GARNET ROCK NEAR WEST REDDING, CONN.*

WILLIAM M. AGAR and PHILIP KRIEGER.

One-third of a mile south of West Redding, Connecticut, which is five miles south of Danbury, the bed rock over an

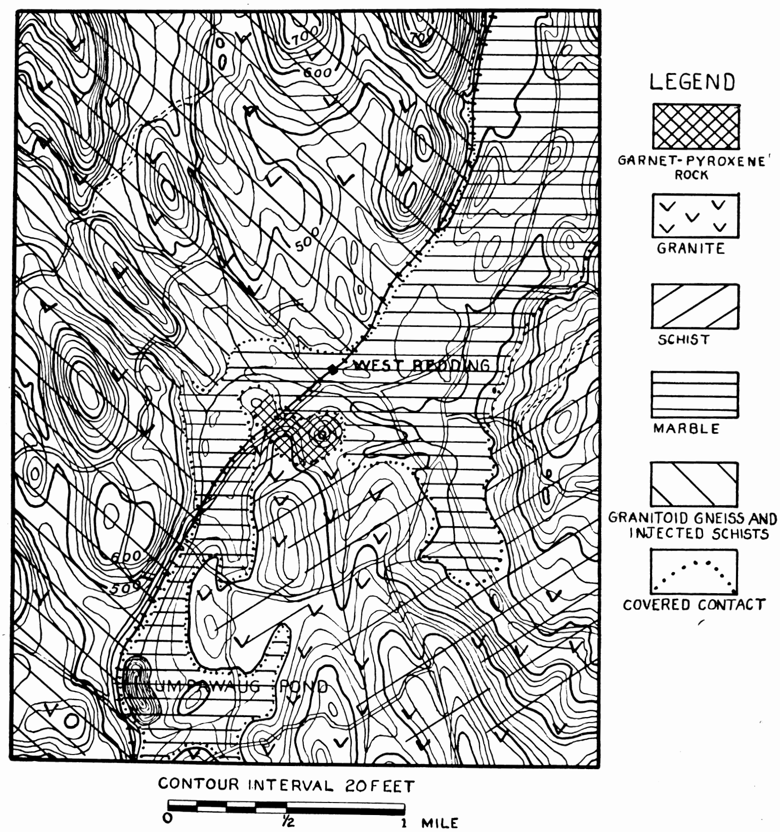

Fig. 1. Map showing geology of region surrounding West Redding garnet rock. Adapted from U. S. G. S. quadrangle map. Danbury, Conn.

area of about sixty acres is a nearly pure, cinnamon-colored, massive garnet. The best exposures are immediately east of the railroad track. The garnet shows well-developed laminar parting, and where irregular openings or vugs exist, small, red-brown garnet crystals occur. There is also a minor

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amount of garnet-diopside mixture and scattered stringers of pure quartz.

The authors have been unable to find any mention of this garnet in the voluminous literature on Connecticut geology and mineral localities except for the brief statement by J. G. Manchester in his book, "The Minerals of New York and its Environs" (p. 47), that a few pits have been dug in garnet rock at this locality. No mention is made, however, of the extent of the deposit, or of the fact that two distinct knolls consist almost entirely of massive grossularite. The occurrence is remarkable both because of the large area it covers and because of the general freedom of the massive garnet from admixtures of other minerals. All of the other known garnet localities in Connecticut are concentrations of garnet crystals in schist and pegmatite. This appears to be a true garnet rock.

The garnet is exposed in the pits mentioned by Manchester, and in scattered outcrops throughout the area, as well as in the railroad cut. The steep hill east of the railroad and road, and the higher knob on the northeast boundary of the area, each present a nearly uninterrupted series of outcrops of massive garnet.

GEOLOGY OF THE REGION.

The garnet rock lies at the north end of a series of schists intersected by granite and pegmatite dikes. It occurs between these rocks and the marble that underlies the valley. Outcrops are scarce and few contacts can be discovered, but the boundaries of the marble can be made out with considerable certainty from the topography and the few contacts available.

West of the marble the rugged hills are composed of a pre-Cambrian complex of granitoid gneiss, granitized schist and paragneisses, and intrusive granite which very likely belongs to two distinct periods—the first pre-Cambrian, and the second probably late Ordovician.

The relation of the marble to the pre-Cambrian rocks is uncertain. Its age may be Cambrian and Ordovician, or it may be pre-Cambrian. It is one of a series of marble belts of uncertain age that extend north and south throughout western Connecticut and reach southeastward into Westchester County, New York, and northward into Massachusetts. In either case the marble probably lies unconformable upon the gneisses and is younger than any rocks immediately to the west, excepting the younger granite.

The schists that lie to the east and south of the marble are designated on the existing map of Connecticut as the Berkshire schist, which is supposed to overlie the marble, and the Hartland schist, tentatively placed in the Silurian period. The so-called Berkshire of this region is not similar to the Berkshire schist that does definitely overlie the marble in the Salisbury region further north. It is better, then, to regard these schists as forming one general group of undetermined age. Whatever their true relation to the limestone may be they are in contact with it in this district.

None of the granite that intrudes these schists, and the limestone itself a mile farther north, can be proved to be pre-Cambrian, but is probably the younger of the two granites mentioned before. A few miles to the south it is the dominant formation. At Branchville, less than four miles south, the pegmatite associated with the granite contains uraninite whose lead-uranium ratio indicates a late Ordovician age.

Without delving further into the complicated geology of the region it is clear that the garnet rock lies along the contact between marble and a series of schists which are intruded by granite and pegmatite younger than any of the other bedrock formations.

PETROLOGY AND ORIGIN.

Large areas of the garnet are almost entirely free from admixtures of other minerals. A minute amount of quartz is always present, but, except where veins or lenses of later quartz cut the garnet (Fig. 2), there is little of it. The garnet itself is nearly colorless in thin section and completely isotropic (Fig. 3). It is discussed fully in the next section of this article.

There are several small areas within the massive garnet where other minerals predominate. Pyroxene and garnet form a green and cinnamon colored rock that outcrops near the northeast end of the area. The pyroxene is a light green diopside. It occurs as anhedral crystals as much as one-quarter of an inch long (Fig. 4). It is monoclinic and optically positive. The prismatic cleavage is well developed and $Z_{\wedge}c$ is 40°. Schiller structure is imperfectly developed in some of the crystals. The relative per cent of garnet and diopside varies from about 70:30 to about 40:60, and the rock is composed of

Fig. 2. Quartz lenses (white) in solid garnet near northeast end of outcrop.

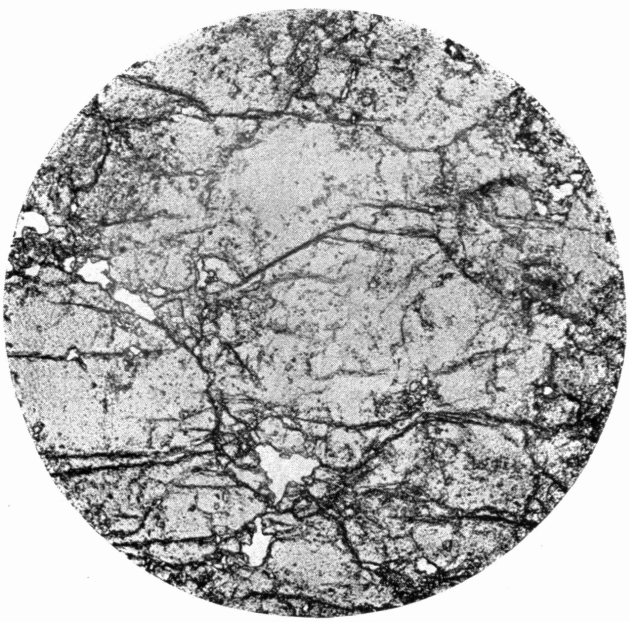

Fig. 3. Photomicrograph of garnet. A few of the small white areas are quartz. The larger ones are all holes in the thin section. Plane polarized light x 22.

essentially nothing but these two minerals with a few grains of leucoxenized ilmenite and some limonite stain as the only impurities. There is another type in which the diopside composes 90 per cent of the mass. This is the light green, granular rock that may be seen in the railroad cut and bordering the garnet in the easternmost of the old pits. It also contains from 1 to 2 per cent of wedge-shaped titanite crystals, occasional

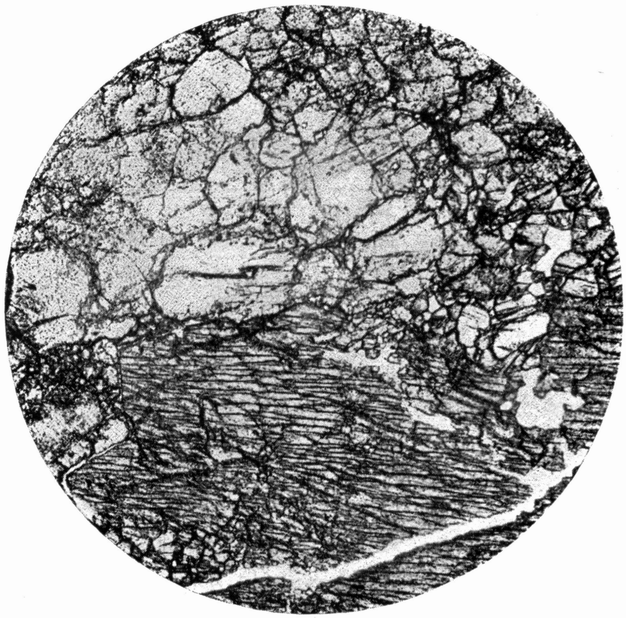

Fig. 4. Photomicrograph of garnet-diopside rock. The contrast between the two is clearly shown by the prismatic cleavage of diopside. Plane polarized light x 22.

grains of apatite in the garnet, and rare flakes or bunches of flakes of dark, greenish-brown biotite. The titanite occurs in both the garnet, and the diopside.

Still a third type of rock, fine-grained and colorless with green and brown lines and specks, forms a few small, irregular patches near the northeast boundary, on the highest nob. It is composed of quartz, diopside, garnet, andesine, zoisite, titanite, wernerite, and apatite, in the order of their abundance (Fig. 5).

Though this type is exposed in very small quantities it is particularly interesting in relation to origin. The garnet itself, the calcium aluminum bearing grossularite of the type known as essonite or cinnamon stone, is characteristic of the igneous metamorphism of lime-rich rocks. Diopside, wernerite, and zoisite are all calcium silicates frequently formed under such conditions. Apatite and titanite, also calcium-bearing minerals, are apt to develop at the contact or within the borders of the intrusive as endomorphic minerals. Their existence as dis-

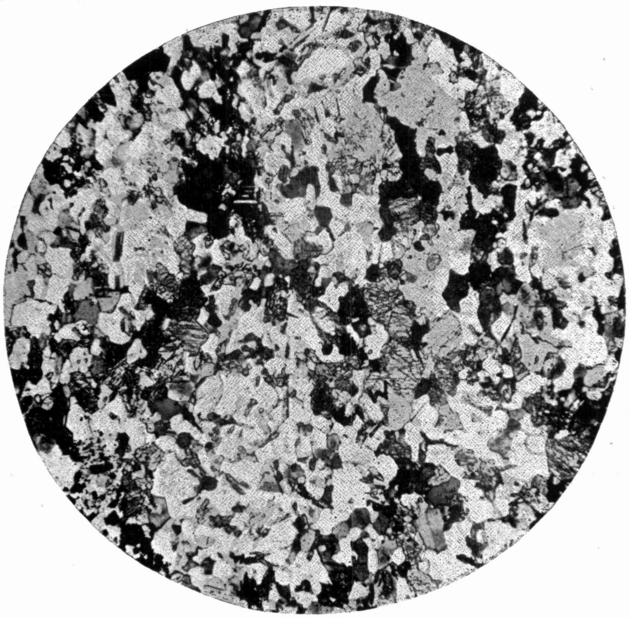

Fig. 5. Photomicrograph of silicate rock occurring as small patches in garnet. Shows isotropic garnet (black areas), diopside with prismatic cleavage, wernerite (W), small grains of apatite and zoicite, and light-colored intergrowth of quartz and andesine. Crossed nicols x 22.

seminated grains in this deposit apparently far from the contact, the fluorine and (or) chlorine in both the apatite and the wernerite, together with the presence of plagioclase, indicate the extent to which the magmatic materials have penetrated the marble. Furthermore, the great amount of nearly pure grossularite can hardly have resulted from recrystallization of an impure limestone without magmatic additions.

If the contacts between the silicate mass and the marble could be seen, the origin of the silicate rock could perhaps be determined with more certainty. However, the position and mineral constitution both point clearly to an igneous metamorphic origin. The quartz veins were introduced subsequent to the major part of this metamorphism, probably as the final episode of the same magmatic sequence. Similar quartz lenses and larger veins are not uncommon in the region in general. It has been impossible so far to correlate them to any particular granite. At this locality, however, they seem certainly to belong to the younger granite and are concentrated here by the same conditions that caused the local silication of so large a mass of the marble.

The history of the development of this mineral aggregate is fairly clear in spite of the uncertainty concerning the age and relationships of the various formations in the district. If the marble is pre-Cambrian and the igneous metamorphism is correctly interpreted as late Ordovician, it had already become metamorphosed to a marble long before the intrusion. It was recrystallized, probably partially silicated, and stable under a wide range of metamorphic conditions. Heat alone would have little effect upon it and a mineralized zone would be developed by an intrusive only where mineralizers were concentrated. Furthermore, the reactions set up by wholesale silication of a large mass of marble necessarily liberate great quantities of CO_2, and these reactions cannot proceed beyond the incipient stage unless channels are present along which the gas may escape. Whether openings already existed, or whether the marble was shattered at this point by the intrusion, is, of course, impossible to say, but some event of this sort must have preceded the development of the garnet.

If the marble is Cambrian and Ordovician in age the formation of the garnet would have had a very similar history, in spite of the fact that the development of the contact zone and the transformation of the original limestone into marble over a vastly greater area, may have overlapped or at least followed one another closely. Heat and pressure due to dynamometamorphism may even have aided the magmatic solutions to form the garnet rock. This is possible since regional igneous metamorphism has undoubtedly worked hand in hand with dynamometamorphism throughout this area. There are many indications in most of the rocks that granitization was a potent factor in their recrystallization. The last granitization, however, occurred sufficiently later than the regional metamorphism—even when more than one such period is clearly shown—to cause a replacement of the foliated structures. Feldspar injectocrysts, so developed, preserve an older helicitic structure. Quartz accompanies the feldspar. Sometimes the two form pegmatitic stringers, or the quartz may exist alone as lenses and irregular masses similar to those in the garnet.

So here, as in the first case, the garnet was probably developed by the igneous metamorphism of an already marblized limestone and the localization of silication must be explained in the same manner as before.

The parting, so well developed in the garnet, and the optical strain revealed in some of the associated minerals, probably developed during the incipient cataclastic deformation that left its mark on the whole region.

MINERALOGY OF THE GARNET.

Aside from a few small veins of white quartz and a minor quantity of pyroxene-bearing rock, most of the deposit appears to be essentially garnet. A description of its appearance under the microscope, together with that of the rocks with which it is associated, has already been given.

A freshly broken surface of the West Redding garnet is brown or cinnamon in color. Where the mineral has been exposed to weathering, however, it is considerably darker and may resemble exposures of the weathered granitic rocks in the vicinity. For the greater part, it is finely crystalline in texture, with a massive appearance. Well-developed parting planes give it a pronounced laminated structure (Fig. 6). Good crystalline forms, while not common, can be found in small vugs or cavities and along the parting planes. These are usually the normal dodecahedrons and may range from microscopic dimensions to five or six millimeters in diameter.

A value of 3.62 for the specific gravity of the garnet was obtained with a pycnometer. The index of refraction, determined by the immersion method, is $1.748 \pm .003$. These values are slightly higher than the figures usually given for grossularite, but this may be accounted for by the greater amount of combined iron present in the West Redding garnet as compared to the value for these components given in other analyses of grossularite. It is well known that even slight variations in the chemical composition of some isomorphous minerals is sufficient to cause a noticeable change in specific gravity or index of refraction.

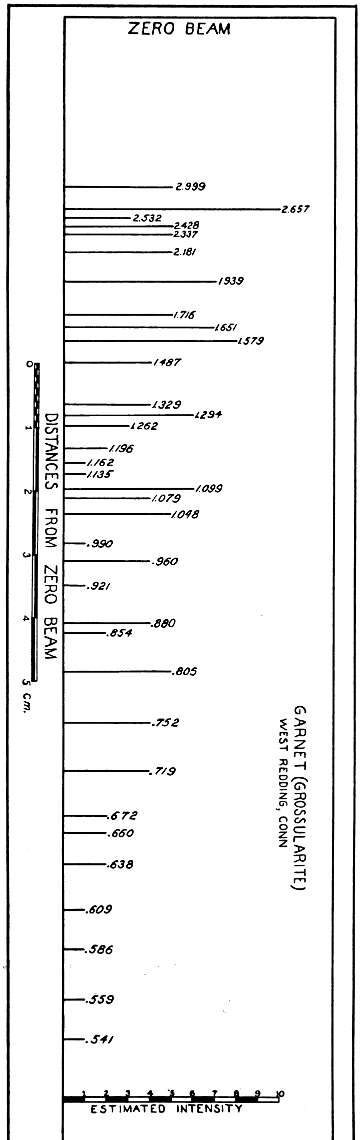

Fig. 6. Photograph of pure garnet showing the well-developed lamellar parting.

The hardness is slightly less than that of quartz. According to Moh's scale it lies between 6.5 and 7.

CHEMICAL ANALYSIS.

To insure obtaining as nearly pure material as possible, small, well-formed crystals were selected for chemical analysis. These were crushed and screened to a uniform size before being submitted to Ledoux and Company, of New York, for analysis. Their results are given in the following table:

ANALYSIS OF GARNET FROM WEST REDDING, CONN.

Ledoux & Company, Analysts.

Moisture @ 100°C	None
Ignition loss	0.10%
SiO_2	39.10%
Fe_2O_3	3.73%
FeO	1.71%
Al_2O_3	19.61%
CaO	34.85%
MgO	0.19%
MnO	0.41%
TiO_2	0.24%
Cr_2O_3	None
	99.94%

Within reasonable limits, this analysis compares favorably with other analyses of grossularite found in the literature. A slight difference is noted, however, in the amount of combined iron, the West Redding garnet containing 5.44 per cent, whereas, in most grossularites the iron content is not as great as this. The silica, aluminum oxide and calcium oxide are present in approximately correct proportions for grossularite. Fractional per cents of magnesium, manganese and titanium oxides would be expectable in a deposit of this type.

The analysis is very similar to that cited by Ford[1] of a variety of grossularite from Piedmont, Ala., in which the combined iron is also rather high. It is interesting to note that in the Piedmont garnet the values for the index of refraction and specific gravity are correspondingly higher than the usual values for grossularite.

[1] Ford, W. E., "A Study of the Relation existing between the Chemical, Optical and other Physical Properties of the Garnet Group," this Journal, **40**, 34. 1915.

X-RAY EXAMINATION.

An X-ray examination of the garnet was made to determine the interplanar atomic spacing and the length of the edge of the unit cube. The powder method of Hull,[2] and Debeye-Sherrer[3] was used, utilizing the Kα radiation of molybdenum. A pattern of sodium chloride was made in the same film holder with the garnet, and corrections applied to the measurements based on the known theoretical values of the interplanar spacings of sodium chloride. The X-ray photographs were taken by Dr. Paul F. Kerr, of the Department of Geology and Mineralogy, Columbia University.

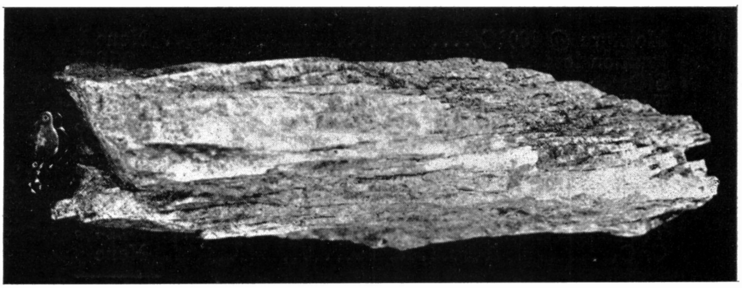

Fig. 7. Chart showing the arrangement and the estimated intensities of the lines in the X-ray diffraction pattern. The interplanar spacings, in Ångstrom units, are given above each line.

A chart showing the arrangement of the lines in the diffraction pattern, the variation in the intensity and the interplanar atomic spacings is shown in Fig. 7. The distances from the zero beam are measured in millimeters and the interplanar spacings are expressed in Ångstrom units ($x10^{-8}$ cm.) computed according to the formula of Bragg,[4] $n\lambda = 2d. \sin \theta$.

The intensity of the different lines correspond closely with those given for grossularite by Stockwell.[5] A somewhat greater value is obtained, however, for the length of the edge of the unit cube. This may be due, in part, to the small dif-

[2] Hull, A. W., Physical Review, **10**, 661-669, 1917.
[3] Debeye, P., and Sherrer, P., Phys. Zeitsch., **17**, 277, 1916.
[4] Bragg, W. H., and W. L., X-rays and Crystal Structure, G. Bell and Sons, London, p. 106, 1924.
[5] Stockwell, C. H., "An X-ray Study of the Garnet Group," Amer. Min., **12**, 327-344, 1927.

ference in chemical composition between the West Redding garnet and that of the specimen from Morelos, Mexico, examined by Stockwell. An analysis of the latter garnet is given by Ford.[6]

ECONOMIC POSSIBILITIES.

Since recognition of the unusual abrasive properties of garnet a great deal of interest has been shown in deposits of this mineral that are of suitable quality and of sufficient size to warrant exploitation. Most of the commercial garnet used at the present time is of the almandite, pyrope or rhodolite variety. Its utility as an abrasive is dependent chiefly on its hardness and lack of cleavage, the latter permitting it to break into sharp-edged, irregular fragments that do not wear down to a smooth surface, but continue to present a good cutting edge under the strain of ordinary use.

Although the garnet here described is slightly inferior in hardness to the varieties named above, there are a number of factors in connection with the deposit at West Redding that appear to give it potential economic value.

The outcrops indicate that the deposit is of sufficient extent to develop a large tonnage by ordinary open cut methods of mining, but a prospective operator would need to determine the exact extent of the deposit by trenching. The persistence of the garnet with depth can only be proved by test pits or, preferably, a few well-placed diamond drill holes. Most of the area indicated on the map carries only a small quantity of overburden. What there is would not interfere greatly with mining operations. The garnet appears to be of sufficient purity to insure a reasonably high grade product. An advantage to be considered is its massive occurrence, without the mixture of the gangue minerals common to most commercial deposits where the garnet occurs as individual crystals.

A branch line of the New York, New Haven and Hartford Railroad is adjacent to the deposit, thus providing readily accessable transportation facilities.

Although the inferior hardness of the West Redding garnet will not permit its use as an abrasive for plate glass polishing, it is sufficiently hard to be used in such industries as the wood and leather working trades. Crushing tests indicate that it will break into irregular fragments that are of good quality for

[6] Op. cit.

abrasive purposes. A potential market also exists in the building industry where an abrasive is used for surfacing and polishing the softer, ornamental stones such as marble, slate, serpentine and soapstone. Garnet has also been used as a cement aggregate for facing tile and concrete block where a surface with a greater resistance to wear is desired.

DEPARTMENT OF GEOLOGY,
COLUMBIA UNIVERSITY,
NEW YORK CITY.