside-like surfaces of certain serpentinous rocks, argued from facts, not necessary to repeat here in full, that their lustrous appearance was due not to movement nor pressure, but to a deposit on the surface of an infinitesimally thin coating of a magnesian silicate. Proof of this was drawn mainly from the fact that the luster appeared not merely on joint surfaces but also on cleavage faces and rough uneven surfaces where there had evidently been no movement. Further, when, as sometimes occurred, a polished serpentinous surface was in contact with limestone, it was the serpentinous rock alone that showed the polish while the limestone remained rough and unchanged. The two cases are not, however, exactly parallel. In the present instance fractured surfaces of the serpentine show frequently a highly lustrous surface, almost resembling a true cleavage, which may very likely be due to the thin coating or glazing suggested by Lemberg. The lustrous condition of the exterior of the nodules can not, however, be thus accounted for. Not merely are they polished, but also are grooved and striated like bowlders from glacial drift; further, this outer portion shows often in places a thinly laminated or platy structure, recalling the platy structure produced in metals by continuous hammering. I believe this condition to have been brought about wholly by pressure and motion generated in the mass itself by increase in bulk rather than by orographic movements. The fact that the inclosing dolomite does not show like polished surfaces may be due simply to the fact that during the molecular re-arrangement incident to the conversion of the diopside into serpentine, and its highly hydrated condition, this mineral would naturally be in a condition to be molded and scratched by the dolomite, even were not the latter under ordinary circumstances the harder mineral of the two.

To further show the relationship between the two minerals, samples of both pyroxenes and serpentines were submitted to Mr. Charles Catlett, of the U. S. Geological Survey, for analysis. The results are as follows:

*Dr. Hunt (Min. Phys., etc., p. 506) has shown that the conversion of olivine into serpentine, if unattended by loss of silica, is attended by augmentation in bulk amounting to 33 per cent.

†Ueber die contactbildungen bei Predazza. Neues Jahrbuch, Vol. XXIV, p. 187.

	I.	II.	III.	IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	51.45	40.23	54.215	42.38
MgO	18.43	39.46	19.82	42.14
CaO	24.02	....	24.71	....
Al_2O_3	2.94	2.18	.59	.07
Fe_2O_3	1.06	4.02	.29	.97
FeO	.96	trace	.27	.17
MnO	trace.	....	....	....
SO_3	trace.	....	....	....
Ignition	1.08	14.24	.14	14.12
	99.94	100.13	99.945	99.85

I. The gray pyroxene. II. The green serpentine resulting from its alteration. III. White pyroxene, and IV, the yellow serpentine resulting from its alteration.*

The changes which are shown to have taken place are self-evident and need not be commented upon. The fact that no free silica or secondary silicates other than serpentine are found in the sections may be due to the entire removal of the excess silica in the pyroxene, as was the case with the calcite, or as seems very probable, the inclosing dolomite may also have been acted upon and yielded sufficient magnesia to convert the whole into serpentine as suggested by Dana† in the case of the serpentine and dolomite of Westchester County, N. Y. In their high percentages of water it will be observed these serpentines approach closely to the so-called retinalite variety as given by Dana.‡ The extreme compactness and homogeneity of the Montville stone, however, will scarcely permit us to consider it as a mixture of deweylite and serpentine as suggested by Professor Dana in the case of the retinalite of Grenville, Canada. Secondary minerals other than serpentine and calcite are, however, by no means wholly lacking. In many cases the granules of the light yellow serpentine (No. IV of analysis) are bordered by a finely microcrystalline, creamy white, somewhat chalky looking mineral, which I have not been able as yet to obtain in sufficient purity for accurate determination, but which is judged to be a mixture of calcite and magnesite. Aside from this are occasional aggregates of a white color, and with a compact microgranular or short fibrous structure which under the microscope are seen to consist of a dense aggregate of minute calcite granules associated with numerous elongated silky fibers scarcely affecting polarized light but giving extinctions always parallel with their greatest elongation. The entire mixture submitted to Mr. Catlett for analysis yielded results showing it to consist of 90.17 per cent. mixed carbonates of lime and magnesia (mostly lime) and 9.97 per cent. of a mineral having essentially the composition of serpentine with traces of iron oxides, alumina, soda, and potash. It is evident that the fibrous

*Analysis of serpentine from this same locality, as given by Dana (System of Mineralogy p. 467) is as follows: SiO_2 42.5; MgO 42.16; H_2O 14.22; FeO 1.96. This, it will be noted, agrees almost exactly with the above No. IV.

† Am. Jour. Sci., July, 1880, p. 32.

‡ System of Min., p. 467.

mineral is simply fibrous serpentine (chrysotile). The compact, light yellow platy mineral coating the surface of the nodule to which I have already alluded is found, on pulverizing and treatment with dilute acid, also to be a mixture of calcite and soft silky fibers of like nature. As already intimated, I am disposed to consider this structure to have been induced wholly by pressure. In the quarry dump were found fragments of the rock, showing aggregates of serpentine, a very compact light greenish amorphous mineral resembling deweylite, but with a specific gravity of 2.5, small scales of deep reddish-brown and nearly colorless mica, very compact aggregates of a greenish micaceous mineral with the blow-pipe properties of vermiculite and other minerals, which for lack of time and a sufficient amount of satisfactory material must be left for future investigation. The secondary calcite, I should say, is usually granular and of a slight bluish tinge. The mineral is, however, sometimes found in fibrous form and of a pure white color.

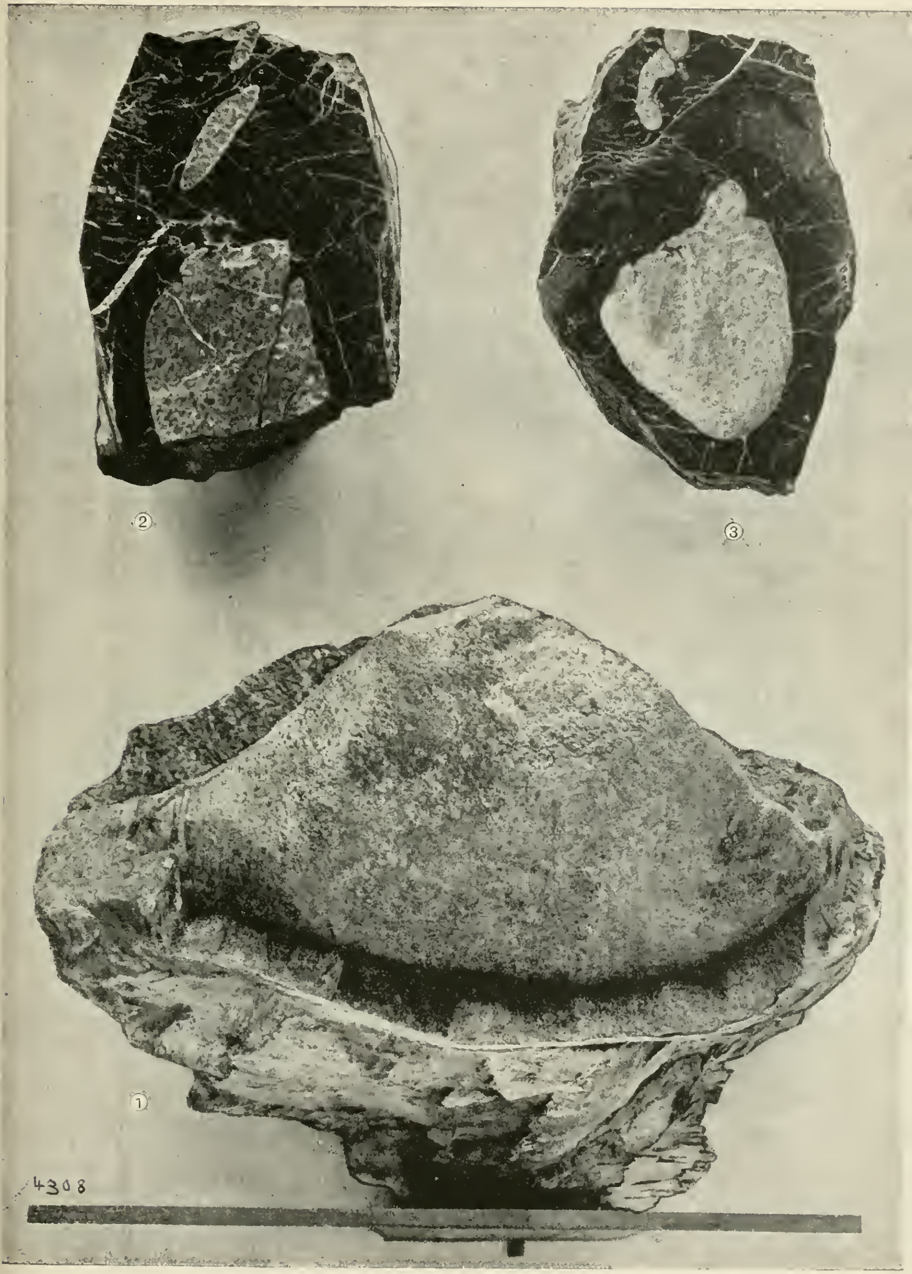
In conclusion: The Montville serpentine is a highly hydrous variety, approaching retinalite in composition, and was derived by a process of metasomatosis* from a mineral of the pyroxene group with the optical and chemical properties of diopside. The change has been accompanied by a considerable increase in bulk, and in most cases the production of beautiful slickensided surfaces and a platy structure due to pressure. The excess of lime has recrystallized chiefly as granular calcite of a light bluish tinge, and also in fibrous forms. Other secondary minerals have been found in the quarry dump, but not having been found in place have not been worked out genetically.

No free silica in the form of chalcedonic veins, such as are an almost universal accompaniment of altered beds of dunite, have been found. It is inferred that sufficient magnesia must have been furnished from other sources to convert the whole into serpentine, or that farther search will bring to light secondary silicate minerals. Concerning the exact relationship existing between the pyroxene masses and the dolomite, I am somewhat in doubt, as the outcrops were poor at the points visited and the time limited. They are apparently segregations, and certainly can not be considered in any way connected with igneous agencies. A very small dike (less than a foot in width) of a dense, nearly black trap rock occurs at the quarry opening, but apparently is in no way connected with the processes of serpentinization. I presume this is the rock described as a porphyrite by Mr. Kemp in the annual report of the State Geologist of New Jersey for 1886 (p. 111).†

The derivation of serpentine from pyroxene is a matter well known to

* I use this word to indicate the process of "indefinite substitution and replacement:" the sense in which it has already been accepted by Dr. Hunt (Min. Phys., p. 130), Emmons, and others.

† It may be well to state that the quarry is the property of Mr. J. J. Gordon, of Boonton, and can be at present easiest reached by rail from New York City to Boonton and thence by carriages. The writer would here express his thanks to Mr. Gordon for his kindness in accompanying him to the quarry and forwarding desirable material.

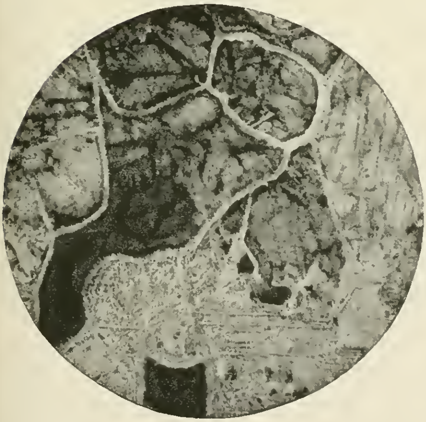


SERPENTINE OF MONTVILLE, NEW JERSEY.—NODULES OF SERPENTINE WITH NUCLEI OF DIOPSIDE.

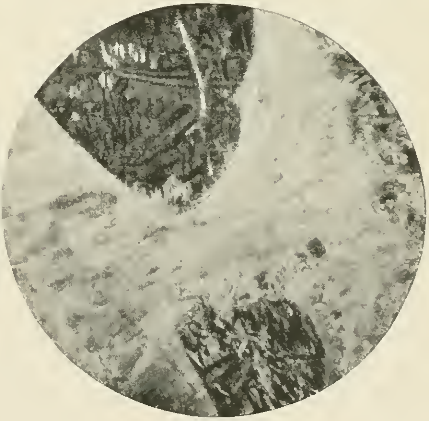
(Explanation on page 111.)

1.

2.



3.



4.

SERPENTINE OF MONTVILLE, NEW JERSEY.—PHOTOMICROGRAPHS SHOWING STAGES OF TRANSITION FROM DIOPSIDE TO SERPENTINE.

(Explanation on page 111.)

petrographers. I have gone so much into detail in the present case for several reasons. The resultant serpentine is of rare beauty and purity, and is therefore much sought for by collectors in general. The possibility of obtaining readily hand specimens which show the abrupt transition within the space of one or two centimeters from pure, unchanged pyroxene to clear, compact serpentine of almost ideal purity, makes the material especially valuable to teachers. I am, moreover, inclined to the belief that future investigation will show very many occurrences of small detached masses of serpentine included in calcareous or schistose rocks to be of similar origin. Indeed, Dr. Hunt,* in arguing against the theory of the intrusive origin of serpentinous rocks, so describes certain localities as to leave almost no doubt that this is the case. He says (p. 435): "In these (the Laurentian gneisses, crystalline limestones, etc.) the serpentine is often disseminated in grains or small irregular masses, giving rise to the varieties of so-called ophicalcite. These imbedded masses of serpentine are sometimes concretionary in aspect and may have a nucleus of white granular pyroxene. They often recall in their arrangement embedded chert or flint, and, like it, sometimes attain large dimensions." Dr. Hunt seems, however, to have regarded the serpentine in all these cases as a chemical deposit about the nucleus, instead of a metasomatic product.

It would seem to the writer, further, that the importance of the movements generated by an increase in volume by any large mass of olivine, pyroxene, or other magnesian silicates in passing into serpentine has not received its full share of attention. May it not be that very many of the slickensided surfaces and local displacements which often prove so misleading when studying rocks undoubtedly stratified, are due wholly or in a large part to this agency?

NATIONAL MUSEUM, *May* 20, 1888.

EXPLANATION OF PLATE XXXI.

MONTVILLE SERPENTINE.

Nodules of serpentine with nuclei of diopside; Figs. 2 and 3 showing cut and polished surfaces. The light gray is the unchanged diopside; the dark, the secondary serpentine. Fig. 1 shows a nodule from which a portion of the serpentinous crust has been removed, showing the ham-shaped nucleus. This figure shows also on the lower edge the laminated or platy structure mentioned on page 108.

EXPLANATION OF PLATE XXXII.

MONTVILLE SERPENTINE.

Photomicrographs showing the various stages of transition from diopside to serpentine. Fig. 1 shows the direct transition of the gray diopside in the upper right side of figure into clear compact serpentine. Figs. 2 and 3 show the transition of the white diopside into serpentine, with separation of calcite and the undetermined creamy white mineral mentioned on page 105. In both figures this mixture of calcite and the creamy white mineral is shown by the irregular dark areas in the lower part of the field. Fig. 4 shows the crowding together of the calcite into a compact bundle by the expansion of two granules of serpentinized diopside.

*Min. Physiology and Physiography.