

map  
3385  
M5  
Vol. 43

DEPARTMENT OF THE INTERIOR

---

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME XLIII



WASHINGTON  
GOVERNMENT PRINTING OFFICE

1903

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

---

T H E

MESABI IRON-BEARING DISTRICT OF MINNESOTA

BY

CHARLES KENNETH LEITH

---

CHARLES RICHARD VAN HISE, Geologist in Charge



WASHINGTON  
GOVERNMENT PRINTING OFFICE  
1903

## SECTION II. THE BIWABIK FORMATION (IRON-BEARING).

## DISTRIBUTION.

The Biwabik formation extends along the slopes of the range for its entire length, from west of Grand Rapids to Birch Lake, a distance of nearly 100 miles. The width of the formation, averages perhaps  $1\frac{1}{4}$  miles, but is in places as great as 3 miles and in others as small as a quarter of a mile. The total area is approximately 127 square miles. The bounding formation on the north is, for the most part, the Pokegama quartzite, but where this is lacking the Biwabik formation comes in contact with the Lower Huronian and Archean rocks. To the south the iron-bearing formation is bounded by the Virginia slate, except in range 12 and a part of range 13, at the east end of the range, where the Duluth gabbro laps up over the formation.

On account of the covering of glacial drift, exposures of the iron-bearing formation, except in the eastern end of the district, are few. But the formation has been reached and pierced in thousands of places by drills and mining excavations, and it is therefore possible, particularly along the part of the range at present productive, to delimit the iron formation with a fair degree of accuracy. In parts of the district where explorations and mining have not been so extensive, especially in the west end of the district, future explorations are likely to show that the boundaries, particularly the southern boundary, are in some localities not correct.

The iron formation in general occupies the middle slopes of the Giants range, and its north and south boundaries have fairly uniform altitudes for considerable distances. By an examination of the map, however, it may be seen that the elevation of the iron formation increases from the west end of the district to the east, the total difference amounting to as much as 500 feet. This corresponds with the increased elevation of the range as a whole in this direction, although the higher elevation of the southern limit of the iron formation at the east end of the range is in part due to the fact that the lower parts of the formation are overlapped by gabbro. It may be further seen that the elevations of the north and south boundaries show local fluctuations as great as 200 feet, due to the folding of the formation and to differences in depth of erosion.

## KINDS OF ROCKS.

The great bulk of the Biwabik formation is *ferruginous chert*<sup>a</sup> more or less amphibolitic, calcareous, or sideritic and gray, red, yellow, brown, or green, with bands and shots of iron ore. It is analogous to the jaspers of the other iron ranges but differs in certain particulars, as will be seen on a subsequent page.

Associated with the chert, mainly in the middle horizon, are the *iron ores*. Their surface area is only about 5 per cent of the total area of the iron-bearing formation, and the proportion of their bulk to that of the iron-bearing formation is much less. Near the bottom of the Biwabik formation is a small amount of *conglomerate* and *quartzite*—that is, coarsely elastic sediments. A minute conglomeratic layer has also been observed in the Mahoning mine, in about a central horizon of the formation. In thin layers and zones throughout the iron-bearing formation, and particularly in its upper horizons, are layers of *slate* and of *paint rock*, the paint rock usually resulting from the alteration of the slate. Between the slate and the paint rock and the ferruginous chert are numerous gradational varieties, most of which come under the head of *ferruginous slate*. Associated with the slaty layers in the iron formation, or closely adjacent to the overlying Virginia slate, are green rocks made up of small green granules of ferrous silicate which are here called *greenalite*. It will be shown later that these are the original rocks from which most of the other phases of the iron formation, including the ores, have resulted by alteration. Finally, certain *calcareous and sideritic rocks* are present in small quantity, particularly near the upper horizons, associated with the greenalite rocks. The rocks of the iron formation are described below, beginning with the original type, the greenalite rock. The ores are reserved for a separate chapter.

## GREENALITE ROCKS.

In limited quantity either just below the Virginia slate, or associated with some slate layer in the iron formation, are dull, dark-green rocks of rather uniform fine grain and with conchoidal fracture. Layers of slate, iron

---

<sup>a</sup>This rock has been called *taconite* by the geologists of the Minnesota survey, and the name has been much used locally. The term is not here retained for the reason that the rock is not different from ferruginous cherts of other parts of the Lake Superior region, as described in the monographs of the United States Geological Survey, and there is no reason to complicate rock nomenclature by adding a new name. There is no objection, however, to its local use.

ore, and other phases of the iron formation usually mark their bedding. (See fig. *B*, Pl. VIII.) On close examination, and particularly when the surface is wet, there may be observed numerous ellipsoidal granules of a green substance of a very slightly lighter green than the matrix in which they lie. They are so small and of a color so nearly like that of the matrix that they are likely to be overlooked unless especially searched for. (See fig. *A'*, Pl. VIII.) An occasional one is of much greater size than the average and looks like a conglomerate pebble in the rock.

Under the microscope the granules are conspicuous. Their cross sections are round, oval, in some cases with much elongation, crescent shaped, lense shaped, gourd shaped, or even sharply angular (Pls. IX, XIII, XIV, and XV). Here and there a curved "tail" seems to connect one granule with its neighbor (Pl. IX). Where in contact with a layer of iron carbonate or calcium carbonate, as they frequently are, the granules become more irregular in shape and project into or are included in the carbonate layers as irregular filaments and fragments. The carbonate is largely secondary and clearly replaces the granules, but some of it is perhaps original, and in this case the variation in shape of the granules where associated with the carbonate layers has a bearing on the origin of the ores, which is discussed on another page. One hundred and twenty measurements of the granules show an average greater diameter of 0.45 mm. and average least diameter of 0.21 mm., with average ratio of greatest to least of 100 to 47. The diameters rarely reach 1 mm. and seldom drop below 0.1 mm. Occasionally certain of the granules may be seen to be aggregated into larger granules, with well-rounded outlines, making the conglomerate-like fragments above mentioned. The greater diameters of the granules, for the most part, are parallel to the bedding, and in fact this arrangement largely determines the bedding. In ordinary light the granules are green, greenish yellow, brown, or black. The green and yellow ones are transparent, while the brown and black are nearly or quite opaque. Under crossed nicols the granules are either entirely dark or show a very faint lightening, hardly sufficient to disclose a color. Here and there incipient alterations to chert, grünerite, cummingtonite, or actinolite, scarcely discernible in ordinary light, give low polarization colors in minute spots and make the term aggregate polarization applicable. In reflected light the transparent green and yellow granules appear black or

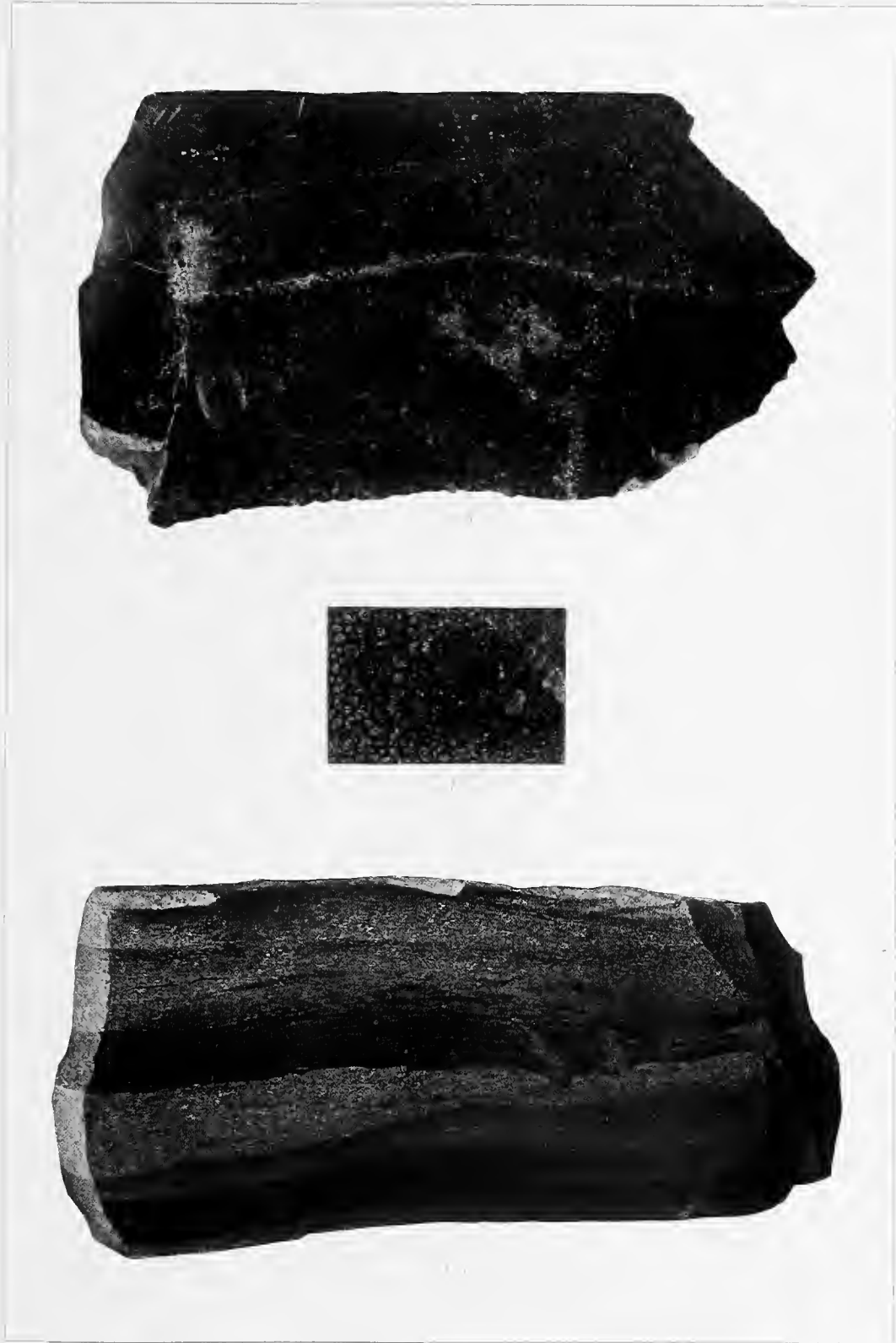
## PLATE VIII.

### GREENALITE ROCK.

FIG. *A*.—Greenalite rock. Specimen 45647. From near Duluth, Missabe and Northern Railway track, 1 mile south of Virginia. Granules of greenalite, but little altered, stand in a matrix of chert. Described pp. 101-115.

FIG. *A'*.—Portion of surface of specimen shown in *A* slightly magnified to show greenalite granules to better advantage.

FIG. *B*.—Interbanded greenalite and slate rock. Specimen 45176. From 100 paces north 500 paces west of SE. corner of sec. 22, T. 59 N., R. 15 W. Natural size. The black portion of the rock is slate and the green portion is made up of greenalite granules lying in a matrix of chert. Greenalite is characteristically associated with slaty layers in the iron formation: indeed, it is due to their protection that greenalite has been retained in comparatively unaltered form. Described pp. 101-115.



GREEN TUFF ROCK

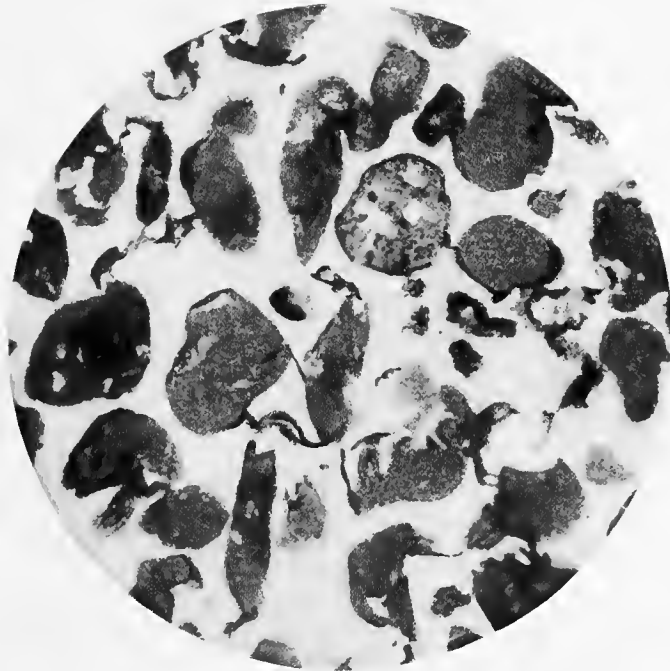
## PLATE IX.

### PHOTOMICROGRAPHS OF GREENALITE GRANULES.

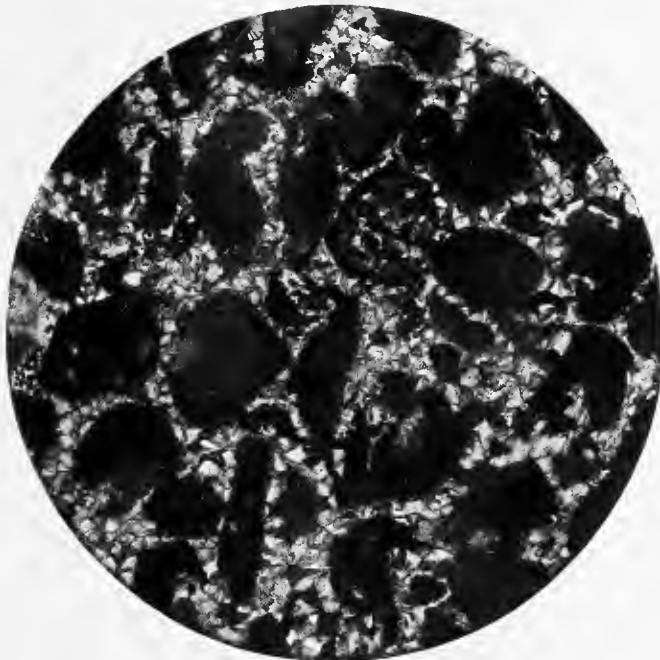
FIG. A.—Greenalite rock. Specimen 45178, slide 15652. From 100 paces north 500 paces west of the southeast corner of sec. 22, T. 59 N., R. 15 W. Without analyzer, x 50. The slide is selected to show both the fresh and slightly altered granules. Note the peculiar greenish-yellow color of the granules, their irregular shape, and their curving tails, which seem in some cases to connect with adjacent granules. The homogeneous greenish-yellow colors represent the unaltered parts. The bright-green and dark-green colors represent grünerite which has been developed from the alteration of the greenalite. The dark green is perhaps in small part iron oxide. Described pp. 101-115.

FIG. B.—The same with analyzer, x 50. The unaltered portions of the granules are nearly or quite dark under crossed nicols. Where the granules have altered to grünerite the polarization colors appear. The matrix consists of fine-grained chert in which the individual particles are very irregular in shape and size. Described pp. 101-115.





(A)



(B)

PHOTOMICROGRAPHS OF GREENALITE SPHERULES

dark green or dark yellow, while the opaque brown and black granules exhibit a rough light-green surface. Were it not for the light-green surface in reflected light certain of the opaque dark-brown granules would be mistaken for iron oxide in ordinary and polarized light.

The matrix of the rocks containing the unaltered green granules varies widely in amount, from a mere interstitial filling to an abundant mass in which the granules are widely separated. The matrix may be almost pure chert; it may be nonaluminous, monoclinic amphibole, actinolite, grünerite, or cummingtonite; it may be largely iron or calcium carbonate, although where the carbonate is abundant the granules are usually sparse and irregular; it may consist of any combination of chert, amphibole, and carbonate, with a small amount of accessory iron oxide.

Originally the matrix may have had a somewhat different character. In the rocks containing the least altered granules the matrix is predominantly chert and subordinately light-colored amphiboles and carbonate. As the rocks become altered they contain more iron oxide and dark amphiboles, which will be shown on a subsequent page to develop from the alteration of the granules. The lighter amphiboles are themselves known to be a secondary development from chert and carbonate rocks. It seems likely, therefore, that the original matrix of the green granules was largely chert and in small part carbonate. In the freshest rocks now found the chert is much recrystallized and the original carbonate is largely leached out or replaced by actinolite.

The specific gravity of the unaltered granules can not be satisfactorily determined, because of the practical impossibility of separating the granules from the matrix. Determinations of the specific gravity of the rock as a whole give results ranging from 2.7 to 3. As the matrix is largely quartz in the form of chert, which is known to have a specific gravity in the neighborhood of 2.65, the figures above given for the unaltered rock are too low for the granules themselves, although their incipient alterations to iron oxide and amphiboles tend to raise the specific gravity. So far as the matrix is colorless amphibole, it is apparent that the specific gravity of the green granules is lower than the figures obtained for the rock, for the specific gravity of the colorless amphiboles is above 3. One exceptionally fresh specimen in which the granules lie in a matrix of chert gave a result of 2.7. The matrix in this case makes up something more than half of the

rock mass, and it therefore seems probable that the true specific gravity of the granules is a little above 2.75.

Four analyses of rocks containing the least altered granules observed have been made by Mr. George Steiger of the United States Geological Survey. He found that by treatment with hot concentrated hydrochloric acid most of the granules and their associated alteration products dissolved out, leaving a residue of almost clear silica, which probably mainly represents the matrix.

*Analyses of greenalite rocks.*

	1.		2.		3.		4.
	Sol.	Insol.	Sol.	Insol.	Sol.	Insol.	
SiO <sub>2</sub> .....	13.45	48.45	<sup>a</sup> 19.30	36.50	33.11	13.01	<sup>b</sup> 50.96
Al <sub>2</sub> O <sub>3</sub> .....	.37	.64	.61	.76	.56	2.60	1.09
Fe <sub>2</sub> O <sub>3</sub> .....	15.00		13.83		6.44		5.01
FeO.....	10.28		17.57		30.93		30.37
MgO.....	2.33		3.22		5.35		5.26
CaO.....	.28		None.		None.		.04
Na <sub>2</sub> O.....	None.		None.		None.		None.
K <sub>2</sub> O.....	None.		None.		None.		None.
H <sub>2</sub> O.....	2.50		2.38		1.34		.75
H <sub>2</sub> O.....	4.17		5.74		6.13		6.41
TiO <sub>2</sub> .....	None.		None.		None.		None.
CO <sub>2</sub> .....	2.04		None.		None.		None.
P <sub>2</sub> O <sub>5</sub> .....	None.		None.		None.		None.
S.....							Trace.
MnO.....							None.
BaO.....							None.
Carbon in organic matter.....							.21
Undetermined.....		.52		.15		.38	
	50.42	49.61	62.65	37.41	83.86	15.19	100.10
	49.61		37.41		15.99		
	100.03		100.06		99.85		

<sup>a</sup>Of which 3.3 was found in the rock upon treatment with HCl. (probably opal).

<sup>b</sup>Of which 23.96 is soluble.

1. Specimen 45758. From 250 paces west, 83 paces north, of the west quarter post, sec. 35, T. 59 N., R. 15 W. The finely ground rock was evaporated on the water bath to dryness, with 50 cc. of 1-1 HCl, taken up with water slightly acidified with HCl, and filtered. Soluble silica was then determined in this residue by boiling with 5 per cent solution of Na<sub>2</sub>CO<sub>3</sub>. A determination of soluble SiO<sub>2</sub> was then made in the rock before treatment with HCl and subtracted from the first soluble SiO<sub>2</sub> found, which gave the figure for SiO<sub>2</sub> in the soluble portion.

2. Specimen 45765. From test pit in Cincinnati mine. The soluble portion was found by evaporating to dryness on the water bath with 50 cc. of 1-1 HCl, and taking up with water slightly acidified with HCl. The residue was then boiled fifteen minutes with a 5 per cent solution of  $\text{Na}_2\text{CO}_3$  to dissolve any soluble silica, this silica determined and placed with the soluble portion. The residue was ignited and finally heated for fifteen minutes over the blast lamp, weighed, and then a rough analysis made, which is found in the second column. The small amount of iron shown in the insoluble portion could easily have been carried down mechanically. A determination of soluble silica was then made in the rock before treatment with HCl and found to be 3.3 per cent. Subtracting this from the total soluble silica 16 per cent of soluble silica remains for the part dissolved in HCl.

3. Specimen 45766. From test pit in Cincinnati mine. The finely ground rock was evaporated on the water bath to dryness, with 50 cc. of 1-1 HCl, taken up with water slightly acidified with HCl, and filtered. Soluble silica was then determined in this residue by boiling with 5 per cent solution of  $\text{Na}_2\text{CO}_3$ . A determination of soluble  $\text{SiO}_2$  was then made in the rock before treatment with HCl and subtracted from the first soluble  $\text{SiO}_2$  found, which gave the figure for  $\text{SiO}_2$  in the soluble portion.

4. Specimen 45180. From 500 paces west, 100 paces north of the southeast corner of sec. 22, T. 59 N., R. 15 W. Owing to presence of organic matter the determination of ferrous iron is probably high.

The interpretation of these results requires separate discussion because of the variation in nature and amount of associated minerals.

1. Green and brown transparent granules, and opaque brown and black ones, containing small amounts of secondary chert, carbonate, and limonite, stand in a matrix of chert. One large pebble-like area consists of granular limonitic material with a small amount of carbonate. In this area the outlines of granules can be distinctly seen, and the limonite clearly results from alteration of the granules.

The undissolved portion probably mainly represents the matrix. The dissolved portion probably mainly represents the green granules, the limonite, and carbonate. In calculating the composition of the green granules, the carbon dioxide, with enough of the bases to satisfy its valence, may be eliminated. As the microscope does not show conclusively whether carbonate is calcite, dolomite, or siderite in the calculation, the bases may be supposed to be combined with carbon dioxide in proportion to their strength. Thus the calcium oxide present, 0.28 per cent, may be supposed to be combined with carbon dioxide, which would leave 1.82 per cent carbon dioxide available for combination with other bases. Magnesium oxide is next in strength, and 1.67 per cent would be required to combine with the remaining carbon dioxide. This would leave 0.66 per cent of magnesium oxide, which may be supposed to belong with the green granules or with the associated alteration products. It is possible that the carbon dioxide may be combined in part with ferrous iron, but in the absence of definite information the above combination is supposed to hold. Whatever

the combination, it will be noted that the total amount of carbon dioxide is so small that the exact determination of the combination is not a matter of consequence. After making deductions for the carbonates, the composition of the green granules and the associated alteration products is as follows:

SiO <sub>2</sub> .....	13.45
Al <sub>2</sub> O <sub>3</sub> .....	.37
Fe <sub>2</sub> O <sub>3</sub> .....	15.00
FeO.....	10.28
MgO.....	.66
H <sub>2</sub> O above 110°.....	4.17

We know that iron protoxide and magnesium oxide never occur in rocks except in combined form. The magnesium compound known as brucite (Mg(OH)<sub>2</sub>) has not been noted in these rocks. It is necessary to assume that sufficient soluble silica is combined with ferrous iron and magnesia to satisfy their valence, and when this amount is deducted little or none is left for combination with the ferric iron. It is thus clear that a large portion of the green granules is ferrous silicate. It is further clear that the ferric iron shown by the analyses is in the form of ferric oxide, and thus probably secondary. If original, it may still be independent of the green granules, and there remains only a possibility that the ferric oxide may be an original constituent of the green granules themselves. This is in accord with the microscopic observation of the presence of a considerable amount of limonite in the slide. The limonite is secondary and independent of the green granules, and thus the ferric iron, with the water combined with it, may be eliminated from the discussion of the composition of the green granules. Of the combined water shown in the analysis 2.53 per cent would be required for combination with the ferric iron, on the assumption that the latter is all in the form of limonite, thus leaving 1.64 per cent of water probably belonging with the green granules. It is concluded, therefore, that the material of the green granules is essentially a hydrated ferrous silicate, with a small amount of magnesium and possibly a slight amount of ferric oxide and alumina. The total absence of the alkalis and phosphorous is to be noted.

2. In this rock the granules are green and transparent and in part dark brown, black, and opaque, and show a very slight and practically negligible alteration to greenish and colorless amphibole. The matrix is chert. The undissolved portion probably mainly represents the matrix. The dissolved portion mainly represents the green granules.

The composition of the green granules, together with their minute alteration products, is therefore as follows:

SiO <sub>2</sub> .....	16.00
Al <sub>2</sub> O <sub>3</sub> .....	.61
Fe <sub>2</sub> O <sub>3</sub> .....	13.83
FeO.....	17.57
MgO.....	3.22
H <sub>2</sub> O above 110°.....	5.74

Arguing as above, we know that iron protoxide and magnesium oxide never occur in rocks except in combined form. The magnesium compound known as brucite (Mg(OH)<sub>2</sub>) has not been noted in these rocks. It is necessary to assume that sufficient soluble silica is combined with ferrous iron and magnesium oxide to satisfy their valence, and when this amount is deducted little or none is left for combination with the ferric iron. From this it is clear that a large portion of the green granules is ferrous silicate. It is further clear that the ferric iron shown by the analyses is in the form of ferric oxide, and thus probably secondary. If original it may still be independent of the green granules, and there remains only a possibility that the ferric oxide may be an original constituent of the green granules themselves, but as no iron oxide can be certainly observed in the slide this possibility must be recognized. Thus most of the ferric oxide, together with any water which may be combined with it, may be eliminated from the discussion of the composition of the green granules. If the iron oxide were all limonite it would not require all the combined water, and thus a considerable portion of the combined water must belong with the green granules. Thus the material of the green granules appears to be mainly hydrated ferrous silicate with a small amount of magnesium and perhaps also small portions of ferric oxide and alumina. The entire absence of the alkalies and phosphorus is to be noted.

3. The granules, of a greenish-yellow color, are slightly altered to colorless and in part slightly greenish amphibole, and lie in a matrix of colorless and slightly greenish amphibole, associated with a subordinate amount of chert. There is present in addition a small amount of oxide of iron which may be either more or less hydrated hematite or magnetite. The insoluble portion, which is small in amount, is shown by the analysis to be mainly silica, with a subordinate amount of ferric iron. The soluble portion contains the greenish granules, the amphiboles, and the major portion of the iron oxide. As there is microscopic evidence both in this

rock and in the iron-formation rocks as a whole that the amphiboles result from the alteration of the green granules, and in many cases, at least merely by recrystallization and dehydration of the substance of the green granules, it is apparent that no great error will be introduced if the substance of the amphiboles be considered together with the rest of the soluble material in determining the approximate composition of the green granules. The composition of the green granules, together with amphiboles resulting from their alteration, and the black iron oxide, is:

SiO <sub>2</sub> .....	33.11
Al <sub>2</sub> O <sub>3</sub> .....	.56
Fe <sub>2</sub> O <sub>3</sub> .....	6.44
FeO.....	30.93
MgO.....	5.35
H <sub>2</sub> O above 110°.....	6.13

The percentage of ferric oxide shown is small, and it is thought that it is largely accounted for by the oxide seen in the slide and thus ought not to be counted as belonging with the green granules. If a portion of the iron is magnetite, then a small percentage of ferrous iron belongs to it. If it were all magnetite, about 3 per cent of the ferrous iron would be so combined, and hence the true figure is probably less than this. At most but a very small percentage of the combined water can be supposed to belong with the ferric oxide, and also but little can belong with the amphiboles; the large percentage of combined water shown by the analyses belongs largely to the substance of the green granules. The analysis therefore shows the original green material to be essentially a hydrous ferrous silicate with a considerable percentage of magnesium, and perhaps small amounts of ferric oxide and alumina. The entire absence of the alkalis and phosphorus is to be noted.

4. The granules are in part yellowish brown and transparent, and in part dark brown, black, and opaque, the latter showing the characteristic rough, green surface in reflected light. They are largely fresh, but a number of them show slight alterations to colorless, light-brown, and light-green amphibole. There is present also a small amount of black iron oxide. The matrix is mainly a felted mass of colorless amphibole, with a slightly greenish pleochroism, with high double refraction and low angle of extinction, which corresponds in its properties to actinolite. The amphibole within and adjacent to some of the granules may be seen in all stages of

development through the alteration of the granules, and it is probable that all of the amphibole has developed in this way.

In this analysis the composition of the entire rock was first determined and then the soluble silica found. No determination was made of the substance left in the residuum after the treatment with hydrochloric acid, and it is not possible to state how the amphibole in the matrix acted under the treatment. The analysis, therefore, affords no direct evidence of the composition of the green granules. But it seems probable that at least a part of the amphibole went into solution with the hydrochloric-acid treatment. The soluble portion would, then, contain the original green material, an unknown quantity of amphibole, and a slight amount of black oxide of iron. If the amphibole which may have gone into solution be considered as an alteration of the original green material essentially by simple recrystallization, as it certainly is in the iron formation as a whole, then its ingredients need not be separately considered in arriving at an approximation of the composition of the original green material. Most of the ferric iron shown in the analysis is accounted for by the black oxide of iron seen in the slide. As the black oxide of iron is at least partly magnetite a small percentage of ferrous iron must be supposed to belong with it. If the ferric oxide all belongs to magnetite, 2.2 per cent would be so required; so the true figure is probably something less than this. A still further deduction must be made from the ferrous iron, as the analyst makes the statement that the percentage of ferrous iron is probably high because of the presence of organic matter. Only a very small percentage of the combined water can be accounted for by combination with the oxide of iron, for this is in small quantity, and, moreover, largely magnetite. Neither can any of the water be supposed to belong with the amphiboles, for the latter are nearly anhydrous. Thus most of the water belongs with the substance of the green granules. It is clear that at least a part of the material of the dissolved portion is a hydrous ferrous silicate, and it is certain that this part belongs with the unaltered green granules.

Assembling the above results, it appears that the ferric iron occurs in the rock mainly as sesquioxide, for the soluble silica is accounted for by the ferrous iron and magnesia present, leaving none for the ferric iron; that in three slides of the four of the rocks analyzed the ferric oxide may be observed to be present and to be probably secondary; and, hence, that



the iron oxide shown by the analyses is mainly secondary and not to be considered as belonging with the substance of the unaltered granules. It appears further that the alumina and lime are in such small quantity as to be practically negligible. It appears still further that there is far more than enough combined water to combine with the ferric iron to form ferric hydrate, and thus that a considerable portion of combined water shown by the analyses may be taken to belong to the green granules. Finally, it appears that the substances which can not be accounted for in any other way and which clearly belong with the green granules are silica, ferrous iron, magnesium oxide in small proportions, and water. It is therefore concluded that the substance of the green granules is essentially a hydrous ferrous silicate with a subordinate amount of magnesium, and that if ferric iron is present at all as an original constituent of the green granules it is in small quantity.

This conclusion is essentially in accord with that reached by Dr. J. E. Spurr in his report on the Mesabi district published in 1894.<sup>a</sup>

Having concluded the substance of the green granules to be mainly silica, ferrous iron, magnesium oxide, and water, we may ascertain whether or not there is any uniformity in the proportions of these elements. The ratios of the silica, ferrous iron, and magnesium in the four analyses, calculated on the basis of 100, appear in the subjoined table. The percentage of water is not included for the obvious reason that, while it is certain that much of it belongs with the granules, no quantitative estimate can be made of its amount because of the uncertainty as to the portion which belongs with the ferric hydrate.

	1.	2.	3.	4.	Average.
SiO <sub>2</sub> .....	55.1	43.7	47.7	40.2	46.8
FeO.....	42.1	47.5	44.6	50.9	46.3
MgO.....	2.8	8.8	7.8	8.9	7.1

The relative proportion of the ferrous iron and silica above shown suggests a combination of the two on the basis of one molecule of each. Theoretically the percentages of the two in such a combination would be—

Silica .....	45.62
Ferrous iron .....	54.38

<sup>a</sup>Geol. Nat. Hist. Survey Minnesota, Bull. No. 10.

The average of the ferrous iron, 46.3, is about 8 per cent less than the theoretical percentage. The magnesium oxide, which has a higher combining power than the iron, more than makes up for this deficiency.

On a subsequent page (pp. 141-143) is given an analysis of a rock in which the green granules have been altered to a dark-green and brown amphibole, probably grünerite, apparently through simple recrystallization and dehydration. The alteration has occurred under deep-seated conditions, and it is probable that little, if any, addition or subtraction of material has taken place, other than that involved in dehydration.<sup>a</sup> The composition of the amphibole ought to give a clew to the composition of the original green substance. It is there found that the principal constituents of the amphibole are silica and ferrous iron, in the following proportions:

SiO <sub>2</sub> .....	47.5
FeO .....	52.5

The correspondence of these percentages with those above given is evident.

It is apparent that the above results are not sufficiently accordant to show that the substance under discussion has a definite and uniform composition. On the other hand, the impurities and alterations cause such variations that it can not be said that the green granules do not have definite chemical composition. If the granules do have a definite composition, the above results indicate the most probable formula to be  $\text{Fe}(\text{Mg})\text{OSiO}_2\text{nH}_2\text{O}$ .

Dr. Spurr, after his study of the green granules, concluded to call them "glaucosite." In view of the fact that potash is insisted upon as one of the essential constituents of glauconite by most mineralogists (see pp. 239-243), the entire absence of potash in the substance under discussion is taken to preclude the application of the term glauconite. The substance apparently corresponds to no known mineral species. As it will be necessary and convenient to have a term by which to refer to it in the present discussion, the name "greenalite" is coined for use in this report.

The origin of greenalite and the details of the similarities and differences between greenalite granules and granules of glauconite, concretions of iron oxide and chert, and other granule and concretionary structures, are discussed in Chapter IX, on the origin of the iron ores.

---

<sup>a</sup> In a monograph on Metamorphism (in press) C. R. Van Hise emphasizes the fact that alterations in the deep-seated "zone of anamorphism" for the most part involve no considerable transfers of material.