PART II.

PETROGRAPHIC GEOLOGY AND DESCRIPTIONS.

No. 1. Gabbro. *(Rice Point Granite.)*

N. W. ¼ sec. 34, T. 50–14, Duluth.

Ref. Annual Report ix, pages 11, 18, 32; Annual Report x, pages 41, 72, 139, 201, 204; Bulletin ii, pages 73–75; American Association for the Advancement of Science, vol. xxx, page 162, 1882; Final Report, vol. i, pages 196–199; vol. iv, pages 571–580.

Compare J. H. Kloos, Zeit. d. deutsch. geol. Gesell, xxiii, pages 440, 441, 1871 (Translation, Annual Report x, pages 193, 194); A. Streng and J. H. Kloos, Neues Jahr. f. Min., etc., 1877, pages 113–117 (Translation, Annual Report xi, pages 51–54); N. H. Winchell, Annual Report viii, pages 22–26, 1880, and Final Report, vol. i, pages 147, 149, 1883; R. D. Irving, Mon. v, U. S. Geol. Survey, page 55, 1883; C. L. Herrick, E. S. Clarke and J. L. Deming, American Geologist, vol. i, pages 342-344, 1888; W. S. Bayley, Journal of Geology, vol. i, pages 696, 697, 1893; vol. ii, No. 8 and vol. iii, No. 1.

Megascopic characters. This rock varies considerably in color and grain, but as a rule is coarse grained, lavender gray or greenish gray and composed largely of feldspar whose twinning striations are very evident and which is usually crystallized in a uniform massive structure, but is sometimes distinctly porphyritic. Its tabular crystals are usually less than half an inch across, but one of our specimens exhibits a single crystal which has a roughly rounded outline and a diameter of an inch and a half on its cleavage face (compare, also, No. 128). Sometimes a lighter-colored feldspar with rectangular cleavages is sparsely scattered amongst the gray crystals, and this sometimes is whitish, and in other places pinkish, and in proximity to areas of red rock (No. 1B) these red feldspars are abundant. With such aspect this rock has received the name "orthoclase gabbro." Between the plagioclase grains, but making only a small part of the rock, are pyroxene and magnetite. The pyroxene has an irregular, though pronounced, cleavage-parting. It is usually in xenomorphic anhedrons, but occasionally it embraces the feldspar crystals ophitically. The magnetite is brightly metallic on fresh surfaces; on weathered surfaces it stands out rigidly after the other minerals have disintegrated. It is sometimes in tabular and other abnormal forms, owing apparently to the shapes of the cavities which it filled after the solidification of the other minerals.

In proximity to the lighter-colored feldspars are occasional nests of epidote and a rare crystal of pyrite. When the two feldspars are in contact the red coloration sometimes slightly penetrates the plagioclase crystal.

While this rock, as a whole, is coarse grained and uniform in texture, the large tabular plagioclases indicate two periods of crystallization. Still, the sizes vary

much and the two periods are not sharply separated. In some places the smaller tabular plagioclases present lath-shaped outlines, and as the pyroxene approaches augite the rock becomes a coarse diabase, with more or less of an ophitic structure.

Microscopic characters. The *feldspar* is usually remarkably fresh, and displays brilliant color-bands, when not too thin, according to the widths of the intersected lamellæ. "Tested by the Levy-Pumpelly method it gives angles of 13° to 14°, and therefore would be classed as labradorite. It contains numerous tubular cavities arranged parallel to the twinning planes; also many glass and other inclusions. The feldspar is somewhat altered and cloudy, some of the sections having suffered greatly. Included in the feldspar is magnetite, chlorite (viridite), quartz and diallage closely approaching augite. The diallage is in places altered to uralite, etc." (Wadsworth.)

A thin section parallel to the brachypinacoid (010), cut from one of the porphyritic crystals, bringing out the cleavage parallel to the base (001) affords an extinction angle of 25° to 27°, which, according to the table of Fouqué,* indicates that the feldspar is labradorite-bytownite.

The twinning striations are more frequently seen on the edges of the tabular crystals (albite law), which exhibit also sometimes the less easy cleavage parallel to the brachypinacoid, than on the sides which are formed by the development of the brachypinacoid. These edges sometimes consist of a wide band without striations, adjoining another which is abundantly striated. Sometimes all the twins which stand in the same direction are narrow, like threads, consisting of the merest films, while their reversed fellows are broad. A basal section may therefore be governed largely, in its direction of easy cleavage, by the broad bands parallel to one of the sets of albite twins, and the narrow bands which are due to the thin albite twins may be inconspicuous or, in small slides, entirely wanting. This apparent absence of banding in basal sections is more likely to occur when the slides are so thin that they do not give colors higher than the grays of the first order in Newton's scale, in which case the lines separating the twins might be mistaken for cleavage. But even then the alternating extinctions are seldom obscured.

The section examined affords an interesting case of Carlsbad twinning in combination with albite twinning. One Carlsbad is cut parallel to the base, the other being oblique, and the two can be examined by the method of Michel-Lévy for the four positions of "éclairement commun."†

In a section cut at random from No. 1, the greatest equal extinction angle on opposite sides of a twinning macle was found to be 38° on one side and 37½° on the other. This, alone, is not diagnostic for labradorite, for anorthite has the same (see plates VI and VII, Determination des Feldspaths). But since in labradorite this

* *Bulletin de la Société Française de Minéralogie*, vol. xvii, p. 428.
† *Determination des Feldspaths*, pp. 20-22.

measurement is near the locus of an optic axis, and in anorthite is far removed from it, search must be made for the proximity of the axial figure; the feldspar is thus again found to be labradorite.

Micro-chemical tests (Boricky) show the presence of lime and soda in this feldspar.

The specific gravity of small fragments of the feldspar from No. 1 was found to be 2.706. The trial was made in iodide of methyl on a Westphal balance.

The impurities of this feldspar, as exhibited in the section, tend to accumulate in lines or elongated masses parallel with the cleavage planes. They are more abundant in proximity to the other minerals, and especially adjacent to the pyroxenes, where an opaque whiteness often spreads irregularly for some distance on all sides, sometimes tinged with green. The same cloudiness accompanies all other cracks, which sometimes may be seen crossing the feldspars irregularly, and occasionally it pervades generally the mass of the feldspar, destroying the characteristic optical phenomena. In addition to this kaolinization are minute grains of magnetite (?) which are in groups or scattered. Occasionally they afford a cubic section, but generally their outlines are irregular. The pyroxene, which ophitically embraces the feldspars, is frequently, and perhaps usually in the specimens from Duluth, much decayed. The brilliant polarization which this mineral, when pure, presents between crossed nicols, in thick sections prepared for the microscope at low powers, is not usually seen, at least in sections cut from No. 1; but owing to incipient disintegration secondary products obscure it. These consist of magnetite, amphibole and chlorite, and sometimes a small amount of epidote.

Chemical analysis of the feldspar of No. 1. The following analysis was made by Prof. J. A. Dodge. He selected the feldspathic portion, by mechanical means, as clean as possible, but this portion was not wholly unmixed with other constituents of the rock:

SiO_2	49.78
Al_2O_3) Fe_2O_3*)	32.36
CaO	11.55
MgO	1.43
K_2O	.41
Na_2O	3.39
H_2O	1.83
	100.76

The *pyroxene* was formed after the feldspars, filling the irregular, angular spaces between them, producing the ophitic structure. Usually the magnetite which has resulted from the breaking down of the pyroxene is in minute grains intimately associated with the resulting amphibole, but grouped together near the centre of the original pyroxene grain or in zonal arrangement at the periphery. But sometimes the amphibole occupies the entire original space of some of the pyroxenes, while magnetite occupies others. In each case the outlines of the pyroxene are preserved.

*The amount of oxide of iron is quite small.

The greenish alteration product from the pyroxene is, however, not always characterizable as amphibole. It is fibrous when the alteration is complete as amphibole, or granulo-fibrous when it is not far advanced. The change also proceeds to the production of a chlorite having the blue color and pleocroism of *pennine*.

There is also seen, rarely, another stage, a micaceous one, between amphibole and chlorite. It is hardly distinguishable, since, in all cases, so far as observed, the mica produced is so far permeated with chloritic characters, both in internal structure and in optical aspect, that it is intermediate in ensemble between chlorite and mica. When the micaceous characters remain they are expressed by higher double refraction and a more widespread uniform darkening at certain angles over the whole area of the grain or by evident cleavage. When the change is so far perfect as to constitute a chloritic element, the polarization is in shades of blue and yellow which supplement each other in rotation, each in the form of bright filaments, and the grain never assumes the darkness which is brought out in the micaceous stage. In ordinary transmitted light the micaceous grains are clear and structureless, or show a crooked cleavage, giving little indication of the fine, confused internal structure which the polarization colors express. The chlorite grains are continuously dark between crossed nicols when the section is parallel to their cleavages.

The pyroxene of No. 1 is further described under No. 1C. *Magnetite* appears both as apparently original and as secondary products. In the former state it constitutes an important ingredient in the composition of the rock, and as a secondary product it seems to have originated in an early stage of the rock's history, probably before it had become cool. Indeed, it is reasonable to suppose that many of the changes to which the various minerals have been subjected were completed prior to cooling. In the case of the magnetite, whether of the original minerals that segregated from the magma, or of those that arose from chemical rearrangement after consolidation, there seems to be no essential difference in its visible characters. The original grains are sometimes two or more millimeters in cross section, and occupy original positions amongst the larger grains, while the secondary grains are of microscopic size, and lie in the cleavage cracks of the labradorite and at the angles of the pyroxenes. Magnetite being normally one of the earliest of the original minerals to take its place in the consolidating magma, it is yet possible that the original and secondary grains, as here distinguished, did not differ widely as to the time of their formation. In any case the magnetite, even in its finest grains, can hardly be considered a product of ordinary weathering, nor of dynamic action, and the intimate relations subsisting between all the grains, especially the approximate pseudomorphism after pyroxene, indicate that some of the larger grains are likewise of secondary origin.

In the magnetite sections that are examined the outlines are not blurred by a leucoxene rim.

The secondary origin of all the magnetite found in this rock at Duluth, where it is so abundant as to have attracted attention as an iron ore (No. 1C), is therefore more than a possibility; that is, if the term secondary be understood with the above limitation. The fact that the large crystals of magnetite in this rock are seldom or never in their normal, entire, cubic forms, nor even as derivatives from the cubic form, but are of irregular shapes and dimensions, precludes their being considered, as now seen in the rock, as original in a molten magma. Yet, as magnetite, it must have originated early and before the final setting as to crystallization, which the rock now presents. If it be supposed that dynamic or other causes may have destroyed the original cubic shapes, it would still be likely, not only that the other minerals would have suffered similar deformations, but that in some places there would be still some remaining indication of an original quadratic crystallization. Neither of these conditions is found. On the other hand, it is a very common observation to note the encroachment of magnetite upon a grain of pyroxene, and the entire occupancy of the area of the latter by the substance of the former. There the magnetite takes the original shape of the pyroxene, which itself was later than the feldspars, and accommodates itself to its forms. Such microscopic quantities of of magnetite seem to be traceable, step by step, to the larger masses, and the secondary origin of all the magnetite seems to be a reasonable conclusion. It may have resulted from profound changes in the chemical or physical conditions just prior to final congealation, by reason of which some of the elements of the earliest crystallizations were rendered unstable, and a widespread resorption of some of the elements took place, leaving magnetite as a consequence.

In numerous places in No. 1C, the magnetite can be seen in contact with unchanged augite and feldspar, which shows that it began to form prior to the commencement of decay of the augite. Still, even in No. 1C, it is found in the central portions of what is now a chloritic mass, resulting from change of augite. Here also are some quadratic forms embraced in pure feldspar.

Chemical analysis of the Gabbro No. 1. The following results were reached by Prof. J. A. Dodge (No. I). Beside it is given (No. II) the composition of a "hornblende gabbro," reported by Streng from the St. Louis river near Duluth.

	I.	II.
SiO_2	50.43	49.15
Al_2O_3	23.83	21.90
Fe_2O_3	17.63	6.60 (FeO=4.54)
TiO_2	trace	....
CaO	4.79	8.22
MgO	2.46	3.03
K_2O	0.34	1.61
Na_2O	2.06	3.83
H_2O	....	1.92

There can be but little doubt that this is the rock which was examined by Streng under the name "hornblende-gabbro," and by Irving under the name "orthoclase-gabbro,"* obtained at Duluth. Streng's specimen was obtained "on the St. Louis river, near Duluth, and Irving's," near the center of sec. 33, T. 50–14. Irving refers to it as the "coarse gray rock of the St. Louis river bluffs, at and near Duluth." From the same mass or hill range, however, Irving reports (viz., on sec. 27, T. 50–14) an "orthoclase-free" gabbro. The sections of No. 1, here described, are from more decayed rock than is usually found in the gabbro range. Several other numbers more fairly represent it, particularly Nos. 1C, 512, 513, while No. 5 is an illustration of a still further impregnation of the same rock with elements from the contacting clastics.

The relations of this rock to a series of clastics of older date are very intimate. For a discussion of this association the reader may consult Part I.

In this rock Streng proved the titanic acid to exist in the form of titaniferous magnetite. The feldspar, after treatment twenty-four hours, was found insoluble, and its powder, after long treatment in the same acid, gave him no jelly. He concluded, therefore, that it is not anorthite, but comes near labradorite. On account of the percentage of 1.61 of potash in the rock, he concluded also that some orthoclase is present.

In the hornblende he found sometimes a "viriditic" substance, giving it a light-green color, with impaired dichroism, and a parallel or radiate fibrous structure. In other cases the brownish-green hornblende, without viridite, is parallel-fibrous and strongly dichroic. This hornblende he considered an original mineral ingredient, and not a product of change from diallage. The grains of diallage did not appear to him to encroach in the least upon those of hornblende, though the two were described as forming a mosaic, with sharp outlines. He mentions large, black metallic, angular crystals of magnetite and menaccanite, and smaller grains of the same embraced in the other minerals. These, with a little epidote, chalcopyrite, quartz and apatite, constitute the minerals of the rock. He concludes thus:

"It is therefore a basic rock whose high per cent of alumina corresponds closely with its abundance of triclinic feldspar. If this feldspar were anorthite the content of lime would have to be higher, and that of soda necessarily less. Furthermore, if this feldspar were oligoclase or andesite, the per cent of silica of the whole rock would be higher, since the 1.61 per cent of potash presupposes a content of orthoclase of about 9.52, which drives the silica to a high percentage. Therefore, the triclinic feldspar comes nearest to labradorite. While the silica per cent rises by reason of the orthoclase, it is reduced again by reason of the percentage of magnetite and

* *Eleventh Minnesota Report*, p. 51. *Mon. v, U. S. Geol. Survey*, pp. 50, 53.

menaccanite. The meager percentage of magnesia corresponds to the low content of hornblende and diallage in the rock. The apatite in the rock amounts to 0.81 per cent."

Seven sections examined.

Age. Cabotian of the Taconic (or Lower Cambrian). N. H. W.

No. 1A. Gabbro *(with orthoclase)*.

From the high land, Duluth. Same rock as No. 1, but further northeast; intersection of Fifth Avenue East and Seventh Street; near a contact with No. 1B.

Ref. Same as for No. 1. Also, Annual Report, x, pages 41, 141; Proceedings of the American Association for the Advancement of Science, vol. xxx, page 165.

Meg. As No. 1 approaches the "red rock" of the region (No. 1B) it begins to acquire other minerals, and a reddish, feldspathic spottedness, as expressed by this rock and by No. 5. At the contact the grain is sometimes considerably finer than at a distance from the contact. The section examined seems to have been derived from near the contact. It was described in the Proceedings of the American Association for the Advancement of Science, Cincinnati meeting (1881), when it was said to contain "labradorite, uralitic augite and titaniferous magnetite. Some of the augite is changed toward viridite; orthoclase in occasional grains;" and it was placed amongst the "mixed igneous and sedimentary rocks." It principally differs from No. 1 in having a visibly greater proportion of the orthoclase element. It is not an independent rock, but an altered phase of No. 1, as will appear more fully in the descriptions of some of the other samples.

One section examined.

Age. Cabotian. N. H. W.

No. 1B. Granite. *(Red.)*

Duluth; probably N. W. ¼ sec. 34, T. 50–14.

Ref. Annual Report, ix, pages 11, 12, 17, 18; Annual Report, x, pages 41, 140, 201, 204; Annual Report, xiii, pages 100, 103; Bulletin viii, pages xxx, xxxiii; American Association for the Advancement of Science, vol. xxx, page 163, 1882.

Compare R. D. Irving, Mon. v, U. S. Geol. Survey, page 119, 1883.

There are two hand samples of this number, both of which have been analyzed. As the two differ considerably, they will be described separately as Nos. 1B and 1B′.

Meg. A medium or rather fine-grained granitic rock of a brick red color. Composed principally of two minerals: a reddish feldspar and a black or greenish black substance, apparently hornblende; the former is in greater amount than the latter. Quartz, in smaller grains than the other two minerals, is not very evident, but is scattered throughout the specimen. A few small yellowish areas are also seen.

Mic. The section shows that the rock is highly altered, but as it is typical of certain phases of the "red rock" of the Cabotian, to which Irving has applied the term augite syenyte, it will be described rather fully. The structure is granitic, although the feldspar has a tendency to an idiomorphic development, and the following

minerals are present, in the order of abundance: *feldspar*, *quartz*, *hornblende*, a greenish yellow, almost isotropic, mineral, *magnetite*, *epidote*, *muscovite* and *apatite*.

The *feldspar* is much altered and reddened, as is usual in rocks of this class, and has sometimes become opaque; thus some of the areas that were originally feldspar show almost no action on polarized light, and many of them have comparatively little of the feldspar material in its original state. However, in a few cases, the traces of polysynthetic twinning can be noticed, but not frequent nor distinct enough for determining the nature of the feldspar. Several simple twins, apparently of orthoclase according to the Carlsbad law, are seen, and also many untwinned grains, some of which are less altered than those which show twinning. From these facts, and from the analysis which is given below, it appears that the feldspars present are (1) Orthoclase, in some quantity; (2) Plagioclase of an undetermined variety, but probably near oligoclase; and (3) Anorthoclase is supposed to be present, as it is known to occur quite frequently in rocks of this class.

As secondary minerals in the feldspar are muscovite, quartz, epidote and a greenish yellow mineral. The last has almost no effect on polarized light, occurs in irregular areas or in branching vein-like forms, and is intimately associated with a fibrous mineral of about the same color; the latter appears to be hornblende. Epidote is seen in small areas and crystals; it is yellowish or colorless. Muscovite exists in small flakes. In altered feldspar crystals three zones can sometimes be distinguished; an inner one composed of rather fresh feldspar, outside of which is an opaque reddish zone more altered than the interior, and beyond this a zone of about the same nature, but less reddened. Very frequently the inner zone, instead of being the less altered, has almost no feldspar material left, but is composed largely of the isotropic mineral mentioned above, oftentimes associated with finely fibrous hornblende, epidote and a few muscovite flakes.

After the feldspars the most important ingredient of the rock is *quartz*, which occurs in two modifications. The first form occurs in the spaces between the feldspars. It has all the characters of ordinary granitic quartz. It is clearly younger than the feldspar by which its outlines are conditioned. The other form taken by quartz is an intimate micropegmatyte with the feldspar. This micropegmatyte pervades the whole rock and is a very characteristic microscopic feature of the granular acid rocks of the Cabotian. As the feldspar is so much altered and darkened, this structure is very easily seen in ordinary light. Large areas of feldspar are sometimes completely penetrated by this network of quartz; again, the quartz particles occur only around the peripheries of a feldspar grain. These apparently detached quartz grains are sometimes oriented with the larger quartz grains adjoining the micropegmatyte, and sometimes are entirely independent of them. This rock does not show

the structure as well as some others which will be figured in this volume, but it is still very evident. For illustrations of this class of rocks and this structure, see plate XV of Irving's "Copper-Bearing Rocks of Lake Superior," and especially figure 1, which is of a rock from the same locality as the one here described.

Hornblende occurs in fibrous masses and in compact grains. The fibrous masses occupy areas which were probably originally filled with augite, but the slide now shows no trace of the original pyroxene. A few of these areas show partial outlines that resemble cross sections of augite. The compact hornblende is brownish-green and distinctly pleochroic, a being straw-colored or greenish-yellow, b dark-brownish, and c, nearly the same as b. The absorption is $c \geqq b \gg a$. The hornblende does not show well defined crystal outlines, but one cross section approaches closely to the form of a pyroxene cross section. The fibrous form is often intimately associated with the compact, the former probably being an alteration of the latter. That the compact hornblende is original, is uncertain, and it is quite probable that all the hornblende is secondary, the original ferro-magnesian constituent of the rock being augite, and the rock one of the augite syenytes described by Irving.*

Magnetite is abundant, occurring in well defined grains, after showing crystal outlines, and in irregular areas and minute grains associated with the hornblende. The rock powder yields many grains to the magnet.

Apatite is quite common in the form of long needles, which penetrate all the other minerals of the rock, even the magnetite.

Chemical analysis. The following analysis was made by Prof. J. A. Dodge and published in the thirteenth annual report, page 100 (Chemical series No. 148).

SiO_2	66.36
Al_2O_3	13.33
Fe_2O_3	7.89
FeO	2.96
CaO	2.14
MgO	1.20
K_2O	3.05
Na_2O	2.63
H_2O	1.21
	100.77

This shows a rock which is more basic than the average of "red rocks," and which has a lower percentage of soda than is common.

Remarks. As has already been stated, this rock belongs to the series of "red rocks" of the Cabotian. In Part III, of this volume, will be found a discussion bearing on these rocks; among the various points discussed will be: their origin, their relations to the gabbro, the secondary nature of the micropegmatyte and the hornblende.

One section examined.

Age. Cabotian of the Keweenawan. U. S. G.

* *Op. Cit.*, pp. 112-124.

No. 1B′. Granite. *(Red.)*

Duluth. Probably N. W. ¼ sec. 34, T. 50–14.

Meg. A rather fine-grained, reddish to flesh-colored granitic rock composed of quartz, a pinkish feldspar and a little epidote. A number of the feldspar grains are considerably larger than the other constituents and are surrounded by a finer groundmass of quartz and feldspar, but these larger grains are not sufficiently distinctly marked off from the rest of the rock to give it a porphyritic appearance.

Mic. The section shows a granitic groundmass of feldspar and quartz, the former in larger quantity than the latter. In this groundmass, and not very sharply separated from it, are larger areas of feldspar with which quartz is plentifully intergrown in most beautiful micropegmatyte; the feldspar of the groundmass does not show this feature. Frequently these areas of feldspar contain more than one crystal and occasionally a core which is not filled with quartz, but the feldspar does not show idiomorphic outlines. The feldspar is much altered and is cloudy, reddened and sometimes almost isotropic; the cleavage is poorly developed and good cleavage flakes on which to make determinations of the extinction angles are almost impossible to obtain. In some crystals traces of polysynthetic twinning can be observed, but most of the grains are too highly altered to show this. As the feldspar is the only mineral of any importance besides the quartz, the analysis of the whole rock, which is given below, will give a good index of the composition of the feldspar. The amount of soda is very high in comparison with the potash and lime, and a considerable part of the feldspar would thus seem to be albite, but anorthoclase, and perhaps some orthoclase, are also probably present.

Reddish iron oxide is quite common in minute flakes scattered throughout the section. A few small areas of chlorite and of epidote are also present. If the chlorite represents an original ferro-magnesian constituent, nothing can now be said as to what it was.

Chemical analysis. The following analysis of the whole rock was made by Prof. J. A. Dodge, and first published in the tenth annual report, page 204 (Chemical series 73).

SiO_2	75.78
Al_2O_3	11.09
Fe_2O_3	2.09
CaO	.86
MgO	.65
K_2O	1.06
Na_2O	6.43
H_2O	1.82
	99.78

Remarks. One of the "red rock" series. See under 1B.

Age. Cabotian of the Keweenawan.

U. S. G.

No. 1C. Gabbro. (*"Rice Point Granite."*)

Duluth. From the rock which has been slightly explored for iron ore. Belongs to the same rock as No. 1, but from a point further east on the hill.

Ref. Same as for No. 1. Also Annual Report, x, page 41.

Meg. This is a fresh rock, of higher specific gravity than No. 1, grayish-black, medium grained, having distinct ophitic structure, in some places largely made up of magnetite, in the mass of which sometimes may be seen rectangular surfaces.

Mic. The coloration of all the transparent grains in a thick section, between crossed nicols, is much more brilliant than that of No. 1, and the ophitic relations of the pyroxene and the plagioclase plates are very marked.

The *feldspar* exhibits Carlsbad and albite twinning, and occasionally also the pericline bands. A section approximately parallel to 010 gave extinction on the edge (001) (010) at $21\frac{1}{2}°$; another parallel to 001, gave an extinction of 22°, which indicate *labradorite*, approximating *bytownite*.

The *pyroxenic element* possesses special interest, as it is usually a lamellated *diallage*, with bright and contrasting polarization colors. The prismatic cleavage, in conjunction with that parallel to the face 100, is common. The fibrous disintegration which precedes the change to amphibole is always perpendicular to the last mentioned cleavage. There is a great range in the degree of change manifest in the diallage. In the section examined there is no apparent tendency to amphibole, but to chlorite; at least no amphibole colors nor cleavage is visible. Some of the diallages are nearly intact, and others are entirely changed. Those which are yet intact embrace magnetite in grains of considerable size, which sometimes show angular forms, as if original, while those which are changed have fine granular aggregations of magnetite of irregular shapes at their centres, the periphery of the diallages being made up of a rim of opaque veriditic matter, apparently of chlorite. The magnetites so embraced in decayed grains of diallage are frequently impacted in epidote, or epidote and chlorite. In the unaltered or slightly altered diallages the contact between the diallage and the included magnetites is clear and abrupt, indicating the original nature of the magnetite. See figure 3, showing cleavages of diallage.

The arrangement of the magnetite in some of the principal magnetic grains is in lines (as seen in section) or sheets. It suggests that the lamellation of the diallage parallel to 100 may have determined its position, and hence, on the view above that the magnetite in the main is not a magmatic secretion, but is a secondary generation after consolidation, before cooling, the lamellation of the diallage must have had a very early origin, prior to the genesis of this secondary magnetite, and hence was probably original, and not a result of change from augite. Still, it is possible, if not probable, that an earlier stage of the diallage was augitic, and that both the

lamellation on 100 and the generation of magnetite date from the cooling period, perhaps contemporaneously.

Magnetite. From the above it appears that the genesis of the magnetite in this rock is not all referable to the same date, but that it was both original and "secondary." It is in quadratic forms embraced in the feldspars and in the diallages, in comparatively unchanged surroundings. It fills angular openings within the feldspars, where it seems to have taken the place of decayed pyroxenes (diallages), and in this form it constitutes the largest amounts. At the time of this substitution of magnetite for pyroxene, there was a general disintegration of the pyroxenes, so that their spaces are not entirely filled with magnetite, but epidote, and especially chlorite, appear as secondary minerals. *Pyrite* appears in a few small grains, mingled with the secondary magnetite.

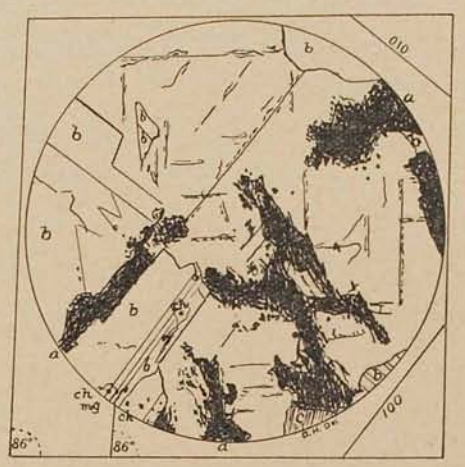

FIG. 3. A GRAIN OF DIALLAGE SEEN IN SECTION OF ROCK NO. 1C, SHOWING THE PRISMATIC CLEAVAGES AND THAT PARALLEL TO 100.

a—Magnetite (black). *b*—Feldspar. *c*—Fibrous diallage. *ch*—Chlorite.
The rest of the figure is occupied by a grain of diallage. In this section the fine fibrous structure is wanting.

The order of genesis of the minerals here seems to have been as follows:

Original—	*"Secondary," or without known order of genesis*—
1. Magnetite.	Chlorite.
2. Feldspar.	Magnetite.
3. Diallage.	Pyrite.
	Epidote.

In the magnetite sometimes there is a connection between a cubic or otherwise angular grain, which is so situated with respect to a feldspar or a pyroxene as to show its original date from the molten magma, and a mass of secondary magnetite, as if the change of the pyroxene had been provoked to begin at a magnetite nucleus, and to spread widely from it. In such a case the original cubic magnetite has a sharp line of separation from the surrounding minerals, whether of pyroxene or of

feldspar, but the "secondary" increment has a laminated structure and an irregular outline, both due to the form of the original pyroxene.

These secondary minerals seem to have been derived entirely from the change in the diallage, for the feldspars are quite free from such change. There is sometimes a patch of chlorite surrounded by a feldspar grain, but in all such cases, so far as observed, there are a few fine grains of secondary magnetite embraced in the chlorite, showing that the place of the chlorite was originally occupied by a grain of diallage; or such chlorite grains can be referred to the effect of a neighboring disintegrated diallage.

From the foregoing, however, it is not established that the great masses of iron ore of the gabbro are of secondary date, though it appears probable. If such a generation be established by such evidence it is necessary to understand the term *secondary* to apply to a date just subsequent to consolidation prior to cooling, when chemical changes were liable to rapid production. The changes that have resulted since cooling, so far as seen in this rock now at the surface, are *nil;* but they may have been great prior to the removal of the weathered surface by the glacial period.

One section examined.

Age. The Cabotian eruptives of the Taconic. N. H. W.

NOS. 1D AND 1E. GABBRO. *(Globular masses, weathering from No. 1.)*

Duluth. At a point half way between Newson's quarry and the depot. Also seen on Michigan street, where it has been cut by grading and forms a bluff about fifteen feet high.

Compare Nos. 4A and 1799.

Ref. Annual Report, ix, page 11; Bulletin ii, pages 73, 74; Annual Report, x, page 41.

Meg. An extensive disintegration characterizes a belt in the gabbro seen at this place and again on Michigan street. It is finer toward the east. At the point where this specimen was obtained the masses were over a foot in diameter, with many smaller. Evidently these larger masses, being fresh and like the rock of No. 1, are of the nature of "boulders of disintegration," as defined by T. Sterry Hunt. But in other places the rock is in the nature of a *gravel of disintegration*, the small gabbro pieces being about the size of apples and walnuts, though surrounded by much decayed rock. The face of the cut on Michigan street presents much the appearance of a conglomerate (plate P, figure 1, vol. iv).

Mic. A thin section from No. 1E presents the same characters as No. 1, but the minerals are much decayed.

One section examined.

Age. Cabotian. N. H. W.

No. 2. Diabase.

Duluth. Dike running N. 30° W., separating No. 1A from No. 3.
Ref. Annual Report, ix, page 11; Annual Report, x, page 41.

Meg. A dark gray, compact rock of rather fine grain. Composed of plagioclase, a greenish mineral looking like an alteration product of augite and magnetite. The feldspar weathers whitish to pinkish.

Mic. A rather fine grained diabase, more or less altered. The ophitic structure is very distinct, and the *plagioclase* is usually little altered. In the angles between the plagioclase, and often penetrating it along the cleavage cracks and twinning planes, is a dirty-greenish alteration product of the augite. In some places fresh *augite* still remains; it has a purplish tinge similar to that of a large proportion of the diabasic augite of these rocks. *Magnetite* is quite abundant, but is confined largely to the areas of altered augite; it is in irregular grains, and especially in rod-like bodies, which often exist in small groups, in each of which the rods lie parallel. Sometimes one rod will have several smaller ones branching off from it at right angles, thus resembling the skeleton crystals of magnetite found in certain glassy rocks.* But in the rock under consideration, the rods are several times larger than these skeleton crystals.

One section examined.

Age. Probably a dike of Manitou.

Remarks. "A finer-grained rock of the same general character as No. 1A, and running in the form of a dike, N. 30° W., and separating No. 1A from No. 3."†

No. 3. Granite. *(Fine, red, hornblendic.)*

Duluth. Fifth avenue east and Seventh street, occurs as patches and veins in No. 1.
Ref. Annual Report ix, pages 11, 12, 17. Annual Report, x, pages 41, 140. American Association for the Advancement of Science, vol. xxx, page 163, 1882.

Meg. This is a fine grained, granitic rock of a reddish-brown color. The hand sample varies somewhat in shade, one side being brown and the other reddish, the change occurring gradually along the centre of the specimen. The mass of the rock is quite fine grained, but seems to be made of reddish feldspar and a darker hornblendic mineral in ill-defined grains, blotches, and some distinct crystals. A few large, but dark colored feldspar crystals two to three millimeters long are seen. These and the larger crystals of hornblende give the rock a sub-porphyritic appearance. The feldspars do not show striation. A weathered surface is lighter red and filled with small cavities due to the more rapid decay of the hornblende.

Mic. In thin section the rock is seen to be sparingly porphyritic with *feldspars*. While these are quite small, the largest one in the section being less than two milli-

* Compare H. Rosenbusch, Mikrosk. Physiog., Bd. I, Taf. II, figure 5, 1892.
† N. H. Winchell. *Ninth Annual Report*, p. 11.

meters long, still they are much larger than the other constituents, and are almost completely idiomorphic. Most of these crystals show no polysynthetic twinning, although in two of them traces of it are visible. An attempt to get cleavage flakes for the measurement of the extinction angle was unsuccessful, as the crystals are quite small and usually considerably altered to a pale-greenish chloritic substance. The porphyritic feldspars are rarely reddened as is the feldspar of the groundmass. No porphyritic hornblende is shown in the slide.

The groundmass is composed of feldspar, hornblende, quartz and magnetite. The feldspar is much altered and reddened, as is so common in the acid granular rocks of the Cabotian, and shows no twinning striations, and the cleavage is ill developed; it is very probably orthoclase. *Quartz* occurs in sharply defined grains and also in micropegmatitic intergrowths with the feldspar. This micropegmatyte pervades almost all the feldspars, and at times becomes almost granophyric. As to how much of this structure is secondary it is impossible to say. The groundmass is, however, holocrystalline and is finely granitic in structure. Hornblende, of the usual green variety, is quite common; it occurs in allotriomorphic grains and in minute flakes, which have a slightly bluish tinge and are scattered throughout the rock. Some of the areas of hornblende appear partially granular and much resemble hornblendes that are secondary after pyroxene, but in no case was any pyroxenic material seen nor suggested by the outlines of the hornblende areas. *Magnetite* is quite abundant; it occurs in a few irregular masses two to three millimeters across and in numerous minute idiomorphic grains.

One slide examined.

Age. Cabotian.

Remarks. The rock is a brownish red, very fine grained, sub-porphyritic, hornblende granite. "This [No. 3] spreads wider and is to be seen at other points back of Duluth, yet appears rather to be in patches, or in veins in other rock. At Newson's quarry a similar red rock penetrates the gray rock in seams, and occupies a larger area in the lower part of the quarry."* U. S. G.

No. 4. Diabase. *(Coarse, decayed.)*

Duluth. Near the Union station.
Ref. Annual Report, ix, page 11; Annual Report, x, page 41.

Meg. This is a much decayed, light gray to flesh-colored rock of medium grain. Feldspar makes up more than half the rock; it is whitish to pinkish in color and appears like decayed orthoclase. Several larger crystals occur in the hand specimen; these have a greenish shade and are one-half to three-fourths of an inch across, but they are not sharply marked off from the rest of the rock and so do not give it a

*N. H. Winchell. *Ninth Annual Report*, p. 11.

porphyritic aspect. Areas of a soft, dark-green mineral, which seems to be chlorite, are common, as are also small particles of epidote. Magnetite is also present.

Mic. This rock is much decayed. The chief minerals present are feldspar, chlorite, epidote and magnetite. The feldspar is largely altered to a mass of minute, grayish, sericite-like fibres, but in many places enough of the original mineral remains to show that it possessed frequent twinning lamellæ. The fibrous alteration product is sometimes arranged in groups of fibres radiating from a point or from a line. The feldspar crystals are partially idiomorphic, and in the spaces between them are some angular areas now filled with chlorite and fine grains of magnetite. The rock thus appears to have been a diabase with the augite now represented only by the chlorite areas. These are, however, in comparatively small amount, as the feldspar makes up the great part of the rock. Epidote has developed to some extent in the feldspar; it occurs in granular aggregates and irregular areas and is colorless to straw colored, the more colored parts being somewhat pleochroic. Magnetite is quite common, and the rock powder yields many grains to the magnet. In some places, however, what appears to be magnetite is probably ilmenite, as it is found partially surrounded by a whitish substance resembling the usual alteration product of ilmenite.

Three sections examined.

Age. Probably an eruptive of the Cabotian.

Remarks. This rock appears to have been originally a rather coarse-grained diabase. Possibly some orthoclase feldspar may have been present, thus giving the red feldspar of the hand sample, as orthoclase is found to some extent close by in basic rocks (diabase or gabbro), where it is intimately associated with the acid "red rocks" (compare No. 1B). In this case, however, it seems possible that the red color of the feldspar is due to staining during the process of decay, and that it was not originally orthoclase. "A cementing material for rounded masses of No. 1."* U. S. G.

No. 4A. Gabbro. *(Breccia, reddened.)*

Duluth. Near the same point as No. 1D and No. 1E, east of Newson's quarry.
Ref. Ninth Report, page 11; Tenth Report, pages 41, 99. See also descriptions of Nos. 1D, 1E, and 1799.

Meg. The specimen is much reddened, but there is no certainty of any other feldspar than a plagioclase, whose albite twinnings are sometimes visible. It is specked or spotted with red and gray, also with epidotic green, and in general is quite coarse. The specimen marked No. 4A is not a fair representative of the description made in the field, but is rather a coarse sample from the matrix which embraces the undecayed and rounded masses. The origin of this breccia (?) is problematical.

No section.

Age. Cabotian?

N. H. W.

*N. H. Winchell. *Ninth Annual Report*, p. 11.

Gabbro.]

No. 5. Gabbro *(with orthoclase)*.

Duluth. Near the old passenger station of the St. Paul and Duluth R. R. [The outcrop from which this sample was obtained was entirely worked out and the spot covered on the construction of the new union depot; but this rock is not an uncommon one at Duluth, as it is a phase of the contact phenomena and fusion of the sedimentary rocks with the gabbro No. 1. It is seldom seen so coarsely crystalline, however.]

Ref. Annual Report, ix, pages 11, 12, 19, 57. Annual Report, x, pages 41, 141. Bulletin ii, page 88. American Association for the Advancement of Science, vol. xxx, page 165, 1883.

Compare R. D. Irving, Mon. v, U. S. Geol. Survey, page 55, 1883.

Meg. A heavy, dark-reddish rock of rather coarse grain, composed of pinkish feldspar, gray feldspar, pyroxene and magnetite. The rock has the appearance of a coarse diabase, except that half or more of the feldspar has a pinkish color, and the rest is gray plagioclase. Where the latter is more abundant, the pyroxene and magnetite are in larger quantity; there thus appear irregular areas, not sharply separated from each other, one of a pinkish, and the other of a darker color; yet, in the areas occupied mostly by one feldspar, crystals of the other frequently occur. There are also some grains which are intermediate in color, and a complete gradation in color, from the pinkish to the gray, can be seen; moreover, in some cases, a single crystal will be pinkish in one part and gray elsewhere; in such cases the centre is usually of the latter color, while the margin is pinkish. The gray feldspar sometimes shows twinning striæ, but none were seen on the pinkish variety. Magnetite, in grains of considerable size, is quite abundant; some of it yields readily to the ordinary magnet, while some does not, thus indicating that at least part of what appears to be magnetite is really ilmenite. In some of the areas of pinkish feldspar a few small grains of quartz are to be seen.

Mic. A basal section was made from each of the *feldspars*. The gray feldspar in this section shows a cleavage trace, and the whole slide extinguishes at 4° or 5°, indicating either albite or labradorite (Fouqué, page 148).* A single basal section is not sufficient to decide, since it is impossible to know from which direction it is examined, whether on the right or left of the obtuse angle 001:010; in other words, whether it is before the observer in the "conventional position" of a triclinic crystal, with the obtuse angle 001:010 at the right. In order to determine between these, a careful test was made with hydrofluosilicic acid, by the method of Boricky, the result being numerous large monoclinic micro-crystals of fluo-silicate of lime, as well as irregular spreading and branching growths of the same, many fine hexagonal micro-crystals of soda, and a few cubes of the same salt of potassium. This result precludes albite and indicates labradorite, in which a small portion of the soda is replaced by potash. Several measurements were made on sections nearly 010, for the extinction angle, which is uniformly high, ranging from 26° to 33°, this result indicating labradorite or bytownite. In one of the sections examined, is a small rectangular section of this feldspar, showing nearly rectangular cleavages and striations, on

*Compare, also: *Bulletin de la Société Française de Minéralogie.* Tome xvii, p. 428, 1894.

which extinction is 24°. In the feldspars the plane of the optic axes is practically in the plane 010, and gives an interference figure indicating the optic normal within the field of the microscope. Comparing this with the "épures" of Michel Lévy (Minéraux des Roches, plate VI, the optic normal (n_m) is found situated between 30½° and 20°; practically at 24°. This again indicates labradorite with the proportions Ab_3An_4. All methods of examination which have been made of this feldspar, *i. e.*, the original gray feldspar of No. 1,) lead to labradorite.

The red feldspar in No. 5 was subjected to the same test. Large cubes of fluosilicate of potash, some of them so rapidly formed as to be partially opaque, monoclinic crystals of lime and an occasional hexagonal rod of soda, pointed unmistakably to orthoclase in which a part of the normal potash is replaced by soda. This shows a mutual interchange between these feldspars, one giving up a little soda and receiving potash and the other receiving soda in exchange for potash. This indicates a tendency on the part of the orthoclase toward the composition of anorthoclase. In general, the red feldspar is nearly or quite opaque, from some alteration, while in immediate contact are the lath-shaped labradorites, with evident cleavage and twinning bands. In the interior of the red feldspars are frequent grains of quartz. The labradorites were formed earlier than both the quartz and the orthoclase. Not infrequently a fringe or red border of orthoclase surrounds the labradorites, a kind of reaction rim between the previously formed labradorite and the acidic elements which subsequently enveloped it. Indeed, there is good reason to assume that, in many cases, the red color simply marks such changed labradorites. This reddened feldspar often constitutes a border round the clearer crystals of plagioclase, and in such cases the border, or colored zone, seems to be a continuous part of the clearer central crystal. This can be explained on the supposition that the crystal is a zonal one, the outer zone being less basic than the inner, and that it has consequently undergone the reddish alteration to which the more acid feldspars of these rocks are so subject. Or, on the other hand, this reddened zone may be simply a peripheral altered portion of a practically homogeneous crystal. However this may be, the reddened feldspar between the clearer crystals appears exactly similar to the similarly colored feldspar of the acid granular rocks, which is known to be orthoclase and anorthoclase. In these areas of reddened feldspar is considerable quartz in small grains, and frequently these two minerals have grown together in the form of micropegmatyte. Such parts of the section resemble sections of the acid red rocks—granites and augite-syenytes (see Nos. 1B, 3).

The *pyroxenic* mineral appears much as in No. 1C, but is not so evidently diallagic. It is much changed to chlorite and replaced by magnetite. Occasional grains are cut nearly perpendicular to an optic axis, as shown by the interference figure.

It embraces the labradorites ophitically but never the orthoclases. On the contrary, the orthoclase surrounds it, in a manner somewhat similar to that in which it surrounds the labradorites. There is, however, an important difference. When the pyroxenic element is surrounded by the orthoclastic the former is uniformly and deeply changed, and converted into chlorite, magnetite, quartz, while the labradorites have usually maintained their forms and chemical integrity. The formation of the orthoclase and the quartz seems to have been consequent, or at least coincident, with the demolition of some of the pyroxene grains. In these sections there is no evidence of the mechanical intermixture of any of the foreign (acidic) elements from the clastic strata, but only of such chemical transformations as the near proximity of such minerals under pressure, heat and moisture may have promoted. This transformation took place, of course, during the cooling period. It may not be inferred that the change in the pyroxenes was due to the action of these acidic transfusions, because similar changes, except the introduction of quartz, took place in the same mineral where it was not subjected to such influence. It is only allowable to infer that the cooling period was the date of activity of both agents of change, and that they combined in No. 5, and added quartz and orthoclase to the usual products.

Magnetite is of two dates, as in No. 1C. By far the larger portion, however, is of secondary (cooling stage) date, and has taken the shape of the original pyroxenes or of a glassy residue. See figure 4.

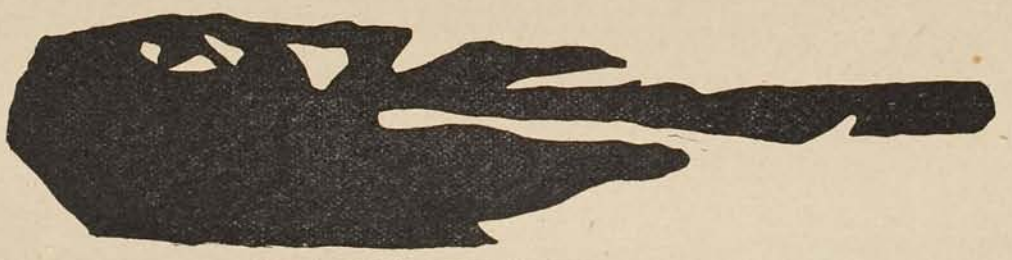

FIG. 4. SECONDARY MAGNETITE FROM NO. 5.
The included grains are of clear feldspar.

Figure 4 is a reproduction of a drawing of a part of a mass of magnetite in No. 5, made by the use of the camera lucida. It shows the form which the magnetite sometimes presents. A fracture line in the section separates this from another portion of the same grain of magnetite, the latter showing similar outlines and inclusions, though not so large as this. The included parts are bright feldspar, which also surrounds the whole mass, there being no augite in contact with it unless it be represented by chlorite scales, which are seen about the larger end. The smooth, rounded outline of the border, and the general absence of pyroxene and its residue, suggest that this may have taken the place of some of the uncrystallized magma, yet its ophitic relation to the feldspar is more like that of pyroxene.

Apatite appears in the midst of the red feldspar, probably not of original crystallization, but a result of change consequent on mineralization after the protrusion of the molten mass, during the cooling stage.

Quartz is not abundant, but is in sizable grains. They are uniformly in the midst of the altered portions of the other minerals, or associated with the red feldspar.

Four sections examined.

Meg. Cabotian eruptives of the Taconic.

Remarks. This rock is thought to represent the intermingling of the basic (gabbro or diabase) magma with the material of the red granites (Nos. 1B and 3). The question of the intermingling of these two magmas will be discussed in Part III.

This rock has been called "orthoclase gabbro." The location of the bare knob from which the samples were derived was favorable for the collection of samples by all visitors arriving by railroad from St. Paul. It consequently has been described by several petrographers, and has been considered the type of the Duluth gabbro. Unfortunately Irving fell into this error. At the same time the "hornblende gabbro" of Streng and Kloos seems to be a phase of the same rock, the pyroxene element being replaced largely or wholly by secondary hornblende. Both phases are due to the transformations attendant on the long cooling time, when in contact with the clastics of the Animikie or older rocks. No. 5 is the same rock as No. 1797, and the same as No. 13 of the Minnesota rocks collected by Prof. A. Lacroix in 1888, preserved at the College de France, Paris. No. 5 is also very similar to No. 53B. N. H. W.

No. 6. Diabase.

Duluth. From near the bay in front of the site of the old "Clark house," east of the Spalding hotel, now covered by buildings and by grading. No. 43 is probably the equivalent of this. By the lake the rock had the appearance of being a wide dike, but No. 43 spreads widely, more in the manner of a general massive.

Ref. Annual Report, ix, pages 12, 18, 19; Annual Report, x, pages 41, 141; Bulletin ii, page 110; American Association for the Advancement of Science, vol. xxx, page 165.

Compare Nos. 8, 43 and 53.

Meg. Medium grained, gray, homogeneous, resembling No. 1C or a fine-grained condition of No. 1.

Mic. The thin section is much like that of No. 1C, but with less magnetite and with a little quartz. Labradorite, pyroxene (augite), magnetite are also easily distinguished. Apatite spicules are in the quartz. The presence of quartz and a little coloration (reddish) of some of the feldspar grains indicate the effect of the same agencies during the process of cooling, as already mentioned in describing No. 5, although, in general, in the hand specimens collected, such coloration is not distinguishable. The segregation of the quartz seems to have been shortly preceded by the formation of the apatite spicules, both as secondary products.

One section examined.

Age. Probably Cabotian of the Taconic. N. H. W.

No. 6A. Diabase *(with olivine)*.

Duluth. An extensive outcrop formerly existed beside the railroad. This is probably an equivalent of No. 43, and a phase of No. 6.

Ref. Annual Report, ix, pages 12, 17.

Meg. A dense, rather fine-grained rock, dark gray in color, having the aspect of an ordinary diabase.

Mic. The *feldspar* of the first generation is evident but in fragmentary crystals. Apparently the same feldspar has taken part in the second consolidation. At least the distinction between the first and second crystallizations is so obscure that apparently the same species grades from one to the other. They are decayed and much twinned.

The *olivine* is changed to an almost isotropic substance, with a light green tinge; along the cleavages of the original olivine much magnetite is gathered.

Augite, much altered, is greenish, but shows its ophitic relations.

Quartz is sparse, likewise *pyrite*. *Magnetite* is not abundant.

Two sections examined.

Age. Probably Cabotian of the Taconic. N. H. W.

No. 6B. Diabase.

Duluth. In immediate contact with No. 6A. Undistinguishable from No. 6A, of which it is probably a portion, but more plainly porphyritic, in thin section, with feldspar.

Ref. Annual Report, ix, page 12.

One section examined.

Age. Probably of the surface Cabotian eruptives. N. H. W.

No. 6C. Diabase. *(Spotted with red, and porphyritic.)*

Duluth. Foot of Lake street. Essentially the same rock as Nos. 6A and 6B. It is, however, spotted with irregular small areas which apparently consist largely of orthoclase and pyrite. The red color faintly pervades the entire specimen. Microchemical test for potassium made on the red substance gave large cubes of fluosilicate of potassium; also, many crystals indicating lime and soda. The whole rock is finely porphyritic with a plagioclase. The red spottedness should not be mistaken for an amygdaloidal structure. The red areas are of another rock and are foreign inclusions in the basic eruptive.

Ref. Annual Report, ix, pages 12, 18.

Age. Probably Cabotian. N. H. W.

No. 7. Diabase (?)

Duluth. Between Second and Third avenues, close to the water. Underlies immediately No. 7A. Dip, E. 18°.

Compare No. 42.

Ref. Annual Report, ix, pages 12, 18; Annual Report, xiii, pages 100, 102; Annual Report, x, pages 63, 109, 140; Bulletin viii, pages xxx, xxxiii; American Association for the Advancement of Science, vol. xxx, page 163.

Meg. A dull, brownish, compact rock of fine grain. Composed of small crystals of reddish feldspar in a darker, very fine-grained groundmass. A very few porphyritic red feldspars are present; these are not more than five millimeters in length. One of them is a simple twin. There are two cavities in the specimen which are

now filled by quartz, with sometimes a little epidote along the edges; possibly these represent amygdaloidal cavities.

Mic. The section shows small, crowded, lath-shaped feldspars in a rather sparse groundmass of alteration products. The feldspar is much altered and reddened; many of the crystals show traces of twinning striæ. Their exact nature cannot be determined, but from the analysis of the whole rock given below, it is probable that this mineral would fall in the labradorite series. These feldspars are from .25 to .75 millimeters in length. The section contains none of the rare porphyritic crystals. The groundmass is clearly secondary and is a confused aggregate of quartz, magnetite, chlorite, calcite and muscovite. What the original nature of this groundmass was is uncertain. It may have been principally augite (and the rock is a fine-grained diabase), or possibly the finely crystalline groundmass of a porphyryte, or even glassy material. Apatite needles are rather common. There is no indication of what the original ferro-magnesian mineral of the rock was, and there are no areas now filled with alteration products, which might represent porphyritic crystals of pyroxene or hornblende.

*Chemical analysis.** The following analysis of this rock was made by Prof. C. F. Sidener and was published in the Thirteenth Annual Report, page 100 (chemical series 149), and in Bulletin viii, page xxxiii:

SiO_2	53.71
Al_2O_3	14.96
Fe_2O_3	14.45
FeO	3.65
CaO	3.35
MgO	4.59
K_2O	0.56
Na_2O	1.40
H_2O	1.60
	98.27

From the data now available this rock can be regarded as most probably an altered fine-grained diabase.

Age. Probably Cabotian. U. S. G.

Remarks. This rock has to be removed from the category of the "red rocks" with which it has been classed in an earlier description.† Its color and the presence of quartz were the characters that led to that classification, but its crystalline feldspars, which seem to prove original complete fusion, and its rather low percentage of silica, seem to preclude its origination from the acid source which gave rise to the most of those rocks. If, however, the red rocks as a group are referable to the fusion of clastic rocks it is necessary to admit that various degrees of acidity and different stages of crystallization must have been the result. The rock is massive, dense and clean, and has the appearance outwardly of having preserved its characters as well as most of the massive rocks of the region. Hence it is allowable, still, to suggest

Ninth Annual Report, p. 12, 1881.

†*American Association for the Advancement of Science*, vol. xxx, p. 163, 1882.

that this may be one of the varied results of the action of the basic eruptives on the varied nature of the clastics with which they came into contact; although it is more likely to have originated from a quickly cooled basic magma which at first took the character largely of zirkelyte, a name applied by Wadsworth to a microlite-charged basic glass in such conditions, afterwards partially or wholly devitrified. (Bulletin ii, Minnesota Survey, page 30.) N. H. W.

No. 7A. Amygdaloid.

Duluth. Apparently overlies No. 7.
Ref. Annual Report, ix, pages 12, 17.

Meg. Nearly black, amygdaloidal, at least with cavities nearly or wholly filled with segregated minerals. The most conspicuous of these secondary minerals is yellowish green, resembling epidote; another is dark green, and appears in the form of radiated coatings, and resembles delessite. Pyrite also is sparse. The structure is very fine, but somewhat irregular and globular.

Mic. This rock is like the last in its essential characters. In some places the section appears reddish, by reason of the abundance of the red feldspars. In others it is porphyritic with fine feldspathic *microlites*. But the whole rock is much decayed, and is seamed by irregular transparent veins and threads, which consist largely of *quartz*.

One section examined.

Age. Probably of the Cabotian eruptives of the Taconic. N. H. W.

No. 7B. Tuff (?)

Duluth. This rock is wrought, or was in 1878, in the alley between First and Superior streets, and Fourth and Fifth avenues east.
Ref. Annual Report, ix, page 12.

Meg. This rock is brownish, but spotted with greenish amygdules and with inclusions of some foreign rock. This foreign rock is of a dun color, rather compact but appears itself like a fragmental rock. On weathered surfaces it is pitted from the oxidation of pyrite. These foreign pieces vary from the size of a pea, or perhaps a pinhead, to about two inches in diameter, which is about the size of a mass attached to the museum sample preserved. They are scattered heterogeneously in the amygdaloidal portion of the rock.

Mic. A section of the matrix which embraces the foreign pieces shows a much decayed condition. There are reddish *feldspars* which come from the first epoch of consolidation, some of them plainly twinned polysynthetically. They are charged with alteration products, such as *epidote*, *pennine*, *pyrite*, *hematite (?)* *magnetite*, and apparently *zircon*, although these minerals are not always arranged so as to prove they are included in areas formerly occupied by feldspars. They, indeed, fill up the

space not plainly embraced within the feldspars. There is no remaining evidence of the nature of the other original minerals.

A better section, made by Marchand, shows distinctly a tuffaceous nature. There is a portion of the microlitic magma, composed of spicules of *plagioclase* surrounded by devitrified *glass*, now greenish, and a portion made up of a minutely fragmental rock, which, between crossed nicols, is nearly dark, but plainly contains numerous angular *quartzes*. In the former are large translucent areas which are contrasted with the dark surrounding rock, and in these areas is seen much of a finely granular gray mineral, having high refraction and also high double refraction, which probably is *epidote*. This mineral is associated with much quartz in these areas, and also is disseminated throughout the rest of the rock in more minute particles.

Two sections.

Age. Cabotian.

Remark. This marks the first discovery of tuffaceous rock in the series that has been called Cupriferous, in the lake Superior region. It appears by the following descriptions that volcanic tuff is not an uncommon substance in the region of Duluth, and at points further east. N. H. W.

The following criteria for the recognition of ancient volcanic rocks have been given by Dr. George H. Williams (Journal of Geology, ii, page 10):

Criteria for the recognition of ancient volcanic rocks.

It is a self-evident proposition that the identification of certain rocks as volcanic products is in no way dependent upon their present association with a recognizable crater or volcanic mountain. By volcanic rocks we understand igneous or pyroclastic material which has solidified or been deposited at or very near the earth's surface. It is of little moment whether or not it was ever piled into conical mountains. That the rocks themselves bear witness to their origin and conditions of formation is sufficient. The successive effects of erosion on the easily removed volcanic mountains has often been so graphically described* that no further reference to the subject is here necessary. If the Eocene or Triassic volcanoes have so disappeared as to leave only traces of their original forms, what may we expect of those of Paleozoic or Archean times?

On the other hand, the association in dissected volcanic regions of the effusive rocks with correspondingly abyssal types naturally suggests that volcanoes may have once surmounted many areas of coarsely granular ancient igneous rocks. As this, however, cannot be proved, only such regions are here considered as yield rocks of unmistakably surface origin.

Again, ancient volcanic rocks may have been subjected to metamorphosing processes severe enough to have destroyed most of their original characters. In such cases, patient study and a careful weighing of all evidence is necessary to decide their origin, and even that may not avail. Igneous rocks may be so altered as to be indistinguishable from metamorphosed sediments, but in many cases where this at first appears to be the fact, some decisive clue may be discovered.

In establishing the volcanic nature of rocks occurring in ancient and more or less crystalline terranes, attention must be given to several different sets of characters. The field relations must be carefully studied and the material collected on the spot and afterward studied in the laboratory. The criteria for deciding on their igneous and volcanic origin may be arranged as follows:

I. If the rocks are igneous, whether abyssal or surface, they will:
   1. Conform in chemical composition to certain well established types.
   2. Show an association of petrographical types which, both chemically and mineralogically, follow the laws of consanguinity.

II. If they are volcanic:
   1. They may be found in the field to occur in distinct sheets, flows or necks.
   2. They will have produced little or no contact action in the adjoining rocks.

*See De La Beche: *Geological Observer*, pp. 526-537, 1851. M. Neumayer: *Erdgeschichte*, vol. i, pp. 202-204, 1887. W. M. Davis: "The Lost Volcanoes of Connecticut." *Popular Science Monthly*, December, 1891.

3. They may include irregular fragments of other rocks.

III. If they are volcanic:

1. They may appear to be striped, banded, or pseudo-"stratified" conformably to adjoining sedimentary deposits.

2. They will probably be accompanied by fragmental (pyroclastic) material, which may or may not itself be really stratified. Such material will vary greatly in coarseness, containing bombs, agglomerates, breccias, tuffs, sands and ashes. The characteristics of these are: (1) Indiscriminate mixture of all sizes and shapes of fragments; (2) Material of same kind as the igneous rocks; (3) Cement, either finer fragmental material (tuff-breccia) or lava (flow-breccia); (4) Very angular shape of smallest fragments (microscopic glass shreds); (5) If ancient volcanoes were on the shore line, such material may have been immediately worked over by water and interbedded with more or less normal aqueous sediments.

IV. Most important of all, however, is the identification of those characteristic structures known to originate only in glassy, half-glassy, or very fine grained porphyritic rocks, solidifying at the surface, or in very narrow dikes where solidification has been rapid. These will be found to be very persistent and can usually be identified under the microscope in spite of devitrification, alteration or even a considerable degree of dynamo-metamorphism. The most common of these structures are:

1. A vesicular, scoriaceous, pumiceous or amygdaloidal structure.

2. A sharply defined, small porphyritic structure with a glassy, half-glassy or felsitic (cryptocrystalline) base.

3. A spherulitic structure, due to either large or small lithophysae, hollow spherulites, or compact-spherulites, arranged either irregularly, or in more or less discontinuous bands or layers.

4. A flow structure, produced either by the elongation of vesicles or the parallel arrangement of constituents or crystallites. It may also be produced by the interlacing of different colored magmas (eutaxitic structure).

5. Corroded phenocrysts, quartz, with embayments, or skeleton crystals due to rapid or imperfect growth.

6. Microscopic spherulites, globulites, trichites, crystallites, real or devitrified glass inclusions, quartz with orientated siliceous aureoles, axiolites, etc.

7. Perlitic structure, wholly or partly devitrified.

Although some of these structures may occasionally occur in dikes or other igneous rocks which have rapidly solidified beneath the surface they are nevertheless so essentially characteristic of effusive lavas, that, in lack of any evidence to the contrary, they may be regarded as fairly safe guides in establishng the effusive nature of rocks. This evidence is beyond doubt, if such rocks are accompanied, as they generally are, by ash material.

While a single one of these characteristics may not be sufficient to identify a volcanic occurrence, many, if not all of them, will be found to occur together, and only in rare instances will it be found that some of them, at least, have not survived the vicissitudes of metamorphism.

No. 7C. Diabase *(with olivine)*.

Duluth. From a dike in contact with No. 7A, equivalent to No. 47, roughly in line of bearing with No. 6. Compare No. 47.
Ref. Annual Report, ix, pages 12, 18, 19.

Meg. A dark gray diabasic rock of medium grain, ophitic, considerably decayed, and with the feldspars about the only mineral that is fresh.

Mic. The structure is distinctly ophitic, and the constituents are plagioclase, augite, magnetite and alteration products. The plagioclase is rather fresh. A series of ten sections of the *feldspar* measured for greatest equal angle of extinction on opposite sides of the twinning line, gave $29\frac{1}{2}°$ and 30°. According to the "épures" of Michel Lévy, this might indicate either a *labradorite* (Ab_3An_4) near *bytownite*, or anorthite. Since, however, an optic axis is also found to pierce the section just outside the area of the microscopic field, the feldspar is certainly near labrador-bytownite. In another section of the same feldspar the bisectrix (n_p) appears in the centre of the field, with distinct black cross and shifting hyperbolas. This grain, however, being encroached on all sides by surrounding grains, no crystallographic character was afforded for measuring the angle of the axial plane, except on an imperfect cleavage trace. This gave an extinction angle of $59\frac{1}{2}°$ to 60°, which also indicates, so far as it is of value, a labradorite, or labrador-bytownite.

It is evident by the partial darkening of the lamellæ that this rock has been subjected to strain and slight distortion. The feldspar in this dike was earlier to solidify than the pyroxene.

The *pyroxene* is, in general, much decayed by the formation of the usual greenish chloritic substance, but some of it is entirely free from it. When thus altered the pyroxene is accompanied by the usual appearance of *magnetite*, which presents a hackly metallic surface in reflected light, and is easily identifiable on turning away the mirror below the stage. There are many areas in the section that were once very probably occupied by *olivine*, though none of this mineral is now present. These areas are filled largely by sepentine (?), and the peculiar net-like structure, so common in altered olivines, is well shown. Frequently the dark threads of the net-work have on either side a narrow strip of a rather brightly polarizing mineral. This shows a cleavage running at right angles to the thread, and is distinctly pleochroic, the ray vibrating parallel to the cleavage being greenish, and that at right angles to it straw yellow. The extinction is nearly parallel. A similar mineral is found in small areas elsewhere in the altered olivines; it is probably hornblende.

One section examined.

Age. Perhaps Manitou. It is also possible that this is a dike of Cabotian age, which supplied the magma of the supposed sill Nos. 44′, 41 and 43.

N. H. W AND U. S. G.

No. 7BC. Porphyryte.

Duluth. Contact rock between Nos. 7B and 7C.
Ref. Annual Report, ix, page 12.

Meg. A dark gray to purplish, porphyritic rock. The groundmass is very fine-grained, and its components cannot be determined macroscopically. The porphyritic crystals are feldspars of all sizes up to ten millimeters in length; these are scattered regularly and plentifully throughout the rock. They are light gray to reddish in color, being the latter color more especially where exposed the most to weathering. A little pyrite is visible.

Mic. The most noticeable feature of the section is the presence of numerous sharply defined, large *plagioclase* phenocrysts. These are frequently abundantly twinned. Small areas of *chlorite* and of *epidote* are not uncommon in these feldspars. The porphyritic crystals are imbedded in a groundmass of very fine grain, conspicuous in which are numerous lath-shaped feldspars two- to three-tenths millimeter in length. Besides these the groundmass is composed of a rather confused aggregate of *magnetite*, green *hornblende*, chlorite, epidote, minute *apatite* needles and a weakly polarizing interstitial substance that may be feldspar or quartz. The chlorite and epidote are secondary, as are also probably the hornblende and part of the magnetite. It is

possible, however, that the hornblende is original, and that, with the exception of the epidote and chlorite, the groundmass is now not much altered from the condition in which it solidified; in such case the rock might be called a dioryte porphyryte, and it is similar to some of the rocks described by Iddings, from the Yellowstone National park.* It, however, seems more probable that the groundmass is considerably altered from its original condition, which might have been an aggregate of lath-shaped plagioclase (still remaining) and augite, making the rock a diabase porphyryte, to which species it is here provisionally referred. U. S. G.

Age. Perhaps Cabotian.

Remark. This rock seems to be from a series of very old eruptives, which at Duluth and elsewhere are cut by a series of later dikes, and are associated with the red rock series. N. H. W.

No. 7D. Diabase.

Duluth. From a dike near the lake running toward Minnesota point, and apparently extending under the point.

Ref. Annual Report, ix, page 12.

Meg. A fine-grained, dark greenish ophitic diabase.

Mic. The *feldspar* preceded the pyroxenic element in date of crystallization. It is uniformly lath-shaped, with more or less tapering extremities, and is less affected by later alteration than the pyroxenes. It composes about three-fourths of the entire rock.

The *pyroxene* is almost entirely altered to a greenish chloritic mineral, with simultaneous generation of much *magnetite*, there being only a few remnants which yet polarize distinctly. The alteration product, aside from the magnetite, consists of a confused mesh of chloritic shreds that overlap each other and give a characteristic felted polarization between crossed nicols. So far as can be seen, the magnetite is entirely of secondary date, taking position in the interstices of the original pyroxenes, and occasionally developing also their forms. The relation of the pyroxene to the earlier feldspar, areally, is that of a mosaic, rather than of ophitic structure. The forms of these minerals are not perfected, the feldspar because of the interference of many cotemporary growths, resulting in a crowded crystalline mass, the latter because of the later generation which allowed them only the interstices between the feldspars for a field in which to develop.

The magnetite and chlorite very probably originated during the cooling stage of the rock (see Part III).

Age. Perhaps Manitou. N. H. W.

* *Twelfth Annual Report U. S. Geol. Survey*, pp. 569-664, 1891.

No. 8. Porphyryte. *(Amygdaloidal.)*

Duluth. Separated near the wall of contact of No. 6.

Ref. Annual Report, ix, pages 12, 13. Annual Report, x, page 140. American Association for the Advancement of Science, vol. xxx, page 164.

Meg. Dense, dark colored, with indistinct small porphyritic feldspars, and in some places amygdaloidal cavities filled apparently with chlorite, or chlorite and quartz.

Mic. The prevailing mineral is a lath-shaped *feldspar* of a brownish red color, apparently one of the first of the minerals to solidify.

Pyroxenic element is not discoverable, as such, but its former presence is indicated by chlorite, and by magnetite. The latter is in numerous cubic and irregular forms, which are seen within the fine quartzes distributed in the body of the section.

The amygdaloidal spaces are occupied sometimes by chloritic substance, and sometimes by quartz, and often by both in more or less zonal arrangement.

Pyrite is occasionally seen in the borders of the amygdules.

Age. Probably Cabotian.

One section examined. N. H. W.

Remarks. Another form, also numbered 8, is much less amygdaloidal, and more porphyritic. It is very fine grained, compact and varies in color from dull black to dark brown. None of the constituents of the mass of the rock can be distinguished. Where the color is black the rock is homogeneous, but as the color becomes brownish numerous rather indistinct small dark blotches are seen. A few irregular areas of reddish feldspar occur; one of these is three-eighths of an inch across. There are also a few larger areas where the rock is colored reddish; in the centre of these areas is often a yellowish substance, probably epidote. One of these areas, or large blotches, is seen to have a centre of yellow material, outside of which is a distinct narrow black band; and beyond this is a red band, which passes into the general color of the rock. The black portion of the hand specimen closely resembles, macroscopically, some of the black flinty slates of the Animikie.

Still other forms of this rock are sparsely porphyritic with a feldspar which has a tendency to become red. Compare Part III. U. S. G.

No. 8A. Tuff. *(Inclusion in No. 8.)*

Ref. Annual Report, ix, page 12. Annual Report, x, page 140. American Association for the Advancement of Science, vol. xxx, page 163. American Geologist, vol. xviii, pages 211–213.

This is similar in all respects to the fine rock seen in No. 7B, as foreign inclusions. It is nearly totally dark between nicols, but shows numerous fine angular quartz grains. With one nicol and the condenser lowered, a varied structure comes out to view. It is difficult to describe it. The glassy grains, charged with inclusions,

are sometimes brown and sometimes light green. Some *epidote* is distinguishable by its high refractive power; and large areas are separable from the rest by reason of a greater darkness, or by a curly, minute, somewhat crescentic structure which embraces the translucent and greenish grains, the crescentic areas themselves being most translucent.

One section examined.

Age. Cabotian. N. H. W.

No. 8B. Tuff (?)

Duluth. At the lake shore near the base of Minnesota point (the spot is now hid by the growth of the city). *Ref.* Annual Report, ix, pages 12, 13. Annual Report, x, page 140. American Association for the Advancement of Science, vol. xxx, page 164.

Meg. This is a light colored rock with disseminated red feldspar crystals, having the aspect of a porphyry. A light greenish yellow mineral, probably epidote, more or less pervades the rock, this being the principal cause of the light colored aspect. The rock effervesces freely with dilute hydrochloric acid. The feldspar crystals are polysynthetically twinned, and the rock has in places a roughly amygdaloidal structure. This structure, however, is not sufficiently prevalent and characteristic to indicate that the rock en masse was ever in the form of a surface flow. The matrix of the feldspar crystals is confused and made up of various minerals that result frequently from the alteration of the minerals of original basic rocks.

Mic. The rock is much altered. The *feldspar* is charged with ferruginous impurities. A series of ten statistical measurements of the extinction angle on opposite sides of the twinning line gave the following figures: 9°, 9°; 19°, 4°; 9°, 11½°; 10°, 8°; 11½°, 6°; 18°, 5°; 5°, 15°; 10°, 1°; 10, 18°; 8½°, 20°.

If the first measurement (9°, 9°) be taken as the maximum equal extinction, according to the spherical projections of Michel Lévy (Det. des Feldspaths, plate 1) the feldspar is *albite*, but owing to its greatly decayed condition this result is not beyond doubt, while the effervescence, indicating calcite, seems to require the presence of a ready source for considerable lime.

No *pyroxene* element can be detected, nor indication of its earlier existence. The angular spaces which are sometimes surrounded by the feldspars may have been occupied originally by a pyroxene which has now been changed, but at the same time there may have been a variety of minerals so included between the feldspars, or even tufa pulp, or a glass, the time elapsed having been sufficient to change either of these into the matrix that now exists.

Quartz is common, but not as a pegmatitic intergrowth in the feldspar. It is sometimes in angular grains, isolated and irregular, and it sometimes embraces portions of the surrounding chlorite and other minerals. It is also in nests resulting from secretion from the rock, and then presents a multiple or aggregate polarization.

Chlorite is abundant, and sometimes its color between the nicols is blue, indicating *pennine*. It constitutes independent angular masses, as if it had resulted from alteration of some allotriomorphic mineral. In small flakes it is distributed generally throughout the rock.

Magnetite occurs in the same manner as the chlorite and is equally abundant.

There may be other minerals in this rock, besides *calcite*, but the section made is not favorable for their determination.

One section examined.

Age. Cabotian.

Remark. When collected this rock was supposed to have resulted from metamorphism of clastic material, through the action of eruptive rock in the vicinity. But the feldspar proves to be twinned, like a plagioclase, and the structure suggests that the feldspars may have once been embraced by crystals of augite or by zirkelyte. While resulting in part apparently from cooling from fusion, and subsequent alteration, this rock, as a whole, may still have been composed of fragmental volcanic debris, or it may have *resulted* from fusion of the clastics at the point of contact of the rocks of the gabbro series, since the ophitic structure is not unquestionable.

N. H. W.

No. 8C. Diabase. *(Fine.)*

Duluth. From a dike in No. 8.

Ref. Annual Report, ix, page 13. Annual Report, x, page 140. American Association for the Advancement of Science, vol. xxx, page 164.

Age. A very fine grained, compact, black to brownish, diabasic rock.

Meg. The rock is composed of minute lath-shaped feldspars in a more or less confused groundmass, which is largely stained to a brownish color. Aside from the feldspars the rock is made up quite largely of magnetite, which occurs in very minute grains, in irregular and often ill defined areas, and in needle-like forms. The rest of the groundmass is quite fine grained and seems to contain chlorite, calcite and probably some little quartz and muscovite. The groundmass appears to be all secondary, except possibly some of the magnetite, but what its original nature was is uncertain. The rock is here called provisionally a diabase, but it may have been a basalt, *i. e.*, its groundmass may have been of the nature of zirkelite.

One section examined.

Age. Probably a Manitou eruptive.

U. S. G.

No. 9. Porphyryte. *(Amygdaloidal.)*

Duluth. Not far from the base of Minnesota point.

Ref. Annual Report, ix, page 13.

Meg. The rock is dark brown in color, presenting a dark aphanitic groundmass in which are reddish brown porphyritic crystals of striated feldspar and

amygdules. These amygdules are filled with a yellow mineral *epidote* and a dark mineral *chlorite*. Some of the amygdules contain only one of these minerals, while others contain both. In the latter case the epidote forms a narrow rim around the outside of the cavity, and within this is usually chlorite, or sometimes chlorite and epidote. At times inside of the rim of epidote is another thin layer of chlorite, and inside of this a mass of epidote.

Mic. Under the microscope the rock is seen to be decidedly altered. The porphyritic *feldspars*, on account of their changed condition and the general reddened appearance of the whole section, are sometimes not sharply separated from the groundmass of the rock, when viewed in ordinary light; but in polarized light, they are distinct. They are plagioclase, but their exact place in the series was not determined. The phenocrysts are replaced more or less completely by epidote, and this epidotization of the feldspars is a marked feature of the section.

The *amygdules*, as stated above, are filled with epidote and chlorite. The former is in a finely granular condition, while the epidote of the feldspar phenocrysts is in crystalline grains of some size. The chlorite of the amygdules is more characteristic than the chlorite of many of the rocks here described in its marked pleochroism and in the fact that it furnishes a beautiful example of the dark blue interference colors of this mineral.

The *groundmass* of the rock is composed chiefly of minute lath-shaped plagioclases. These are closely matted together and fill up nearly the whole section. The little space in the groundmass not occupied by these feldspars is filled with a confused, fine grained mass of chlorite, epidote, magnetite and apparently a little quartz. In fact, these minerals are scattered throughout the section, and are clearly secondary. The original nature of the groundmass aside from the feldspar is uncertain. The rock is provisionally called a diabase porphyryte, although it is not improbable that it was more in the nature of a trachyte.

Two sections. Only one, however, was examined, as the other is an inferior section, and there is some doubt about its being correctly labeled.

Age. Probably a Cabotian eruptive. U. S. G.

No. 10. Porphyryte. *(Amygdaloidal.)*

Duluth. Overlies No. 11.
Ref. Annual Report, ix, page 13.

Meg. This rock closely resembles No. 9, except that its color is reddish. It has the same porphyritic feldspars and amygdules filled with *epidote* and *chlorite*. The epidote, however, is much more abundant than the chlorite.

No section.

Age. Cabotian eruptive. U. S. G.

No. 11. Porphyryte. *(Diabase.)*

Duluth. East of the elevator; extends along the shore about 800 feet.
Ref. Annual Report, ix, page 13.

Meg. The groundmass of the rock is dark brown to black in color, is aphanitic, and is thickly strewn with reddish porphyritic feldspars. Blotches of epidote are scattered through the rock, and there are spots of epidote and chlorite which perhaps represent amygdules, although it seems most probable that there are no true amygdules and that the rock is one of the pseud-amygdaloids described by Pumpelly and Irving.

Mic. The most prominent feature of the section is the sharply defined *plagioclase* phenocrysts. They have been more or less altered to a micaceous mineral, and sometimes to *epidote*. The groundmass is composed of small interlacing plagioclase laths, much *magnetite*, with *hornblende*, *chlorite*, *epidote* and perhaps a little *quartz*. With the exception of the feldspar, and possibly some of the magnetite, all these minerals are secondary. The hornblende is in small grains, usually fibrous, and occurs in the interstices between the feldspars. It evidently is an alteration product from augite, and in places part of the original augite is questionably present. Small *apatite* needles are rather common.

One section examined. U. S. G.

Age. Cabotian.

Remarks. This rock is very similar to Nos. 7BC and 9. While none of these certainly show augite in the groundmass, there still seems good reason to assume that it was there originally, and so the rocks are called diabase porphyrytes.

"No. 11 is mainly a massive, homogeneous rock, but in some places finely jointed, so that under the weather it parts into numerous angular blocks. In it are veins (near its eastern extension) that seem to cause a greater abundance of the red feldspar crystals in the mass of rock adjoining on either side; * * *"† U. S. G.

No. 11A. Calcite and Epidote.

Duluth. From a vein in No. 11.
Ref. Annual Report, ix, page 13.

Meg. The calcite and epidote are arranged in rough bands, from one-eighth to one-half inch wide. Some reddish material is mixed with the epidote.

No section.

Age. In the Cabotian porphyryte. U. S. G.

No. 11B. Geode.

Duluth. From No. 11, which extends about 800 feet along the shore. Some geodes are several feet in diameter, and are rather layers than geodes.
Ref. Annual Report, ix, page 13.

† *Ninth Annual Report*, p. 13.

Porphyryte. Quartz.]

Meg. The minerals in the specimen are promiscuously arranged, and seem to have been deposited secondarily in a porous rock, much of which has been changed into these minerals. The rock is spotted coarsely with white (calcite and quartz), green and yellow (chlorite, epidote) and red (which is perhaps orthoclastic). There are also considerable areas of a gray or dun-colored aphanitic rock, not so durable as the red mineral.

Mic. The foregoing named minerals all appear in the slide. The red mineral appears in the prepared slide as an irregularly disseminated reddish powder, scattered sometimes abundantly, but without crystalline form. Some of its crystalline grains, taken from other parts of the specimen, subjected to hydrofluosilicic acid, give crystallites of potassium fluosilicate, large and abundant, with some of lime, but none evident of soda, thus proving the *orthoclastic* character of the feldspar.

In another part of the slide a portion of the original rock is seen. It is finely sprinkled with slender microlites of a *feldspar* that is lath-shaped, but tapering at the extremities. In immediate connection with this are also a number of large *apatites*, showing their characteristic transverse fissuring. The great thickness of the section is shown by the fact that these apatites gave colors of double refraction, viz.: yellow and red. The slide must therefore have a thickness of about .08 millimeters, according to the scale of Newton's colors, given by Lévy and Lacroix.*

One section examined. N. H. W.

No. 12. Porphyryte. *(Amygdaloidal.)*

Duluth. Extending forty-nine paces along the lake shore, east of No. 11.
Ref. Annual Report, ix, page 13.

Meg. A brown amygdaloid, containing numerous porphyritic plagioclases. The amygdules are filled with epidote, chlorite and quartz.

Mic. Essentially the same as Nos. 7BC, 9 and 11, except in two particulars. First, the feldspars are in part replaced by chlorite, and second, the lath-shaped plagioclases of the groundmass are fewer in number.

One section examined.

Age. Cabotian. U. S. G.

No. 12A. Quartz. *(Nodule.)*

Duluth. A large nodule from No. 12.
Ref. Annual Report, ix, page 13.

Meg. The quartz is white and grayish, having a fibrous structure that radiates from a centre, but a coarse banding somewhat agate-like, but without coloration. Its radiated and banded structure shows the continued growth of crystals from a common point, with some variations in the environment. The central nucleus of the mass,

* *Minéraux des Roches* (plate).

or of the masses, since there are several nuclei, is sometimes seen to be a knot of finely granular or cherty quartz. The elongated fibres are quartzine, being positive.

N. H. W.

No. 13. Aporhyolyte.

Duluth. Near midway between Minnesota point and Chester creek, at the lake shore.* Extends fifty-four paces.

Ref. Annual Report, ix, pages 13, 14.

Meg. A fine grained brownish rock, in which the only identifiable mineral is a minute lath-shaped plagioclase whose cleavage affords a reflecting surface visible under the loop. The rock breaks with a conchoidal fracture, and outwardly, in the field, it weathers into a laminated or slaty structure which dips east 15°. In other places it is a lumpy amygdaloid with epidotic spots and veinings. A little pyrite also is visible in the mass of the rock.

Mic. The lath-shaped *feldspars* are usually gray, but some of them are reddened by iron. In reflected light fine metallic particles are visible, both of *magnetite* and of *pyrite*. If the rock ever contained pyroxene, it is wholly changed, for the matrix of the feldspars consists of a fine mass of *chlorite, magnetite, quartz* and apparently of a little *calcite*.

One section examined.

Age. Cabotian.

Remarks. This seems to be one of a series of rocks, of which several have already been described, viz.: the porphyrytes and diabase porphyrytes, Nos. 7BC, 8, 9, 10. No. 13A is also similar. They may all be considered Cabotian lavas that followed soon after the Beaver Bay diabase. N. H. W.

No. 13A. Diabase Porphyryte (?)

Duluth. Overlies No. 13, being apparently a layer of No. 13.
Ref. Annual Report, ix, pages 13, 14.

Meg. Slightly amygdaloidal and porphyritic, having a brown color and close texture. Except in its disseminated red feldspars, which appear more on one side of the specimen than on the other, this rock is like No. 13.

Mic. The *feldspars* are fine and tubular, striated, much decayed. The intervening groundmass consists of *quartz, calcite, pennine, magnetite,* and an isotropic substance whose nature is unknown. *Epidote* is not abundant, but occurs sparingly.

One section examined.

Age. Cabotian.

*The lake shore east from Minnesota point was formerly rock bound. It was examined carefully, and these specimens were collected when the alternations could easily be noted. Since then buildings have been erected, which, with street grading, have effectually hid all these outcrops. It can only be said that from No. 7D up to No. 36 from the mouth of Kinichigaquag (now Chester) creek, the descriptions apply to rocks occurring between Minnesota point and that creek, all situated within the limits of Duluth. There will probably never be an opportunity to verify the succession. In general these numbers represent the "porphyry-like melaphyr" mentioned by Mr. Kloos.

Remarks. In the hand specimen are visible both varieties of this series of rocks, viz.: the porphyritic, represented by No. 8, and the non-porphyritic, represented by No. 13. They apparently grade into each other, the latter becoming very fine grained, as if from contact on cooler rocks, along one side, and also assuming a darker color. This rock might have the name zirkelyte, on the supposition that the matrix of the feldspars was originally glassy. N. H. W.

No. 13B. Zirkelyte. *(Glassy basalt.)*

Duluth. A layer of No. 13.
Ref. Annual Report, ix, page 13.

Meg. Earthy, amygdaloidal, thin sheeted, green, fine grained.

Mic. The amygdules are largely occupied by *quartz*. The rock, in general, is made up of a confused mixture of very fine crystallites which cannot be separated sufficiently for determination. They seem to have prevailingly a stout and even globular form, often stained by a green viriditic substance which in some places renders the slide dark, even like an isotropic substance between crossed nicols. Quartz is disseminated in these darkened portions of the slide, as well as in the amygdaloidal spaces.

The rock seems to have resulted from devitrification of a glassy amygdaloid, of the basic sort.

Age. Cabotian. N. H. W.

No. 14. Zirkelyte.

Duluth. A dike, breaking through No. 13, running W. 10° N.
Ref. Annual Report, ix, page 13.

Meg. A compact, very fine grained, brownish rock showing minute feldspars.

Mic. The section is composed of small lath-shaped plagioclases in a groundmass of altered material which consists of *magnetite, chlorite, calcite*, and some feldspathic material.

Age. Manitou (?)

Remarks. This rock is very similar to Nos. 13 and 13A, but its occurrence as a dike indicates it is younger than they are. It has no porphyritic feldspars. The matter between the feldspar microlites is semi-isotropic, appearing like a devitrified glass rather more than like a changed augitic mineral. N. H. W. AND U. S. G.

No. 15. Diabase *(with olivine)*.

Duluth. A dike fifteen feet wide, running N. 25° W.
Ref. Annual Report, ix, page 14.

Meg. A medium grained, dense, apparently fresh, dark-colored rock glittering with cleavage surfaces of the pyroxene element, and with the striated feldspar, the latter, however, being less conspicuous and acicular in outline.

Mic. The *feldspar* has an average extinction, on 010, on a cleavage, of 25° to 28°. On the face 010, in convergent light a curved dark bar is the only portion of the interference figure that is visible. Most of the grains are in the form of lath-shaped twinnings, elongated parallel to the edge 001: 010; and extinction is not coincident on all portions of the separate lamellæ. This indicates some deformation since consolidation. By the statistical method the highest equal extinction angle on opposite sides of a line separating two twins is found to be 19°. This result agrees with the foregoing measurement on the cleavage in indicating labradorite, although the measurement on the cleavages seen in 010 seems to show a tendency toward bytownite.

After some search, some sections of this feldspar can be found showing, in convergent light, optic axes and bisectrixes. In the latter case, in two instances, it proves to be n_g (c) in one case not in connection with distinct cleavage, but in another on a face showing evident cleavages parallel with the striations, indicating that the section is nearly on 010. It is therefore the positive bisectrix appearing somewhat obliquely in the brachypinacoid, which is characteristic of the labradorites and bytown-labradorites. Many of the microlites are crossed nearly at right angles by a pericline twinning.

The *pyroxene* was later in crystallization than the feldspar, and embraces the feldspar. It extinguishes over considerable areas, often involving several detached parts. It is quite fresh, in some grains. The optic plane makes an angle of 4° to 5° with a distinct cleavage, and with a coarse parting an angle of about 40°. These measurements are made on the straightened dark bar crossing the interference figure of a single optic axis. On this figure, in blue light, the curved dark hyperbola is further dispersed than the same in red light, hence the red color lines the concave side, indicating, for this axis $\rho < v$, but as the dispersion in the monoclinic pyroxenes is inclined, these colors may be reversed in the interference figure, in the manner of their position on the hyperbolas.

After some search a small crystal of the augite is found perpendicular to a bisectrix. Its form is roughly that of a prismatic section, with a cleavage that nearly agrees with the position of extinction. This cleavage must therefore be that parallel to the brachypinacoid. Other cracks cannot be identified with certainty with any cleavage. In other sections nearly rectangular cleavages are frequent. The optic axes are carried beyond the field of the microscope, and are not brought within it by the use of methyl iodide as immersion liquid. This bisectrix is n_g (c), as shown by the use of the *teinte sensible.*

The *olivine* is almost entirely changed. The change consists in the formation of both serpentinous fibres and a great many minute crystallites of quartz, and calcite and of a ferruginous dark substance that may be magnetite. The olivines

thus changed show their nature sometimes by the remnants left of the original grains, and nearly always by their relation to the feldspars, which they preceded in origination. Although the changed olivine resembles somewhat the product of change from augite, these two are frequently alongside of each other without interpenetration. The figure below (figure 5), illustrates the different aspects of the augite and the olivine. It was drawn from No. 15 by camera lucida and shows the parts all magnified about seventy-five diameters. The changed mineral (olivine) is frequently closely associated with the unchanged (augite) in so much that in some instances, either by superposition or by some corresponding alteration in the augite, there is difficulty in separating them at a definite boundary. They both enclose irregular grains of magnetite. The olivines, however, crowd upon and indent the feldspars, though their forms are never perfect, while the augites, being later than both, are interrupted by their contours.

FIG. 5.

No. 1—Olivine.
No. 2—Augite.
No. 3—Labradorite.
No. 4—Magnetite.

Magnetite is in all forms, especially in angular to subangular sections, sometimes almost square, and in rods. These rods are sometimes between two minerals, or between cleavages, but they are also often sections of tabular sheets of magnetite. The largest amount of magnetite is within the decayed olivines.

One section examined.

Age. Manitou (?)

Remarks. This rock is noticeably contrasted with the eruptives which it cuts, in two respects: (1) It is not porphyritic nor amygdaloidal, but has a uniform granular structure. (2) It is comparatively fresh, with a preserved ophitic structure.

N. H. W.

No. 15A. Diabase *(with olivine)*.

Duluth. From the west side of the same dike as No. 15.

An ophitic diabase like No. 15, but here the augite is wholly lost by decay, and in its place is *chlorite* (or *penninite*) charged with magnetite. This change is not due to a simple weathering, but to the activity of super-heated water during the process of cooling. This *magnetite* is all plainly of that origin.

One section. N. H. W.

No. 16. Diabase (?) *(Amygdaloidal.)*

Duluth. A modification of Nos. 13 and 13A, extending (next east of the brewery) 125 feet.
Ref. Annual Report, ix, page 14.

Meg. A black, apparently much decayed, aphanitic rock with epidote amygdules.

Mic. The rock is composed of small lath-shaped *plagioclases*, between which is largely an opaque black substance (in part *magnetite*) *chlorite* and some small grains of *epidote*. This groundmass does not entirely exhibit the characters of an alteration from augite, and it is not improbable that the rock was originally glassy.

The amygdules, some at least of which appear to be pseud-amygdules, are filled with epidote and *quartz* in small grains.

One section.

Age. Cabotian. U. S. G.

No. 17. Tuff.

Duluth. From the series east of Minnesota point, near the old breakwater, east of the Brewery creek; extends twenty feet, having a dip 43° E.
Ref. Annual Report, ix, page 14; Annual Report, x, page 140; American Association for the Advancement of Science, vol. xxx, page 164; American Geologist, vol. xviii, pages 211–213.

Meg. A firm, granular, brown, fragmental rock.

Mic. At a glance at the thin section the fragmental character of this rock is apparent. The constituent grains are of two sorts, viz., lapilli and glass. The former are vesicular, their more minute cavities now being filled with a translucent mineral, and their framework charged with ferruginous matter, rendering it nearly opaque. The latter are similar to the former, but are sometimes translucent, or partly opaque and partly translucent. They differ from the lapilli in being simple instead of composed of a number of vesicular masses embracing several translucent areas. It appears that the rock was originally essentially a glassy tuff, composed of glassy vesicular lapilli and of angular or sub-rounded *glass* fragments.

Between crossed nicols the whole slide is nearly dark, which is due to the opaque, ferruginous products, the isotropic chloritic areas, and the possible remnants of the original glass. The only light particles, as seen between crossed nicols, seem to be of secondary *quartz* and *epidote*. They are very fine, and multiple, the former not affording sufficient area for the action of convergent light to form an interference figure.

There are no feldspathic or augitic fragments that can be detected, and judging from the persistent endurance of the minute feldspar microlites, at least in form, in the lavas and all the diabases of the series, it is necessary to conclude that they never existed in this rock. An abundant cement of *calcite* is distinguished by its iridescent polarization.

Ordinary erosion and sedimentation could hardly produce such a rock, and although it has a slaty or bedded structure which suggests sedimentary action, it is probable that the ocean had but little to do with its origination. Its dip is coincident with that of the lavas and amygdaloids of the immediate vicinity. Its stratiform arrangement may have been the product of oceanic forces in spreading out the debris of volcanic ejection.

Three sections examined.

Age. Cabotian.

Remarks. Although some of the former numbers of this series (Nos. 8A, 8B, 7B) have already been described as probably of tuffaceous origin, this rock is the first which has been met with presenting positive characters of that kind. Indeed, it is the first positively identified tuff in the so-called Keweenawan. N. H. W.

No. 18. Diabase *(with olivine)*.

Duluth. East of the Brewery creek, and east of Minnesota point, at the lake shore. Over this comes down a little creek; this rock extends perhaps 300 feet, nearly into the bite of the next little bay, and at the eastern limit of the exposure it has a dip easterly of 26°.

Ref. Annual Report, ix, pages 14, 16; Annual Report, x, page 36.

Meg. A much decayed, rusty-green, finely-granular, massive but remotely-jointed rock. On the weathered surfaces it is finely pitted by the loss of some mineral, apparently olivine. In other places it is amygdaloidal, and in others it crumbles like a rotted shale. It appears, in the field relations, like a surface flow of diabase. Its weight indicates a considerable percentage of magnetite.

Mic. Microlitic *feldspars* are frequently reddish, from ferruginous oxidation; no coarser feldspars present.

Augite shows, though much altered and in general without its original forms, occasionally its ophitic relation to the feldspars.

Olivine, though conspicuous in the section, is changed to an almost isotropic chloritic substance, yet which sometimes is finely fibrous, a fact which is seen on lowering the lower nicol. These grains are the most conspicuous in the slide. They show, by the dark lines of ferruginous matter, the original cleavages of the olivine.

Quartz is a product of alteration, sometimes arranged radially, surrounding chloritic masses.

Magnetite is usually plainly of secondary origin, and is disseminated widely.

One section examined.

Age. Cabotian.

Remarks. This rock seems to fall into the class named melaphyr by Pumpelly. It is similar to No. 6A, in its petrographic characters. N. H. W.

No. 18A. Vein Matter in No. 18.

Duluth. From laminations in No. 18.
Ref. Annual Report, ix, page 14.

Meg. Light greenish yellow and white, granular, but mingled apparently with more or less rock matter. Apparently largely composed of a honey-like garnet and calcite.

Mic. Besides *garnet* and *calcite* the microscope reveals *quartz*, *magnetite* and titaniferous magnetite, and *apatite*, and, further, a little *gold (?)* The *magnetite* is in very fine particles, visible only microscopically, an alteration product. The *titaniferous magnetite* is in larger grains which are frequently surrounded by a rim of gray sub-opaque substance, which is taken for *leucoxene*. In some cases such dark grains are mostly changed to such sub-opaque substance. This mineral does not appear in the midst of the calcite and garnet, but in those portions which are probably rock fragments. They are microscopic rods and angular masses. They are associated with *quartz*, *epidote* and secondary minute magnetite grains. A fine, white fibrous mineral is probably *tremolite*. The small amount of gold present is associated with the garnet. The only particles seen were subjected to nitric acid and remained bright. The particles having been lost in the examination, the existence of gold in this vein matter requires further evidence.

Two sections. N. H. W.

No. 19. Zirkelyte. *(Amygdaloidal.)*

Duluth. At the lake a short distance west of Chester creek, suddenly replaces No. 18 on the east and extends about 200 feet.
Ref. Annual Report, ix, page 14. Annual Report, x, page 36. Annual Report, xiii, pages 100, 102. Bulletin viii, page xxxiii.

Meg. A compact, almost aphanitic rock, of a dull reddish or brown color, with a few scattered, brick-red feldspars a quarter of an inch long, but not enough to warrant the unqualified term porphyryte for the rock. There are also some scattered amygdules now filled with what appears to be epidote. These amygdules are from very minute size to one-half inch across.

Mic. Rock is composed of minute interlocking laths of *feldspar*, in a confused mass of magnetite grains, yellowish granules (apparently of *epidote*) and some *chlorite*. One of the larger feldspar crystals is seen in the section; it contains small flakes of a *muscovite*-like mineral. In general these larger feldspars are striated. The brownish red color is evidently due to the fine dissemination of *hematite*, which colors most of the transparent grains. There is visible no ophitic structure, although

fine linear crystallites are common. *Magnetite* in fine grains is scattered everywhere. A dirty greenish or grayish mineral can be seen abundant in the vicinity of the magnetite, resembling that seen in No. 18A, probably the result of alteration of the magnetite, and indicating its titaniferous nature.

The rock contains also some *quartz*, in minute granules embraced in the general trachytic areas, also a mono-axial mineral darkening with the nicols which appears to be *apatite*.

One section examined.

Age. Cabotian.

Remarks. This rock has been grouped by the Minnesota Survey in the series of "red rocks." The microscopic characters seem to indicate that this is not correct. The following chemical analysis* shows the rock is rather lower in silica than the most of those rocks.

SiO_2	57.50
TiO_2	.....
Al_2O_3	13.29
Fe_2O_3	11.62
FeO	4.54
MnO	.....
CaO	6.12
MgO	1.63
K_2O	0.80
Na_2O	1.85
H_2O	1.48
Total,	98.83

N. H. W.

No. 19A. Calcite and Epidote.

Duluth. From a large concretion in No. 19.
Ref. Annual Report, ix, page 14.

Meg. A mass of epidote, calcite, a light-gray, soft rock and a dark greenish rock.

Mic. The section is largely a mass of calcite grains in which is considerable epidote in small crystals and grains and some quartz. A little chlorite is present, as is also magnetite. Scattered through the calcite is a gray opaque substance, which at times is arranged so as to give the calcite a zonal structure.

One section.

Age. Concretion in Cabotian rocks. U. S. G.

No. 20. Zirkelyte. *(Amygdaloidal.)*

Duluth. A tougher condition of No. 19. Embraces angular masses of No. 21, and extends about forty feet.
Ref. Annual Report, ix, page 14.

Meg. A dark aphanitic rock containing a few red porphyritic feldspars. The rock is thickly strewn with small vesicles which are in part empty and in part contain epidote, and sometimes quartz or calcite..

Thirteenth Annual Report, p. 100.

Mic. Only two small fragments of the porphyritic *feldspars* are seen in the section. These are untwinned and are considerably altered; one contains a grain of *epidote*. The amygdules are filled largely with *quartz*, with some *epidote* and a little *chlorite*. One amygdule contains some *calcite*. The rest of the rock is composed of minute feldspar laths and a very fine grained confused mass of magnetite, chlorite, epidote and opaque matter. It seems probable that the mass of the rock outside of the feldspars was originally a *glass*.

One section.

Age. Cabotian. U. S. G.

No. 20A. Tuff.

Duluth. Embraced in No. 20.
Ref. Annual Report, ix, page 14.

Meg. An aphanitic, brownish gray rock, looking some like a hardened shale. It seems to be the same as No. 8A, which see.

No section.

Age. Cabotian. U. S. G.

No. 21. Tuff.

Duluth. Overlies No. 20, extending fifteen feet.
Ref. Annual Report, ix, page 14.

Meg. Laminated like a shale, also fine grained, of a light green color, but stained in spots with iron oxide. Apparently a fragmental rock.

Mic. This rock varies in relative prevalence of the fragmental parts, making it appear varigated with light and dark. Scattered throughout are sharply angular bits of quartz lying in a confused, fine matrix of granular devitrified glass. This *glassy* element is sometimes much finer than throughout the most of the section, having been originally in the form of an ash or dust. Again, on the other hand, some areas in the section are remarkably coarse, but these all consist of the same elements. The glassy particles are sub-rounded, clouded by hematite or by other opaque impurities, or are changed to a green chloritic substance. In all cases it is practically dark continually between crossed nicols. Rarely a feldspar microlite appears in one of these grains, and still more rarely they seem to be of the nature of lapilli. Such is a grain in which is much *magnetite*, with only a few translucent specks. In one translucent, quartz-looking grain an interference figure indicating the bisectrix (n) was discovered in making examination in convergent light.

One section.

Age. Cabotian.

Remarks. This is not a typical volcanic tuff, but a subaqueous deposit of tuffaceous material. The contrast in contour between the sharply angular quartzes (and plagioclases) and the rounded glassy matter is the most striking and inexplicable feature of this rock. Indeed, it is of all these Duluth tuffs. N. H. W.

Zirkelyte. Diabase. Tuff.]

No. 22. Zirkelyte. *(Amygdaloidal.)*

Duluth. Overlies No. 21. Extends about 300 feet along the lake shore.
Ref. Annual Report, ix, page 14.

Meg. A dark gray, aphanitic rock confusedly mottled with black and yellowish areas, the latter apparently containing considerable chlorite. The rock thus seems to be an amygdaloid.

Mic. The main part of the section contains many minute *feldspars*, mostly lath-shaped, in and between which is a confused fine-grained aggregate of *magnetite*, *chlorite*, *epidote*, *leucoxene*, and apparently a little *quartz* and *calcite*. The rock is much altered, and it is thought to have originally contained some glassy material, although this is not certain. Scattered through the section are amygdules, or rather pseud-amygdules, which contain quartz, chlorite, epidote and calcite. Much of the quartz shows distinct undulatory extinction, thus indicating that the rock has been subjected to pressure or strain since the quartz was deposited in the cavities.

One section.

Age. Cabotian. U. S. G.

No. 23. Diabase *(with olivine)*.

Duluth. From a dike which cuts No. 22, fifteen feet wide, running north and south. Compare No. 8C.
Ref. Annual Report, ix, page 14.

Meg. A fine grained, brownish black rock.

Mic. *Feldspar*, not much stained, appears in lath-shaped microlites, and in the angular interspaces is seen the remaining stage of the *augites* which are considerably, though not entirely, altered to chloritic and ferruginous products.

Olivine, in the same manner, appears in the form of greenish spots, which are accompanied by magnetite, but these differ from those resulting from augite, in the fact that they crowd on the shapes of the feldspars, having preceded the feldspars in date of formation.

One section.

Age. Probably Manitou. N. H. W.

No. 24. Tuff.

Duluth. Next east of the dike represented by No. 23, with laminations of green. It is coarser than No. 17, dips 35° to 40° easterly, and extends fifty feet along the beach.
Ref. Annual Report, ix, pages 14, 15; American Geologist, vol. xviii, pages 211–213.

Meg. Apparently a fragmental rock of a brown, granular appearance, but without evident silica grains.

Mic. The slide is made up of irregularly shaped areas of lighter and darker rock, the latter being apparently embraced in the former. The dark areas are frequently rounded but not wholly. Some are elongated and more rough, and some of them are themselves vesicular. The minerals in these dark areas are *magnetite*,

epidote, calcite and an isotropic substance which is greenish and similar to that which frequently follows an alteration of olivine or augite. These areas are darker, apparently, because of the greater proportion of the magnetite. The matrix which embraces these darker areas consists of about the same secondary minerals, with also much devitrified *glass*, but having less of the greenish isotropic substance and less of the magnetite. Also, the opaque substance has more frequently the color of hematite than of magnetite. Quartz is not wanting, but is very scarce.

Two sections examined.

Age. Cabotian.

Remarks. This rock, when collected, like several others obtained in the immediate vicinity, was considered a shale belonging to the sedimentary series. It is not probably wholly, nor perhaps chiefly, due to erosion of other rocks, but its general stratiform structure points to the action of oceanic forces in giving distribution to a fine ash, in which were mingled also larger masses of a vesicular rock of the same nature as the ash, but probably of the origin of volcanic lapilli. N. H. W.

No. 25. Zirkelyte. *(Amygdaloidal.)*

Duluth. Occurs twenty feet east of No. 24 and extends 100 feet.
Ref. Annual Report, ix, page 15.

Meg. A brownish aphanitic rock in which are many amygdules, some of which are half an inch across. The amygdules contain much epidote; especially are the outer layers of the amygdules of epidote. Calcite, sometimes in crystals of considerable size, also occurs, as does a soft, greenish, clay-like material.

Mic. The section is too thick for careful study. It is composed almost entirely of quartz and an opaque greenish yellow substance. The section was evidently cut from one of the amygdules.

One section.

Age. Cabotian. U. S. G.

No. 26. Diabase *(with olivine, altered).*

Duluth. A rocky point near the old Fishery.
Ref. Annual Report, ix, page 15.

Meg. The rock is aphanitic and almost black. Its most noticeable feature is the presence of numerous red areas which at first appear like porphyritic feldspar crystals. But on closer inspection these areas are seen generally not to possess crystal outlines; they are in fact very irregular in outline and are not rounded like amygdules. The red material exhibits no cleavage surfaces; it is easily scratched with a knife, and effervesces with cold nitric acid. There are also other less sharply defined yellow areas (epidote), and the lens shows that these yellow areas, often of minute size, extend all through the rock. Two rounded areas of calcite are seen in

the hand specimen. Sometimes these red and yellowish elements are united in the same spot, the former surrounding the latter, and occasionally the red spots show distinctly a twinning on the albite plan.

Mic. The rare porphyritic *feldspars* are much decayed, showing quartz and hematite, and apparently calcite, as resultant minerals, the iron probably derived from the surrounding matrix, yet they are distinctly striated in some places and undoubtedly they resulted from the cooling of a molten basic magma. Throughout the rock are also microlitic plagioclases.

The *augitic* element is so changed that it cannot be identified as such, but the products of change from augite are the only evidence of its former existence (see No. 27).

That *olivine* was originally in the rock, is shown by the roundish green chloritic, isotropic areas, crossed by the ferruginous bands that indicate the original cleavage of that mineral. These areas crowd on and displace the crystalline boundaries of the feldspars, showing their earlier date.

A micro-chemical test was made on the red element, not showing definite crystalline characters, and the only result was the appearance of fluosilicate of lime with very rare hexagonal rods of the same salt of soda. The conclusion to be drawn from these facts seems to be that the feldspar was a lime-soda plagioclase. In decay it has given up its soda, its lime has given rise to calcite, and, with the formation of a little quartz, the forms of the plagioclases have been lost, a red stain involving not only the remnant of the plagioclase itself but spreading irregularly through the surrounding rock, thus converting a porphyritic feldspar into irregularly shaped areas of a red color.

One section examined.

Age. Cabotian.

Remarks. This rock seems to be one of the series of eruptives extending along the shore eastward of Minnesota point, mingled with amygdaloidal and tuffaceous material. The red stain, which usually is evidence of the proximity of some of the clastics of the Animikie and of the fusion, or at least the wide dissemination of some of their elements in the basic eruptive, cannot certainly be attributed to that cause in this rock. Yet it is also equally impossible to exclude that agency in the change of these feldspars—a change that took place, probably, mainly while the rock was yet hot, a period during which both gas and water must have permeated the eruptive, carrying out such chemical alterations as were fittest to the nature of the attacking agent. N. H. W.

No. 27. Diabase *(with olivine)*.

Duluth. A dike cutting No. 26. This dike changes its direction twice. It leaves the lake in a direction east and west, but on ascending the rocky bluff it immediately changes to W. 15° S. It runs so about eight feet and shifts again to nearly west.

Ref. Annual Report, ix, page 15.

Meg. Very fine grained and dark; not porphyritic.

Mic. Fine feldspathic microlites lie in the midst of the usual ferro-magnesian and magnetic minerals. This rock differs in one particular from many of the associated and similar rocks already described. A considerable amount of *augite* still remains. This is colorless and shows alteration to greenish to colorless grains, which often have borders of *magnetite*. These grains are fibrous in structure, have a low extinction angle, and polarize in rather bright colors. They are referred to *hornblende*. In No. 26 there is no augite, but the hornblende grains are very abundant and are similar to those in No. 27.

One section.

Age. Probably Manitou. N. H. W. AND U. S. G.

No. 28. Diabase *(with olivine)*.

Duluth. Next east of No. 27.

Ref. Annual Report, ix, page 15.

Meg. Fine grained but scantily porphyritic with the earlier plagioclases. This rock is quite similar to No. 27, but when collected it was considered the continuation of the rock on the easterly side of the dike represented by No. 26. It has an evident bedded dip, extends 300 feet and passes, on the east, under No. 29.

Mic. This rock differs from No. 26 in wanting the irregular red areas, but it shows some scattered *red feldspars*. At the same time it very closely resembles No. 27.

Age. Cabotian.

Remarks. Nos. 26, 27 and 28 are lithologically closely allied, but structurally they are widely separated. No. 27 is a dike which cuts the rock Nos. 26 and 28, these two being from opposite sides of the dike. It is only on the ground of these structural relations that the dike is classed as probably Manitou and the other as probably Cabotian. N. H. W.

No. 29. Basalt. *(Amygdaloidal.)*

Duluth. Apparently the amygdaloidal upper portion of No. 28; about five feet thick.

Ref. Annual Report, ix, page 15.

This rock is much altered to *epidote*, and it crumbles in the weather. Microscopically it differs none from several that have been described.

Age. Cabotian. N. H. W.

No. 30. Sandstone. *(Pyroclastic.)*

Duluth. Rock next west of Mallmann's dike, east of the old Fishery. Extends 400 feet.

This rock shows non-conformable stratification or cross-bedding, perhaps separated by igneous eruptions and lava flows in other places. One part dips but little, and the other part dips east 30° south, and in amount about 15° or 20°. It varies from a brownish, siliceous sand rock to one that is greenish and aluminous.

Ref. Annual Report, ix, pages 15, 20; Annual Report, x, page 36.

Meg. A thinly bedded, grayish or greenish rock, of homogeneous grain and aspect.

Mic. The section shows a fragmental structure, and a composition mainly of particles referable to eruptive agencies. These grains consist of *quartz*, titaniferous *magnetite* (changed to *leucoxene*), *plagioclase*, *epidote*, *sphene*, and devitrified *glass*. These are cemented together by *chlorite*, *calcite* and probably some *hematite*. There are a few grains that have the appearance of having been derived as particles from a glassy rock.

Two sections.

Age. Cabotian.

Remarks. This rock is probably of sedimentary origin, even by erosion. There cannot be distinguished any lapilli, as a product of explosive action, but the particles consist almost entirely of mineral fragments frequently rounded as by beach friction.* N. H. W.

No. 31. Diabase *(with olivine)*.

Duluth: from Mallmann's dike.

Ref. Annual Report, ix, page 15.

Meg. Fine-grained, nearly black. Similar to Nos. 7D and 15.

Mic. Ophitic relation of the *feldspars* to the augite (or the devitrified glass) is conspicuous at a glance. They are twinned, lath-shaped, and although more stained with hematite than the feldspars in No. 15, their large extinction angle (about 28°) indicates that they are probably labradorite. Sections cut parallel with the tablets (*i. e.*, about parallel to 010) exhibit sometimes a zonal or shelly structure.

The *augite* (?) is entirely changed to a greenish substance, with accumulation of much magnetite. It is impossible to affirm what portion of this ophitic substance was originally augite—perhaps none of it. It appears that in some cases, after the crystallization of the feldspars, the rest of the magma never gave birth to augite, but, being consolidated in a more or less glassy condition, has afforded products that are undistinguishable from altered augite, and this may be the case in many others of these rocks.

Olivine, though giving a product very similar to that of augite, yet shows the following differences: (1) The earlier original independent crystalline form is apt to be preserved. (2) The magnetite accumulates along the original cleavages, or

*Compare "Volcanic ash from the north shore of lake Superior," by N. H. Winchell and U. S. Grant. *American Geologist*, vol. xviii, pp. 211-213. October, 1896.

fissures, and hence appears more frequently in lines. The border is also always heavily charged with magnetite as well as these fissures, leaving one or more central areas free from magnetite; while in the decay of augite the secondary magnetite appears more uniformly throughout the grain often as a fine powder or in particles of some size. (3) The greenish substance that takes the place of these minerals is apparently, in chemical composition, the same in one as in the other, but in the case of olivine the alteration product is apt to show a finely fibrous structure. (4) In this slide a further noticeable difference consists in the presence of considerable hematite with the magnetite, in the changed augite, and the almost entire absence of this mineral in those changed grains that are unmistakably derived from olivine. These differences are not always pronounced, and do not always coexist, but by one or more of them usually the original olivinitic nature of the rock, pro or con, can be determined.

Hematite, as already noted, is quite abundant, not only in the form of fine powder staining the feldspars, but in company with the magnetite in the grains that have resulted from the change of the pyroxenic mineral, where it appears as brownish red microscopic crystalline scales and groupings. Such hematite groupings appear dull red in ordinary light, both transmitted and reflected, but when the stage is rotated in strong reflected light they show minute reflecting surfaces which reappear at the proper angles.

Calcite is seen in isolated patches.

Two sections examined.

Age. Probably Manitou. N. H. W.

No. 32. ZIRKLEYTE.

Duluth. At the lake shore, east of Minnesota point, on the east side of a fault.
Ref. Annual Report, ix, page 15.

Meg. A very fine-grained rock, dark brown in color, spotted with clusters of green epidote or epidote and chlorite.

Mic. This is a very fine basalt in which the minute *plagioclases* are lath shaped and rarely twinned beyond two lamellæ, and embraced ophitically in the now changed matrix, which was probably glassy.

Magnetite is abundant.

With the *epidote* and *chlorite* filling the amygdaloidal (?) spots, is a little *quartz*.

One section examined.

Age. Cabotian. N. H. W.

No. 32A. ZIRKELYTE. *(Weathered modification.)*

Duluth. Taken from No. 32 near the top of the bluff, where it becomes reddish-brown and breaks into angular blocks of a few inches.
Ref. Annual Report, ix, page 15.

Vein matter. Aporhyolyte.]

Meg. A fine-grained, brown-weathered condition of No. 32. Perhaps was at first largely of *glass*. It is now permeated with *epidote* and *calcite*. N. H. W.

No. 32B. Vein Matter *(from No. 32)*.

Ref. Annual Report, ix, page 15; Annual Report, x, page 141.

Greenish, fine grained, consists of *epidote*, *calcite*, *quartz*, *leucoxene*, some of the last showing the *sagenite structure*, *plagioclase* (albite ?). These minerals all appear as fragments, somewhat rounded, and without any evidence of vein structure.

One section. N. H. W.

No. 33. Amygdaloid.

Duluth. About sixty feet east of No. 32, on the east side of a fault, near the lake level. The cavities and the fissures have been generally filled with epidote and calcite, with a layer of greenish segregated material, probably delessite, lining each cavity nearest the rock.

Ref. Annual Report, ix, page 15.

No section. N. H. W.

No. 33A. Aporhyolyte (?)

Duluth. From patches in No. 33.

Ref. Annual Report, ix, page 16.

Meg. A reddish compact aphanitic rock with a few apparent amygdules. On one side two of these extend out from the rock, and appear somewhat like pebbles.

Mic. Very minute *feldspar* microliths are scattered through a groundmass which is composed of irregular ill-defined areas of *quartz*. This quartz contains the microliths and the minerals of the groundmass poikilitically (see No. 42). The rest of the groundmass, aside from the quartz, is composed of *epidote*, *chlorite*, *magnetite* and minute red particles (hematite).

One section.

Remarks. It is not certain just what this rock is, but it is thought to be a devitrified lava, perhaps as acid as a trachyte.

Age. Cabotian. U. S. G.

No. 33B. Porphyryte. *(Amygdaloidal.)*

Duluth. Taken from the stratigraphical equivalent of No. 33.

Ref. Annual Report, ix, page 16. Proceedings American Association for the Advancement of Science, vol. xxx, page 164.

Meg. A brown, very fine grained rock, containing many red, porphyritic feldspars; also considerable epidote.

Mic. The section is poor. It shows very few of the porphyritic feldspars, and these are highly altered. The groundmass contains small lath-shaped feldspars and the usual alteration products. There is also present a considerable amount of very fine grained material between these feldspars. This probably is largely quartz.

One section.

Age. Cabotian. U. S. G.

No. 34. Amygdaloid.

Duluth. Near the mouth of Chester creek.
Ref. Annual Report, ix, pages 16, 20.

Overlies No. 33B, and is about fifteen feet thick, the two passing gradually into each other across the bedding. This is a beautifully specked and spotted amygdaloid, some of the concretions being white (one-half to one inch across), some red (one-fourth to one-half inch), some green (one-fourth inch), and some with a red centre enclosed in a green coating. The rock itself is so altered that it is impossible, in the thin section at hand, to identify the original minerals. It can only be said that a reddened twinned plagioclase whose general forms are still sometimes quite distinct, is distributed idiomorphically amongst the other minerals. The matrix consists of chlorite, magnetite, altered glass, hematite, quartz.

Two poor, very small sections examined.

Age. Cabotian. N. H. W.

No. 34A. Concretions, etc. *(from No. 34).*

Ref. Annual Report, ix, page 16.

The red amygdules are colored by *hematite*, which seems to be distributed with slight reference to any crystalline structure or form. It is occasionally in parallel or radiating coarse fibres. The rest of the section is largely made up of a light-greenish chloritic substance which is so fine that it appears dark, like an amorphous substance, or when coarser affords an aggregate polarization. This chloritic substance pervades the whole mass, except where a few grains of quartz or of calcite have been generated. The hematite seems to be distributed through this chloritic substance. With the exception of a few irregular grains of *magnetite* and of *epidote* which are independent of the hematite, this constitutes the nature of these red amygdules. The white concretions are of *quartz* or partly of *calcite*.

In some parts of the slide the forms of the hematite indicate that it has taken the place of some fibrous or radiated mineral. Some of these amygdules, when stained red, have a *calcite* matrix, which, when they are broken, shows its cleavage distinctly. Both the calcite and the quartz sometimes embrace the red material in a micro-poikilitic manner.

Two sections examined.

Age. Concretions in Cabotian surface lava. N. H. W.

No. 35. Diabase *(with olivine).*

Duluth. Near the mouth of Chester creek, on the west side.
Ref. Annual Report, ix, pages 16, 17.

Meg. A hard, reddish imperfect amygdaloid, with numerous natural seams which cause it to part easily in all directions without affording a fresh fracture; a

layer twelve feet thick; much decayed; fine grained; evidently a phase of the same rock as No. 34.

Mic. The feldspar is reddened, lath-shaped, and idiomorphically distributed amongst the other grains, which, however, are none of them in their original condition. They consist of *magnetite, hematite, chlorite, glass (?), epidote, leucoxene.* In strong polarized light (the same is less evident in natural light) and high powers the whole section glitters with bright specks, either sericitic or chloritic, or with fibres which appear to be serpentinic. This effect is hightened by lowering the polarizer. Even the opaque grains of magnetite are thus seen to be impure. They are more or less involved in this iridescence, and enclose minute parts of the minerals for which they are substituted. This is another evidence of their secondary nature. Most, if not all, of the magnetite in the section is of this character. The only evidence of original titaniferous magnetite, or of ilmenite, consists in occasional gray sub-translucent grains which are apparently *leucoxene.*

One section.

Age. Cabotian. N. H. W.

No. 36. Diabase (?)

Duluth. West side of Chester creek.
Ref. Annual Report, ix, page 16.

Meg. Hard, gray, or brownish-gray, fine-grained, and fresher condition of the eruptives at the mouth of Chester creek, a basic trap with alternating and irregular belts of amygdaloid.

Mic. The *feldspars* are very fine and lath-shaped, lying ophitically amongst the more or less altered pyroxenes and the remnants of the magma.

The *pyroxene* occasionally shows its bright polarization colors. The sections show much of the light-green, amorphous substance supposed to result from residuum from the magma.

Two sections.

Age. Cabotian. N. H. W.

No. 36A. Diabase (?) *(Amygdaloidal.)*

Duluth. Amygdaloidal porous condition of No. 36, from the upper portion of the bluff immediately west of the mouth of Chester creek. This porous condition occurs in layers or belts in No. 36.
Ref. Annual Report, ix, page 16.

Meg. An aphanitic brown to reddish rock in which are numerous cavities of all sizes up to those a quarter of an inch in diameter. These cavities sometimes contain epidote, and this mineral also permeates almost the whole rock.

Mic. The slide is made up of numerous *feldspar* microliths in a groundmass which is composed of *magnetite*, in large amount, and an almost colorless isotropic substance. Under a high power this isotropic substance is seen to be greenish,

fibrous *chlorite*. The cavities of the rock are in part filled with *epidote* and a little chlorite, and the former mineral is found in abundance in the groundmass. The groundmass shows no evidence of having contained augite, and it may have been originally *glass*. No. 36, however, of which 36A is a part, contains augite.

One section.

Age. Cabotian. U. S. G.

No. 37. Diabase (?)

Duluth. At the shore immediately east of Chester creek, standing up like a dike.
Ref. Annual Report, ix, page 16.

Meg. Compact, fine, basaltiform, with some large geodic concretions; pyritiferous; extends four rods. This rock is not essentially different from No. 36, but has spots of calcite and epidote. It is more decayed and contains more numerous gray grains that are semi-opaque and seem to be *leucoxene*.

One section.

Age. Cabotian. N. H. W.

No. 37A. Calcite.

Duluth. From a concretion in No. 37.
Ref. Annual Report, ix, page 16.

Meg. The hand specimen is a large mass of well crystallized *calcite*. On one side of the specimen is some *epidote* and *hematite*.

No section.

Age. Concretion in Cabotian eruptives. U. S. G.

No. 38. Diabase.

From a dike east of the mouth of Chester creek. This dike runs north and south, and hangs toward the east 10°. It is eighteen feet wide. On the west side the adjoining rock has been hardened and rendered similar to the dike in external aspect. This dike cuts the foregoing eruptive sheets.
Ref. Annual Report, ix, page 16.

Mac. The rock is fresh and gray, medium grained, evidently a basic rock of the gabbro family.

Mic. The *feldspars* are embraced ophitically by the pyroxenes. A section perpendicular to the bisectrix (n_g) gives extinction on cleavage at 25° to 28°, and on macles at 0° to 2°. The optic plane, determined by the greatest curvature of the hyperbola in a section nearly perpendicular to an optic axis, makes an angle, with cleavage, of about 12°. If this section be near 001 the measure indicates *labrador-bytownite*. If it be near 100 the indication lies between *andesine* and *labradorite*. A tabular section showing distinct cleavage is taken for 010, and extinction on it is 25° and on another 30°, also pointing to labrador-bytownite. (This cleavage, in the first case, is not parallel with the macle. Many of the microlitic feldspars are crossed by such cracks, sometimes at right angles to their elongation and sometimes obliquely.)

Graywacke. Diabase.]

The *pyroxene* in the body of the rock is ophitic and tolerably fresh. A vein or fissure of later date crosses the section, and this is filled with *chlorite* scales standing vertically on the sides of the fissure. This chlorite, in some instances, spreads more widely, affecting chiefly the pyroxene. In many cases this chlorite is in leaves, favorably cut, and shows a strong pleochroism.

Magnetite is in angular masses, as if it had taken the position of some mineral, or of a residuum of the magma, since the consolidation of the feldspars. It is also in fine particles in the altered pyroxenes.

The good preservation of this rock, in contrast with the sheets of eruptive rock about Chester creek, the latter cut by the former, seems to prove a shorter period of exposure for the dike or better protection from the atmosphere.

One section examined.

Age. Manitou. N. H. W.

No. 39. Graywacke. *(Breccia.)*

Duluth. On the east side of the dike, No. 38. Extends thirty-five feet, and dips east.
Ref. Annual Report, ix, page 16.

Meg. The most of the hand specimen is composed of a fine-grained siliceous rock, which might be called graywacke. It has pyrite crystals disseminated through it. It has on one side, and was apparently surrounded when *in situ* by a very different kind of rock. The appearance is as if a gray siliceous breccia had a cement of a basic eruptive.

Mic. The rock is made up of fine angular and sub-rounded fragments of *quartz* and *plagioclase*, and of devitrified *glass*, with a few scattering grains of *pyrite*, and a few larger areas of secondary quartz. Except in its much greater content of quartz this included rock is similar to some already mentioned, viz.: Nos. 7B, 8B, 21 and 30. Its fragmental manner of occurrence in the lava is also similar.

Two sections examined.

Age. Inclusion in Cabotian eruptives. N. H. W.

No. 40. Diabase *(with olivine).*

Duluth. East of Chester creek, at the lake shore, about forty feet east of the dike, No. 38. Hard, firm beds, in thin contorted layers, varying in durability and in color, some greenish and some brown, some nearly black. The whole is fine-grained, compact, of a dark grayish or brownish color.
Ref. Annual Report, ix, pages 16, 17.

Meg. Compact, rather fine grained, occasionally with a porphyritic feldspar crystal, and other colored spots. Undistinguishable from numerous others that outcrop between this point and Rice's point.

Mic. The texture does not present the strong idiomorphic characters seen in the feldspars of No. 38, yet it is an ophitic rock. The *pyroxene* is changed to the usual decomposition products. *Chlorite, magnetite* and *hematite* abound.

One section examined.

Age. Cabotian. N. H. W.

No. 41. DIABASE *(with olivine, in basaltic columns).*

Duluth. Across a little bay, east from the last. Basaltic rock, the columns dipping about 10° from the perpendicular toward the northeast. Varies from a texture like that of No. 7C, to a finer grain, much like No. 43. Adjoins No. 50 on the east.

Ref. Annual Report, ix, pages 17, 18.

Meg. A tolerably fresh, medium grained, dark, basic rock, showing a polysynthetic feldspar, magnetite and a pyroxene.

Mic. The feldspar is *labradorite,* its extinction angles on opposite sides of a twinning line being as high as 25° and 27½°, and 31° and 33°.

Pyroxene is generally well preserved and exhibits a characteristic relation to the feldspars. It is in the form of *augite.* Some of it was at first taken for olivine, owing to its generation earlier than the feldspars, as evidenced by its independent outlines. In some instances the earlier and the later augite grains are associated in groups, in which their different relations to the surrounding feldspars are contrasted. In order to determine these earlier grains more certainly, the slide was uncovered, washed with turpentine to remove the Canada balsam, then with alcohol, and lastly with water. It was then immersed in hydrochloric acid during about eighteen hours, in order to convert it, if olivine, to gelatinous silica. The slide, after washing again in water was then covered with iodine green and left for twenty minutes. When examined for gelatinous silica, none was found; at least those augites which most clearly maintained their independent outlines were found unattacked, and as clearly polarized light as before the test. Other grains absorbed the color, some of them being probably *olivine* and others remnants of the magma uncrystallized. The latter were originally greenish, and chloritized. This is the first rock in which we have distinguished augite amongst the early generations from the magma. It is still more interesting that it was also later than some of the feldspars. In one instance, indeed, a single augite grain can be noticed, which is ophitic toward one feldspar crystal and idiomorphic toward another.

Olivine. There appears to be some later olivines which can hardly be distinguished from pyroxene, except by a careful noting of the cleavage and extinctions. They are both colorless or faintly straw yellow, and their double refraction, in a section of ordinary but unknown thickness (though less than 0.03 millimeters), is so nearly the same that the interference colors are not characteristic. Two sections were found, however, perpendicular to an optic axis and showing two cleavages per-

pendicular to each other, in which extinction takes place parallel to the cleavage cracks. One cleavage was distinct, even marked, and the other was imperfect. These grains, therefore, unless they be of augite cut in the zone of symmetry, must be of olivine, cut in the zone 100:010, and the cleavages those parallel to the prism and to the base 001. The oldest olivines, which were numerous, are wholly changed to magnetite and the usual green products.

Magnetite is not only in the fresh and undecayed pyroxenes, but also in the feldspars, though less commonly. It is most abundant in connection with the greenish grains which are now chloritic, and in this situation it is very often the result of a change from other substances, probably, in the main, from the older olivines whose forms are outlined by the chloritic areas. Although a part of the magnetite seems to date from the magmatic state of the rock, no distinct cubic outlines are perceptible.

Apatite needles pierce the feldspars in great numbers and are in the other minerals.

Chlorite masses are common and seem to have the form of the olivinitic grains of the earliest generation.

Quartz is present in scattered grains, so sharply separable from the surrounding minerals that it has the appearance of being an original secretion from the magma. Were the rock much decayed this quartz might be taken for a secondary product; but the rock is quite fresh.

One section examined.

Age. Cabotian.

Remarks. Another section of this rock, made later, brings out some characters not before distinguishable, viz.: some of the green "chloritic" masses are green hornblende instead of chlorite. These hornblendes are derived from or accompanied by a chloritization apparently of the early olivines. Through them run the magnetite accumulations, marking the irregular cleavages of olivine, and these are also seen in the chlorite areas, though here they do not follow so exactly the old cleavages. The hornblende cannot be said, correctly, to have epigenized on the chlorite, although these two are sometimes found in the same grain so related as to suggest that origin; but probably they are nearly cotemporary growths after olivine. In a single case a brown hornblende forms a part of a border of an augite.

Brown remnants of the glassy magma are also discernible. This rock is so strikingly like the great dikes at Grand Portage bay (Nos. 248, 253) that it seems necessary to classify it with them. Its structure and composition even conspire to warrant the designation *hornblende gabbro*. It is hence of Cabotian age, and an eruptive that preceded the Manitou. This is evidently a heavy surface flow allied to the Beaver Bay diabase but of later date, or a sill in the Animikie now denuded.

N. H. W.

No. 42. Aporhyolyte (?)

Duluth. Four blocks north of the depot.
Ref. Annual Report, ix, pages 12, 17. Annual Report, x, pages 62, 109. Annual Report, xiii, page 40.

Meg. An aphanitic rock of a reddish brown color. Scattered through it are very small reddish porphyritic feldspars and irregular areas of epidote and of a darker mineral, probably chlorite.

Mic. The most striking feature of the rock is that under polarized light it breaks up into irregular interlocking, often not sharply outlined, areas of quartz. (This is similar to, but more pronounced than in No. 33A.) The whole rock is composed of these quartz areas holding the other materials poikilitically. This structure has already been described many times in altered igneous rocks; it has been described by Irving* from the lake Superior rocks, and recently Miss Bascom† has discussed this structure from the rocks of South mountain. In the latter article are many references to other descriptions.

The porphyritic *feldspars* are very much altered. They in no case show polysynthetic twinning; however, some of them are so highly altered that no trace of this twinning could be expected to remain.

A few *quartz* grains, not showing crystal outlines, but possibly representing corroded quartz phenocrysts, occur. Frequently the quartz of the groundmass in the immediate vicinity of one of these grains has the same orientation as the grain.

Throughout the section are small particles of magnetite, chlorite and epidote, and red stains and specks (hematite).

Two sections.

Age. Cabotian.

Remarks. Because of the nature of the groundmass, which is similar to that found in altered acid lavas, the presence of quartz which was possibly porphyritic, and the apparent orthoclastic nature of the porphyritic feldspars, this rock is thought to represent an altered acid lava, most probably a rhyolyte. The name aporhyolyte is applied in accordance with the usage proposed by Miss Bascom.‡ No. 42 is similar to No. 45; also No. 850.

U. S. G.

No. 42A. Concretion *(in No. 42).*

Duluth.
Ref. Annual Report, ix, page 17.

Meg. This concretion seems to grade into the mass of the rock through a siliceous periphery. The concretion, which is two and a half inches in diameter, is composed almost entirely of finely crystallized epidote.

No section.

Age. Concretion in Cabotian rocks.

U. S. G.

* *U. S. Geol. Survey, Mon. v*, pp. 99, 100, plate 13, figures 13, 14, 1885.
† *Journal of Geology*, vol. i, pp. 814-817, 1893.
‡ *Loc. cit.*, p. 825.

No. 43. Diabase.

Duluth. On the hill slope, back from the base of Minnesota point, in front of the engine house. Width and form of this rock could not be made out. Surface rounded over by glaciation. Apparently has a dip east 30° north. Approximately the equivalent of No. 6A, and of No. 44 ′, and perhaps of No. 41.

Ref. Annual Report, ix, pages 12, 17. Annual Report, x, pages 107, 109.

Meg. Generally of very uniform character, but in some places finely porphyritic with a red feldspar.

Mic. The *feldspar*, without further specification, may be said to be a plagioclase, and probably labradorite. It is much changed, showing secondary microlites of various sorts.

The *pyroxene* is also much changed, some of it being entirely lost, but some still plainly preserving sufficient of its molecular structure to give the high polarization colors characteristic of thick sections.

Olivine grains are quite common, but largely serpentinized so as to give an aggregate polarization. They are the favorite gathering-places for magnetite which forms strings and reticulations marking the original irregular cleavages of the olivine. It is apparent that in some cases olivine grains have been entirely replaced by magnetite. These olivine grains preceded the feldspars in generation, although they do not now manifest perfect crystalline outlines.

A considerable portion of the section is occupied by a mineral substance now changed so as to give a similar aggregate polarization, but coarser. This is apparently the same that was described in section No. 41 as uncrystallized magma. Toward this the feldspars are idiomorphic but it also spreads widely throughout the slide.

Magnetite is common, and apparently is entirely a secondary product, occupying the place of either olivine or of pyroxene.

Chlorite scales are sparse in the changed feldspar, but more common as a product of decay of the pyroxene and in the masses of undifferentiated magma.

Pyrite in fine grains is seen occasionally.

Age. Cabotian, allied to the Beaver Bay diabase. N. H. W.

No. 43A. Diabase *(with olivine)*.

Duluth. Same locality as No. 43.

Ref. Annual Report, ix, page 17.

Meg. A fine-grained diabase with small, red, porphyritic feldspars. The red color also penetrates somewhat into the mass of the rock.

Mic. The rock is essentially like No. 43, of which it is a part. However, most all of the feldspar is reddish. The porphyritic feldspars are very highly altered, but some of them still show traces of polysynthetic twinning.

One section.

Age. Cabotian. U. S. G.

No. 44. Mica Schist. (*"Black Rock."*)

Duluth. From the top of the hill at the head of First Avenue East. Very fine grained, black, like a basalt. Apparently this is what has been known later as "the black rock."

Compare Nos. 1966 and 1967.

Ref. Annual Report, ix, page 17.

Meg. Even with a loop nothing can be seen that would distinguish this rock, in the specimens at hand, from a very fine diabase.

Mic. But under the objective, and especially between crossed nicols, it is seen at once to be very different from any of the fine-grained rocks so far described. It has no ophitic structure, but is finely granular, with many translucent areas resembling *quartz*. These are of irregular shapes, but sometimes several contiguous darken simultaneously, as if they had the same crystalline orientation. In other areas the darkening comes on in spots and disappears in the same way, showing several independent grains. In general, finally, this same mineral (quartz) seems to extend as a cementing framework throughout the section, being invisible in other places on account of the presence of brightly polarizing or of opaque grains of other minerals. The interference figure, so far as seen, consists of a broad straight bar which crosses the field, indicating a uniaxial mineral.

Besides the foregoing are two other principal minerals which make up much of the rock. One is entirely opaque and black, and on reflecting surfaces has the metallic lustre of *magnetite*. It is scattered promiscuously as a powder, with no definite crystalline form, or is aggregated into granular masses of some size, the cement even then being the same quartz. The other is in very fine grains or scales which, in ordinary transmitted light, give a brown-gray coloration when they are frequent and superposed, somewhat resembling in this respect the color of *biotite*. Between the crossed nicols they extinguish four times in a revolution. Sometimes they show an elongation, but usually they are of irregular shapes and of sub-oval or orbicular angular outlines. When they are lengthened the extinctions take place parallel to the elongation. Sometimes they are aggregated in sufficient thickness to give a polarization color of reddish-yellow or of light blue, but their principal effect is to darken the matrix of quartz in which they are intimately embedded.

While these are the principal minerals there are also *calcite* and *epidote* in small amounts.

One section examined.

Age. Taconic (Animikie).

Remarks. This rock is the same as rock No. 1, of the series collected at Duluth by Prof. A. Lacroix, in 1888, deposited at the College de France. The biotite has the forms and relations to the quartz characteristic of "contact" mica as distinguished from granitic mica and the mica of gneissic rocks, *i. e.*, it embraces the quartzes,

instead of being embraced by them. Its forms are secondary to the quartz. This is true of the original quartz grains, yet there is a secondary quartz also, which surrounds some of the biotite grains. This latter is that which spreads widely and constitutes apparently the matrix. It contains bubbles.

It is difficult to find a suitable name for this rock. Its relations to the gabbro and to "red rock" are interesting and important, and will be found discussed in Part III. N. H. W.

No. 44'. Diabase.

Duluth. Top of Kinichigaguag falls. Apparently the eastward extension of No. 43, and a part of No 41.
Ref. Annual Report, ix, page 17.

Meg. This rock consists of plagioclase in lath-shaped forms, very fine, and of a changed pyroxene, with magnetite and chlorite.

One section.

Age. Cabotian. N. H. W.

No. 45. Aporhyolyte.

Duluth. From a ravine between No. 44 and No. 1B which is further north on the hill.
Ref. Annual Report, ix, page 17.

Meg. An aphanitic, reddish brown, compact rock, holding small, red, porphyritic feldspars. There are also scattered through the rock, small areas, sometimes showing crystalline outlines, of a black mineral.

Mic. In all essential characters this section is like No. 42. However, epidote does not seem to be present in No. 45, and the porphyritic *feldspars* are in part not so highly altered. None of these feldspars show polysynthetic twinning, although many of them are so highly altered that no trace of this twinning would remain even if it was originally present. The least altered of these porphyritic feldspars show untwinned and simply twinned crystals. The alteration of these crystals is usually toward chlorite, and some of them are entirely replaced by this secondary mineral. Where this replacement has been entire the crystal appears black in the hand specimen.

One section.

Age. Cabotian.

Remark. This rock is similar to Nos. 42 and 850. U. S. G.

No. 45'. Slate (?) *(Altered.)*

Duluth. Foot of Chester Creek falls.
Ref. Annual Report, ix, page 17.

Meg. An aphanitic, dark, almost black rock, streaked with gray and reddish.

Mic. The section is a confused mass of *quartz*, *magnetite*, *chlorite*, *epidote* and *calcite*. The quartz, which is in minute interlocking grains, forms the background of section. Magnetite occurs in irregular grains and in minute dust-like particles.

None of the minerals, except some grains of epidote, show any crystal outlines. The magnetite and chlorite are in some places more abundant than in others, thus giving an indistinct mottled appearance to the slide. The calcite sometimes spreads widely with the same orientation, embracing numerous grains of the quartz and of the magnetite.

One section.

Age. Animikie.

Remark. It is impossible to state definitely what was the origin of this rock. It is thought to be a slate, or very fine graywacke. The groundmass of crushed and stretched quartz porphyries frequently resembles this section, but in this case there is no evidence of the remains of old phenocrysts, nor of dynamic action in the rock, nor in the associated strata. The overlying rock No. 44′, occupies the position of a sill similar to those in the Animikie along the boundary. U. S. G. AND N. H. W.

No. 46. Basalt. *(Zirkelyte.)*

Duluth. Brewery creek.

Ref. Annual Report, ix, page 180. Annual Report, xiii, pages 100 (No. 151), 102. Annual Report, xi, page 39.

Meg. A black aphanitic rock thickly strewn with porphyritic crystals of dark red feldspar. Epidote has pervaded the rock to some extent, sometimes partly replacing the phenocrysts and sometimes occurring in small areas in the groundmass. On one corner of the hand specimen is an area of finely crystallized quartz about one half an inch in diameter. This is surrounded by a narrow green rim which contains some epidote, and outside of this is a wider rim of epidote which is not very sharply separated from the mass of the rock.

Mic. The porphyritic *feldspars*, which are such a characteristic feature of the hand specimen, and which constitute nearly one-half the rock mass, are imbedded in a groundmass which is composed of minute plagioclase laths and a black opaque substance appearing like *glass*. The feldspar of the groundmass and also of the porphyritic crystals is highly altered and reddened, and its exact composition cannot be determined; but, judging from the analysis of the whole rock given below, both of these feldspars are quite basic plagioclases. In some cases they still show the remains of polysynthetic twinning, although usually altered too highly to show this.

The black glass-like material on examination with a high power is seen to be composed almost entirely of black specks (magnetite) and chlorite. It seems most probable that this substance was originally glass.

Epidote and *chlorite* have both pervaded the rock in irregular patches.

One section shows part of an area similar to the quartz area described on the hand specimen. This is made up of epidote, quartz, chlorite, *calcite* and magnetite. In one part of the area the quartz, calcite and magnetite are arranged concentrically.

Two sections.

Granite and gabbro. Diabase.]

Chemical analysis. This analysis was made by Prof. James A. Dodge, and was first published in the Thirteenth Annual Report, page 100 (No. 151).

SiO_2	48.81
Al_2O_3	23.27
Fe_2O_3	11.80
FeO	3.66
CaO	5.15
MgO	1.72
K_2O	.75
Na_2O	2.38
H_2O	2.53
Total	100.07

Age. Cabotian. U. S. G.

No. 46′. Red Granite and Gabbro *(contact of)*.

Duluth. Weller road, south side of hill. Showing contact of No. 1B and No. 1.

Ref. Annual Report, ix, page 18. Annual Report, x, page 142. Proceedings American Association for the Advancement of Science, vol. xxx, page 165.

Meg. The specimens show two rocks in contact. One is a fine grained granite composed of red feldspar, quartz, epidote and hornblende. The other is dark colored and made up almost entirely of plagioclase; in places it contains long thin crystals of this mineral. A few reddish feldspars are also seen in the gabbro. The two rocks are closely welded together and the granite extends in vein-like forms into the gabbro, thus showing it to be at least a little younger than the gabbro.

Mic. The section shows both rocks. The *granite* is made up of *quartz* and *red feldspar*, with some *epidote*, *hornblende*, *magnetite* and *chlorite*. The feldspar, like the usual orthoclase or anorthoclase of these red acid rocks of the Cabotian, is much altered and completely filled with minute dust-like red particles (hematite). The gabbro is essentially composed of plagioclase, somewhat altered, and not very distinctly separated into grains and twinning lamellæ under polarized light. Throughout this plagioclase and embraced poikilitically by it, are scattered grains and rough rods of magnetite; also chlorite and grains of brownish hornblende.

The junction of the two rocks is quite a distinct line, and there is no mingling of the elements of one with the other, except that the red stain of the feldspar of the granite has, just at the contact, penetrated to a small extent the feldspar of the gabbro.

One section.

Age. Cabotian. U. S. G.

No. 47. Diabase *(with olivine)*.

Duluth. From a dike, same as No. 7C, from on outcrop on Superior street.

Ref. Bulletin ii, page 110. Annual Report, ix, pages 12, 18.

Meg. Medium grained, showing a plagioclase, a pyroxene, magnetite, pyrite, and occasionally a spot reddened by hematite; a massive homogeneous rock of the gabbro series.

Mic. The description of No. 7C applies well to this rock, except that it is less decayed. It might be added that the generally fresh condition of the rock, and the contrast between the undecayed augite (sometimes *diallage*) and that which is presumed to be a changed condition of the pyroxenic element renders it doubtful whether the pyroxenic element has really suffered this change. It provokes the query why such change should attack some of the grains and continue to total obliteration, and leave the rest wholly fresh. The *augite* in this section shows numerous grains cut so as to show optic axes and bisectrices in the field of the microscope, and occasionally an optic normal. The decayed, now chloritic, substance may be a condition of the residuum of the magma.

Olivine is quite common in the slide and is distinguishable from the augite by the fact that its boundaries encroach on all the other minerals, by its slightly darker tint of yellow in common light and by the irregularity of its cleavages. It is further distinguished, when a bisectrix can be found perpendicular to the plane of the slide, by the axial angle being about 90°. In the case of augite the smaller axial angle is much less than 90°, and the larger one much more. One such bisectrix (n_p) occurs in the slide examined. The olivines are quite fresh in this rock, but in No. 7C they are much altered.

The *magnetite* is angular and fresh, as if an original secretion from the magma.

One section.

Age. Manitou? (but possibly a feeder to the Cabotian sill No. 44′.)

Remark. The freshness of some of the augite in the thin section, contrasted with the completeness of the alteration in some of the other ophitic, greenish substance, suggests the possibility that the alteration product does not arise from augite. Its evident late date in the generation of the various minerals shows that it can have arisen, if not from augite, only from a non-differentiated portion of the original magma. Again, the freshness of the olivine rather precludes the supposition that the augite may have suffered so much. N. H. W.

No. 48. Basalt.

Duluth. Second street, corner Fourth avenue east. This runs from in front of C. Markell's house, under the Hayes block. It is a large member, at least 150 feet thick, and apparently falls between Nos. 7 and 6C.

Ref. Annual Report, ix, page 18. Annual Report, x, page 38.

Meg. Close grained and firm, hard, bluish gray to black, heavy, not visibly amygdaloidal, but finely and sparsely porphyritic.

Mic. The groundmass is made up of microlitic feldspars and magnetite. Evidently several other minerals are also present, but they are too fine, and the section (too thick at best) is too much decayed in general to warrant any attempt to differentiate them. The section shows a portion of a tabular crystal of a porphyritic

feldspar, likewise charged with impurities. The rock has the appearance of a basalt, but it is not impossible that it is a condition of the "black rock" mentioned under No. 44. It contains, however, no observable quartz, or very little, and the feldspars are distinctly idiomorphic in the midst of the other grains.

Age. Cabotian.

Remark. This rock falls into the category of which Nos. 6C and 7 are other examples. If, as the field notes record, this falls into the unobserved interval between Nos. 6C and 7, it shows a thickness of at least 200 feet of such rock. The note already made, under "remarks," in connection with No. 7, is even more applicable to this rock. It is necessary further to call attention to the great thickness of this dense black rock. In that respect it resembles the outcrops on Piedmont avenue (Nos. 1966 and 1967), and, as an eruptive amongst clastics or as a surface lava, it ought to manifest considerable more variation in texture. While, therefore, No. 48 is classed with Nos. 6C and 7, with the basalts, it should be noted that there are certain structural reasons, and some anomalies unexplained, as yet, which render that reference questionable, and which seem to point to an alliance with rock like No. 44, or Nos. 1966 and 1967, *i. e.*, to the action of the basic eruptives on the black slates of the Animikie, and hence to a greater age than the Cabotian.

Remark. Another section, made thin, shows that this rock is a micro-crystalline basalt, in which there is still a considerable amount of isotropic glass. Among the minerals may be distinguished feldspar, augite, olivine, much magnetite, while an isotropic substance, probably resulting from glass, renders the whole slide very nearly dark between crossed nicols. N. H. W.

No. 49. Diabase *(with olivine)*.

Duluth. Behind the M. E. church, between Second and Third streets, and Third and Fourth avenues west.

Ref. Annual Report, ix, p. 18; Annual Report, x, p. 139; Proceedings American Association for the Advancement of Science, vol. xxx, page 162; Bulletin ii, p. 108.

Meg. A rather coarse diabasic rock, of black color; some of the feldspars are grayish and a very few inclined toward a pink color.

Mic. The description of Dr. Wadsworth (Bulletin ii, page 108) is as follows: "The section is granitic in texture and composed of lath-shaped, somewhat kaolinized feldspar, magnetite, brownish augite, greenish pseudomorphs of serpentine after olivine bearing much magnetite, apatite, viridite, pyrite and quartz. Of these the only original minerals are the feldspar, augite, olivine and part of the magnetite."

One section.

Age. Cabotian; allied to the Beaver Bay diabase. U. S. G.

No. 50. Lava. *(Vesicular.)*

Duluth. Next east of No. 41.
Ref. Annual Report, ix, pages 17, 18.

Meg. A reddish-brown, aphanitic rock with many vesicles which are in part empty and in part filled with calcite. The specimen also contains fragments of other rocks. A few small, red, porphyritic feldspars are also seen; dip, E. 10° S. 18°; extent about 150 feet.

Mic. The section is very thick, but on its edges it can be seen to be made up of a transparent background in which are crowded specks and grains of a red material, probably *hematite*. Where the section is thicker this red material renders it completely opaque. Under a high power and in polarized light the background breaks up into a very finely crystallized aggregate of *quartz*. It is possible that some of this background is feldspathic, but no feldspar could be determined. In small areas the red material becomes much decreased, or entirely lacking, and here the quartz is in larger interlocking grains. The few porphyritic feldspars seen in the slide are much altered, but seem to be *orthoclase*. While the original nature of this rock is not clear, it still seems likely that it was a highly vesicular, probably rather acid lava.

One section.

Age. Cabotian. U. S. G.

No. 51. Diabase. *(Porphyritic.)*

Duluth. From a point, the next one beyond No. 50. Extends 200 feet. Sometimes rises twelve feet perpendicular from the water.
Ref. Annual Report, ix, page 18.

Meg. A fine-grained, brown rock made up of small, reddish feldspars, a dark, almost black, substance, and epidote. There are a few porphyritic red feldspars, and some larger areas with narrow, red periphery and dark interior. These latter, perhaps, represent large tabular feldspars which have been largely replaced by chlorite. One of these is three-fourths of an inch in diameter.

Mic. The section is composed of small lath-shaped *plagioclases*, which are much altered and reddened. Between these crystals are *quartz*, *magnetite*, *calcite*, *chlorite* and some *epidote*. *Apatite* needles also occur in the rock. The most characteristic feature of the section is the large amount of quartz in distinct grains. This fills in the spaces between the feldspars, and occasionally a considerable area is seen to be covered by quartz of like orientation; thus the quartz sometimes embraces the feldspars poikilitically. One section has on its edge a part of one of the porphyritic feldspars. This is reddened, much altered and contains some chlorite, and on the edge of the section it passes into an area of almost pure chlorite. It thus seems very probable that the large black areas already mentioned in the hand specimen represent

feldspars replaced by chlorite, although we have no complete section of one of these dark areas.

Two sections.

Age. Cabotian.

Remark. The structure of this rock allies it with the diabases. The quartz is regarded as secondary. In almost every particular this rock resembles No. 7. An analysis of No. 7 is given and there are also some remarks concerning the origin and nature of the rock. In the field this rock disintegrates into small angular pieces according to innumerable weather joints. U. S. G.

No. 52. Basalt *(or zirkelyte).*

Duluth. Underlying No. 51, to which there is, in the field, a gradual transition, and overlying No. 53. This rock makes three heavy layers, or beds, each bed being finely and closely basaltiform, the columns being set so as to constitute layers running west 10° north, and east 10° south, from an inch to two inches in thickness, in position perpendicular to the heavy bedding. They were doubtless produced by the baking effect of No. 53, which comes on suddenly.

Ref. Annual Report, ix, pages 18, 19; Annual Report, x, pages 109, 110.

Meg. Apparently a dense, black diabase, contacting with cooler rocks. There is great uniformity of aspect in this rock. It shows in some parts a finely disseminated microlitic feldspar, and in others such feldspar is wanting entirely. It has much pyrite in isolated fine specks, and occasionally in form of a thin seam.

Mic. Sections made from this rock differ somewhat in fineness of grain, and in the amount of *quartz* present, but they are essentially the same. In some of the sections the feldspars are quite well formed, though small, the *augite* can with some uncertainty be identified, and the *magnetite* and spongy *pyrite* are abundant, particularly the former. There is a brown amorphous and isotropic glassy remnant of the magma which in the angles between the feldspars acts ophitically about them. *epidote* is gathered sometimes, in these coarser portions of the rock, in the pseudamygdaloidal areas, and in other small areas quartz appears. *Apatite* crystals pierce the section in all directions.

Other thin sections evidently come from more glassy portions. The *feldspar* crystallites are identifiable only occasionally as straight openings amongst the aggregated globulites of magnetite and augite(?) or olivine(?). When the section is highly magnified the magnetite globules appear crowdedly immersed in the glassy matrix, and occasionally are ranged so as to form fine thread-like crystallites.

Between crossed nicols the sections are nearly dark constantly, owing to the prevalence of the glassy magma.

Three sections.

Age. Cabotian.

Remark. Nos. 50, 51 and 52 are allied in the field and in petrographic characters. The first and the last are coarser grained, and have much more quartz. No.

51 lies between them. They were probably all cooled at or near the surface, and they show the volume of the basic and glassy floods which occurred at or near the surface in Cabotian time in the vicinity of Duluth. N. H. W.

No. 53. Diabase *(with olivine)*.

East Duluth. At the lake shore, N. W. ¼ sec. 24, T. 50–14. Has a basaltic structure.
Ref. Annual Report, ix, p. 19; Annual Report, x, p. 139; Bulletin ii, pp. 106, 107; American Association for the Advancement of Science, vol. xxx, p. 162.

Following is Wadsworth's description:

"This is microscopically a dark-gray, compact crystalline rock, showing lath-shaped feldspars. Microscopically the section is seen to be composed of a brownish *augite, feldspar, olivine, magnetite, apatite,* and various secondary products. The augite shows the ophitic structure first described by M. Michel Lévy,* and later by professor Pumpelly under the name 'lustre-mottlings.'† Attention has further been called to this structure by professors A. Geikie,‡ R. D. Irving§ and J. W. Judd.‖ This structure consists of a large irregular area or various areas all belonging to the same augite or diallage individual and cut by lath-shaped divergent feldspars. In one form or another this structure is very common in the diabases, and usually is the form of crystallization standing next to the granitic, in its coarseness of texture, or one step nearer the fine-grained basalts. Many of the preceding described rocks show the ophitic structure more or less perfectly, but not so well as this section. The olivine is altered for the most part to greenish, yellowish brown, brownish yellow and black serpentine, containing secondary magnetite sometimes marking the former olivine fissures. Considerable dirty green viridite and secondary apatite occur in the section, while some secondary biotite was observed in the vicinity of the magnetite. The augite in places has the secondary cleavage of diallage."

Age. Probably one of the Cabotian eruptives of the Taconic. See *remarks* under No. 52, etc. N. H. W.

No. 53A. Diabase *(with olivine)*.

Duluth. Same locality as No. 53.
Ref. Annual Report, ix, page 19.

Meg. A decayed, earthy condition of No. 53.

No section.

Age. Cabotian. U. S. G.

* *Bulletin Société Geologique de France*, 1877 (3), vol. vi, p. 156.
† *Proceedings American Academy of Arts and Sciences*, 1878, vol. xiii, p. 260.
‡ *Transactions Royal Society*, Edinburgh, 1880, vol. xxix, p. 495.
§ *The Copper-Bearing Rocks*, 1883, p. 42.
‖ *Quarterly Journal, Geology Society*, 1885, pp. 360, 361; 1886, p. 68.

No. 53B. Diabase. *(Modified.)*

Duluth. N. W. ¼ sec. 24, T. 50–14. From the longest rocky point; a part of No. 53, but here containing some flesh-red crystals, making it resemble No. 5.

Ref. Annual Report, ix, page 19; Bulletin ii, page 107.

Mic. The section shows a rather coarsely crystalline rock quite similar to No. 5, except that it seems to embrace more *quartz*. The grains of this quartz are sometimes of considerable size. They are both irregular in form and also sharply angular. In the latter case the quartz embraces in an ophitic manner portions of the reddened feldspars and some of the greenish products of decay from other minerals. It also encloses *apatite* and *magnetite*. This shows it to be of later origin than these minerals, but these minerals themselves, excepting, perhaps, the apatite, are not original, as shown by numerous observations already noted. While taking part, therefore, in the general transformation during the cooling process, quartz was the latest of the secondary minerals to take its place. The presence of quartz here, and not in most other cases of such change, is to be assigned, as in No. 5, to the proximity of some of the clastic rocks which afforded it in connection with the general metamorphism resultant from the cooling period when hot, and hence silicified waters would have been abundant.

The *apatite* has every appearance of being one of the earliest crystallizations. It is not only in the greenish and serpentinous grains resulting from change in pyroxene, and perhaps from olivine, but it is in the unchanged or comparatively pure pyroxene and in the feldspars, whether the latter be reddened or entirely fresh. Its spicules are large and persistent, and sometimes very long. Its sections, perpendicular to the principal axis, are numerous and hexagonal. The fact, mentioned by Wadsworth in description of No. 6, that apatite when "entirely enclosed" in secondary quartz is probably of secondary origin, seems not sufficient to prove it so, but, on the contrary, simply shows it was of earlier date than the quartz. In the section, as stated, while it is perhaps more common in the vicinity of, and embraced in, the secondary minerals, it is not confined to them. Some conspicuous spicules penetrate the freshest of the feldspars. Its prevalence in the decayed minerals is probably due to its previous greater abundance in the pyroxenic grains.

Biotite in small scales is rare in connection with the alteration products.

Two sections examined.

[Evidently Wadsworth's description assigned to No. 53B is of some other rock.]

Age. Cabotian.

Remarks. This rock resembles No. 5. It thus connects No. 53 with the age of the great gabbro, or eruptive epoch, that closed the Animikie, and in that respect again points to the eruptive origin of the doubtful rock No. 52 and its equivalents, as the surface expression of the great Cabotian eruptive revolution. Compare the description of rocks Nos. 854G and 854aG, and the accompanying remark. N. H. W.

No. 54. Diabase.

East Duluth. From a dike three and one-half feet wide, associated with others, cutting No. 53 in a direction N. 50° E., forty rods east of No. 53B.
Ref. Annual Report, ix, page 19.

Meg. A black, fine-grained diabase.

Mic. Lath-shaped *feldspars* occur imbedded in *augite*, alteration products of the same, and black opaque material, much of which is *magnetite*.

One very poor section.

Age. Probably Manitou. U. S. G.

No. 55. Aporhyolyte.

East Duluth. In the bite of a little bay, continuing half a mile, by the coast, becoming broken and slightly amygdaloidal. It is reddish, angularly and finely jointed, sometimes a jaspery-looking rock; overlies No. 54; sometimes dips at 60° N. E.
Ref. Annual Report, ix, pages 19, 20; Bulletin ii, page 118.

Mic. This rock is like the red elements in No. 53B, but is finer grained. This remark applies to the gray, or slightly reddish-gray, portions, of which one section is examined.

Another section, numbered 55, and evidently from that part of No. 55 which in the field description was considered jaspery, is almost wholly red, but had originally amygdaloidal spots which are now filled with *quartz* having various orientation.

Quartz is also otherwise widely disseminated. This is a finer-grained rock than the last, but evidently a portion of the same mass more altered.

Two sections.

Age. Cabotian. N. H. W.

No. 55A. Quartz *(from No. 55 in concretions.)*

Duluth. Same locality as No. 55.
Ref. Annual Report, ix, page 19.

Meg. A red-brown, very fine-grained, earthy rock, irregularly blotched with darker areas. Scattered through the rock are areas of quartz mixed with and surrounded by brick red material, which is a little redder in color than the main mass of the rock. A few small porphyritic red feldspars are also seen.

Mic. The section is very thick, but seems to show a rock essentially like No. 50. The section shows one area of coarsely crystalline *quartz* into which extend small prisms of a brown to black opaque substance, which in reflected light is red like the mass of the rock. These prisms in outline and general relation to the rock and to the quartz remind one of the epidote crystals which are so common in such situations, and it is not impossible that they are altered epidotes. There is, however, no trace of the original epidote substance in any of the prisms.

One section.

Age. Cabotian. U. S. G.

Aporhyolyte. Diabase. Vein material.]

No. 56. Aporhyolyte (?)

Duluth. A condition of No. 55.
Ref. Annual Report, ix, page 19.

Meg. Almost exactly like No. 55A, except that the porphyritic red feldspars are more abundant.

Mic. This rock is similar in general aspect to Nos. 50 and 55A, but the background of the rock, instead of being composed of quartz in minute grains, is made up of larger areas of quartz holding the other materials poikilitically. The slide contains one small black mass which is composed of black granular material (magnetite), in which are a few feldspar microliths and one highly altered feldspar phenocryst.

One section.

Age. Cabotian. U. S. G.

No. 57. Diabase.

East Duluth. From a dike cutting No. 56, which is said to be a condition of No. 55, running N. 5° E., four feet wide.
Ref. Annual Report, ix, page 19; Final Report, i, pages 196–199.

Megascopically this is a brownish, dark, compact and fine-grained rock.

Microscopically it is an ordinary diabase, consisting of lath-shaped *plagioclases* and pyroxenic element much obscured by change. *Magnetite* is abundant and *hematite* rare.

One section.

Chemical analysis. The following analysis was made by Prof. J. A. Dodge and first published in the Final Report, vol. i, pages 198, 199:

SiO_2	48.51
Al_2O_3	13.79
FeO, Fe_2O_3	19.34
CaO	8.34
MgO	4.81
K_2O	0.19
Na_2O	1.67
Total	96.65

The specific gravity was found to be 2.95 by one determination, and 3.005 by another.

Age. Manitou. N. H. W.

No. 57A. Vein Material.

Duluth. Just east of No. 57, from another dike.
Ref. Annual Report, ix, p. 19.

Meg. A roughly laminated mass of quartz, calcite and a dark green chloritic material. Evidently from a vein.

Mic. The sections show aggregates of *calcite*, *chlorite*, *hornblende (?)* and finely crystallized *quartz*. A considerable amount of *ilmenite*, largely altered to *leucoxene*, is also present.

Three sections.

Age. Vein material in a Manitou dike. U. S. G.

No. 58. Porphyryte. *(Diabase.)*

Duluth. On the lake shore, a little west of the line between ranges 13 and 14. Extends 15 rods. Sometimes rises in a bluff twenty-five feet high.
Ref. Annual Report, ix, page 20.

Meg. A dark-brown, fine-grained rock consisting of small feldspars in a darker background. Porphyritic plagioclases, of a light-brown to pinkish color, are abundant. Minute bright red spots or stains are seen throughout the rock.

Mic. This rock is quite similar to some already described (Nos. 7BC, 46). The large *plagioclase* phenocrysts are embedded in a groundmass which consists of minute lath-shaped feldspars in a mass of alteration products—*magnetite, chlorite, calcite, quartz* and red material (*hematite*). It is not improbable, although not at all certain, that augite was originally present in the groundmass. There are some areas now filled by chlorite and magnetite which probably represent *olivine*. A red hematite stain pervades the rock in places and extends into cracks in the phenocrysts.

One section.

Age. Cabotian. U. S. G.

No. 59. Amygdaloid.

East Duluth; east of Tischer's creek; small outcrop in the shingle of the beach, having an apparent dip west.
Ref. Annual Report, ix, page 20.

Meg. The amygdules are filled with green epidote, white calcite and quartz, and the rock itself is porphyritic with red feldspars. It is also veined by quartz and epidote, making an attractive rock; contains fragments of a foreign rock, apparently a tuff.

Mic. The large reddened *feldspars* are sometimes zoned, and twinned polysynthetically. The microlites are adjusted to greenish areas, which have apparently resulted from a change of *pyroxene* to *chlorite*. The minerals are all stained with *hematite*.

Age. Cabotian. N. H. W.

No. 60. Porphyryte. *(Diabase.)*

East Duluth. From a little rocky point and round the bay immediately west of London. This rock forms a high and continuously rocky shore.
Ref. Annual Report, ix, page 20.

Meg. Reddish-brown, finely crystalline, frequently jointed, hardly amygdaloidal or porphyritic, becoming amygdaloidal in patches and coarsely concretionary, containing nests of dog-tooth spar.

Mic. Lath-shaped *feldspars* are abundantly distributed in an ophitic surrounding, which, while possibly originally pyroxene, is now a reddened secondary mineral which polarizes in the aggregate manner characteristic of a mineral wholly altered. The chloritic products usual after such a decay of pyroxene are almost

Calcite. Amygdaloid. Tuff.]

wanting. *Hematite*, and especially *magnetite*, have accumulated in these areas, the latter disposed in parallel bars, as if it occupied the spaces of former cleavage openings. Indeed in some places the prismatic cleavage of a *pyroxene* is simulated in the angles presented by these rods of magnetite. The feldspars are also sometimes somewhat colored by a hematitic powder, and usually are much affected by incipient alteration, which renders it useless to attempt to further define them than to say that they are probably *labradorite*.

The *pyroxene (?)*, changed as above described, was a very abundant ingredient, on the supposition that the grains which embrace the feldspars ophitically, and are reddened by hematite, are of pyroxene.

Olivine, now wholly serpentinized so as to give a close, greenish, almost opaque, polarization, is quite common in this rock. These grains are uniformly embraced in a coating of magnetite, and sometimes they are colored within by hematite.

One section.

Age. Cabotian.

Remark. The interesting feature about this rock is the fact that instead of chloritic secondary products, as a result of alteration of the pyroxene, the product is reddish and brownish, with very little and often no chlorite visible. It may hence be of the nature of a residuum of the magma. N. H. W.

No. 60A. Calcite.

Duluth. Same locality as No. 60.
Ref. Annual Report, ix, page 20.

Meg. "Dog-tooth crystals of calcite which occur in a finely-jointed or brecciated condition of No. 60, which occurs suddenly, like a dike, extending up and down across the face of the bluff. This breccia is about twenty feet wide and the characters of No. 60 return on the east of it." The crystals contain a considerable amount of impurities. The largest crystal is near two and a half inches in length.

No section.

Age. Calcite crystals in Cabotian porphyryte. U. S. G.

No. 60B. Amygdaloid.

East Duluth. West of London. Same place as No. 60.
Ref. Annual Report, ix, page 20.

This is an amygdaloidal portion of No. 60. Besides abundant calcite the amygdules contain *epidote*, resinous *garnets (?)* and *quartz*.

No section. N. H. W.

No. 61. Tuff. *(Submarine.)*

East Duluth. Six rods west of a massive overhanging bluff, and at the eastern limit of No. 60, two feet thick, in a lot of thin beds, with a definite dip of 24° in a direction N. 60° E.
Ref. Annual Report, ix, page 20; American Geologist, vol. xviii, pages 211–213.

Meg. Evidently a clastic rock of rounded and sub-rounded grains, in a thin or shaly stratification, some of the individual grains being lighter and some darker than the general tone of the specimen, which is a light brown, varying to a grayish, with a tint of green. Some of the larger pieces, which are also the darker ones, are apparently from some aphanitic rock. Ready effervescence follows the application of a small drop of hydrochloric acid.

Mic. The rounded grains are of various composition, but the major part of them consist largely of *quartz*, perhaps mingled sometimes with a little mica and a little plagioclase. This quartz may be distinguished in two categories:

1. Clear limpid quartz, the grains apt to be somewhat angular, supposed to be a primary portion of the grit accumulated to form the rock; not common.

2. Quartz derived from an alteration of volcanic glass. This appears in three conditions:

(a) As clear quartz with a single orientation, constituting a border that surrounds a more or less confused and cloudy nucleus; some of the larger grains are of this character.

(b) As quartz more or less clouded and flecked by minute opaque particles, such quartz occupying the whole area of a grain, and with one or with several orientations.

(c) As microlitic or globular quartz, the minute globules not having crystal outlines nor clearly separate orientation, but crowded and grouped in the central parts of grains which (as in *a*) have clear quartz in their peripheries, or in some other places.

Calcite forms some of the rounded grains, some of it showing the peculiar, marked cleavage characteristic of that mineral. It is also sometimes as an important part of the devitified grains.

Other grains are made up now of a greenish substance, probably some form of *chlorite*, which occasionally has a finely fibrous structure perpendicular to the circumference of the grain. This, however, is generally destitute of such a structure. It is but slightly less abundant than the silicified grains.

Rarely a grain is simply gray, and semi-opaque, and its nature cannot be determined.

Magnetite and *pyrite (?)* are not common, though a ferruginous dust which appears to be of hematite or of magnetite, is scattered generally through, not only some of the individual silicified grains, but more abundantly in the finer matrix.

The most striking feature of the slide, as seen under the microscope, with a low power, is the non-resolvable nature of most of the grains, though sufficiently translucent to show light.

Two sections.

Diabase. Basalt.]

Age. Cabotian.

Remark. Two other sections, made very thin, show still further the volcanic origin of much of this rock. It consists almost entirely of devitrified glass and of rhyolitic fragments, the latter showing their fluidal structure and the former a spherulitic. The grains that remain irresolvable in a thick section are found to consist of a crowded aggregate of microlites which never darken as a mass, and give no separate polarization. Their sombre tint indicates that they consist largely of quartz and of feldspar. Some of the grains were evidently in the condition of granulitic quartzes embraced in a mass of apobsidian. Some still show such partial extinctions, the area of their sections being divided between several orientations.

It is probable that this rock resulted from a sand of volcanic glass and a few fragments of augite. The parts are hardly sufficiently angular to be referred directly to volcanic explosive action. In many particulars it agrees with the volcanic breccia described by George H. Williams from the Sudbury district of Canada,* but is rather a clastic accumulation than a breccia. N. H. W.

No. 62. Diabase (?) *(Altered.)*

Duluth. Returns after No. 61; like No. 60, but bedded like No. 61.
Ref. Annual Report, ix, page 20.

Meg. A very fine-grained, compact, reddish-brown rock.

Mic. Rock much altered and reddened as is usual. Section consists of very small lath-shaped feldspars and a confused mass of magnetite, hematite, chlorite, calcite and quartz. What was the original nature of the rock, aside from the feldspars, is uncertain. Resembles No. 65.

Two sections.

Age. Cabotian. U. S. G.

No. 63. Basalt (?) *(Amygdaloidal.)*

Duluth. Overhanging rock which, toward the east, becomes brecciated.
Ref. Annual Report, ix, page 20.

Meg. A dark, much rotted, almost black, aphanitic, earthy rock with numerous small amygdules of chlorite, a few of quartz and less of calcite. Pyrite, in small crystals, is disseminated throughout the rock.

No section.

Age. Cabotian. U. S. G.

No. 64. Basalt. *(Amygdaloidal.)*

Duluth. In a heavy bed three feet thick. Overlies No. 65.
Ref. Annual Report, ix, pages 20, 22.

Bulletin of the Geological Society of America, vol. iii, p. 138; *Geological Survey of Canada*, vol. v (new series), Part I. Appendix I, p. 75F, 1893.

Meg. Almost identical with No. 63.

No section.

Age. Cabotian. U. S. G.

No. 64A. Vein Matter *(from No. 64).*

Ref. Annual Report, ix, page 20.

The specimen shows a vein about half an inch thick, largely consisting of calcite, but also containing purple and green *fluorite*. When collected this was also said to contain *bornite*, and it can be distinguished still on the hand sample.

Age. Vein in Cabotian basalt. N. H. W.

No. 65. Porphyryte (?) *(Diabase.)*

Duluth. Evenly bedded, many jointed, forming bluffs of eighteen to twenty feet, holding large calcite nodules.

Ref. Annual Report, ix, pages 20, 21.

Meg. A brick-red, very fine-grained rock holding small, red, porphyritic plagioclases, which are in part replaced by epidote and chlorite. These two minerals also occur in the rock in small irregular areas.

Mic. The porphyritic *feldspars* are very highly altered, but in places show the remains of polysynthetic twinning lamellæ. The groundmass of the rock has the usual red color and consists of *chlorite*, *magnetite*, *hematite*, *calcite* and *quartz*; the last mineral is abundant and forms the ultimate background of the section, frequently including the other substances poikilitically. In the groundmass are also microliths of feldspar. Many of these have no effect on polarized light and can be recognized only by their form, being now a mass of red material often penetrated by the adjacent quartz areas.

One section.

Age. Cabotian. U. S. G.

No. 65A. Calcite. *(Crystals.)*

[A large collection was made of crystals from nodules lying nearly loose in cavities in No. 65. They were shipped at Duluth, but were never received at Minneapolis.]

Ref. Annual Report, ix. page 20.

N. H. W.

No. 66. Porphyryte. *(Amygdaloidal.)*

A modification of, though probably overlying, No. 65.

Ref. Annual Report, ix, page 21.

Mic. The reddened *feldspars*, their very finely ferrated matrix, the fineness of the texture, the prevalence of *quartz*, as a background for the fine minerals of the matrix, and the quartz fillings of the amygdaloidal cavities, denote that this porphyryte was originally glassy, and would properly be styled zirkelyte.

Age. Cabotian. N. H. W.

Apobsidian.]

No. 67. Apobsidian.

Near London [East Duluth]. Forms the point that is next west of the larger creek; continues thirty-five or forty rods, and is subjected to great upheaval and pressure.

Ref. Annual Report, ix, page 21. Annual Report, x, page 141. American Association for the Advancement of Science, vol. xxx, page 164.

Meg. A light red or pinkish specked rock, fine groundmass and some porphyritic and amygdaloidal tendency, appearing as if a siliceous and shaly rock in masses had been embraced in it. Some of these fragments weather dark green, and some purplish red, or fawn color. It also has nests of calcite accompanied by fluorite. It appears like a confused, half-baked, pudding-stone-like rock, or flow breccia. Evidently a continuation of Nos. 65 and 66.

Mic. The groundmass of the rock is reddened by *hematite*, and hardened by poikilitic *quartz*, both being secondary products after *glass*. These, with much *calcite*, are the only identifiable minerals. The quartz is sometimes grouped in interlocking clear grains in what may have been originally vesicles in the glassy mass, but in general it spreads through the whole slide, making a firm rock.

Age. Cabotian. N. H. W.

No. 68. Apobsidian.

PLATE I, FIGURE 3.

Near London, just east of Duluth. A thin-bedded, red or pinkish, hard, condition of No. 67.

Ref. Annual Report, ix, page 21. Annual Report, xiii, pages 100 (No. 152), 102. Bulletin viii, page xxxiii.

Meg. A brown aphanitic rock, with small whitish to pinkish areas which represent porphyritic feldspars. The rock has a laminated appearance and readily splits along parallel cracks, in places splitting into leaves less than one-sixteenth of an inch in thickness. Between the laminæ are very frequently layers or veinlets of quartz, sometimes of almost microscopic width, and sometimes nearly one thirty-second of an inch in width. On a weathered surface these laminæ produce the appearance of flow structure in a lava.

Mic. The characteristic feature of the sections is the presence of large, irregularly outlined areas of *quartz* which contain the other materials of the rock poikilitically. The whole rock is made up of these poikilitic areas and furnishes a most excellent example of the micropoikilitic structure which is so common in the acid rocks of the Cabotian. Scattered all through the quartz are minute grains and specks which, even under a high power, are not clearly shown, of magnetite, hematite and a grayish, almost opaque, substance. The latter is brought out more clearly in polarized light, when it appears isotropic and gives to the section a blotchy "pepper and salt" appearance. Although not now determinable, it seems probable that this substance represents feldspar, now much altered, as is usual with the feldspar of these rocks. In ordinary light the section shows irregular blotches darker than the mass of the rock; these are areas more rich in the iron ores.

The *porphyritic feldspars* are highly altered and reddened and cannot be determined specifically. Frequently the quartz of the groundmass has penetrated these phenocrysts, almost completely replacing them. In such cases the outline of the original grain is shown by the increased deposits of hematite. From the analysis of the rock as a whole, given below, it would seem that these phenocrysts were anorthoclase, or more probably a plagioclase rich in soda.

In sections cut across the laminæ the *quartz veinlets* are very prominent. Most of them are not continuous for great distances, but rapidly decrease in size and disappear. They are recognized easily in ordinary light simply because in them the opaque (feldspathic ?) and iron ore areas are lacking. In the smaller ones the quartz is oriented similar to adjacent areas in the groundmass. But in the larger veinlets the quartz is rather coarsely crystallized, one grain extending across the veinlet, and is usually of orientation independent from the quartz of the surrounding groundmass. In the larger veinlets there is sometimes on each side a narrow layer of clear quartz, then a layer of the feldspathic (?) material, and then the clear centre of the veinlet.

Aside from the appearance of flow structure given to the rock by the veinlets of quartz, there are indications of flowage in other places, especially around some of the porphyritic feldspars, but this flowage is not pronounced.

Three sections.

Chemical Analysis. The following analysis was made by Prof. J. A. Dodge, and was first published in the Thirteenth Annual Report, page 100 (No. 152):

SiO_2	73.72
Al_2O_3	12.82
Fe_2O_3	2.51
FeO	.22
CaO	1.70
MgO	.35
K_2O	2.40
Na_2O	2.70
H_2O	.94
Total	97.36

Age. Cabotian.

Remarks. This rock is referred without hesitation to a devitrified acid lava. It is very similar to the acid lavas, some of which are yet glassy, found farther east on the north shore of lake Superior at the Great Palisades and at Beaver Bay. Nos. 140, 138, 139, 127 and 129 represent these lavas from these localities, and these rocks will be discussed more fully under these numbers.

The origin of the quartz veinlets is uncertain. They may simply represent cracks in the rock or they may now take the place of old chains of spherulites. These veinlets much resemble such bands of spherulites from the South Mountain area in Maryland and Pennsylvania, and the slides were sent to Dr. Florence Bascom,

of Bryn Mawr College, who has carefully studied these South Mountain rocks, and she states that it is impossible to reach any other conclusion regarding the rock in question (No. 68) than that it is an ancient acid lava. She also states that the thin seams of quartz are probably cross sections of the former layers of spherulites.*

U. S. G.

No. 69. Diabase.

Near London, forming a point next east of the mouth of the creek, and not more than six rods from it; by its position apparently overlying the last, cut by a dike, north 5° east, three feet wide.

Ref. Annual Report, ix, page 21.

Meg. A brown, compact, medium grained, scantily porphyritic rock, with epidotic linings in the seams.

Mic. The poor slide at hand only shows that this is an ordinary diabase, with feldspathic microlites trachytically exhibited. The augite areas are converted to a greenish, probably chloritic substance, and the presence of original olivine can only be predicated on the apparently independent outlines of some of these greenish areas. In general the minerals are all reddened by hematite.

Age. Cabotian. N. H. W.

No. 69A. Laumontite and Calcite.

On the east of the dike cutting No. 69 this rock is roughly amygdaloidal, but subsequently resumes its dense structure and thus continues more than half way to Lester river, cut by occasional dikes.

Ref. Annual Report, ix, page 21.

Meg. With a layer of calcite, next the rock, a second growth of a brick-red mineral is deposited on the calcite. The latter is closely fibro-lamellar and fragile, but less so than is usual for laumontite.

Mic. This red mineral gives gelatinous silica in boiling HCl, has low refraction and low double refraction. Its cleavage plates, when examined in fine powder, frequently give an oblique optic axis, and it has n_p in the acute optic angle, making it negative. Its angle of extinction with the principal elongation of the fibres is large.

These characters combined indicate laumontite. Its somewhat greater durability and darker red color are to be attributed to a copious cementation by infiltrated iron oxide. The sign of the elongation is positive, but as the angle of extinction measured on the elongation is about 25°, it is necessary to make that allowance for the position of the axis of elasticity.†

Age. Cabotian. N. H. W.

*Cf. an illustration of aporhyolyte with spherulites in layers. F. Bascom: The ancient volcanic rocks of South Mountain, Pennsylvania. *U. S. Geol. Survey, Bulletin cxxxvi*, pl. 10, 1896.

† *Bull. Société de Minéralogie de France*, vol. viii, 322. The student will find here a useful classification of all zeolitic minerals according to their optic characters, followed by a tabulation of their diagnostic characters. The zeolites having negative elongation are those in which the smaller index of refraction (n_p, a) is parallel, or nearest parallel, with their greatest dimension, as determined by the easy cleavages. The direction of this axis is easily observed by crushing fine a small quantity of the mineral and observing the colors between crossed nicols with the quartz plate interposed when the mineral and the quartz plate have their axes at 45° from the principal directions of the nicols. There is a later and improved classification of the zeolites in Lacroix's *Minéralogie de la France et de ses colonies*, vol. ii, 1897. In the case of laumontite the axis n_g is nearer parallel with the principal cleavages and the elongation is normally positive.

No. 70. Amygdaloid. *(Silicified.)*

Near Lester river, on the west side, forming a prominent point or break in the coast line; overlies No. 69.
Ref. Annual Report, ix, page 22.

Meg. Apparently a fragmental rock, containing rounded pebbles (?) of quartz with a dark, fine-grained matrix, in which is disseminated much pyrite in the form of cubes, as well as some calcite.

Mic. The matrix proves to be trachytic with *feldspars*, which have independent tabular forms in the midst of the other minerals. The pyroxenic element, which was probably augite, is changed to secondary products, which are dark, in general, with *magnetite*. There are other areas which now give a blue tint between the crossed nicols *(pennine)*, which seem to have consisted of *olivine*. The rounded *quartz* areas are probably fillings of vesicular cavities in the original rock. They consist of numerous interlocking grains of different orientation and sometimes are very finely granular. Other cavities are filled with *calcite*.

Two sections.

Age. Cabotian. N. H. W.

No. 71. Diabase. *(Fine grained.)*

Near Duluth. Just west of the mouth of Lester river. Overlies No. 70. Continues but six or eight rods and disappears under the beach, and nothing appears again till at Lester river.
Ref. Annual Report, ix, page 22.

Meg. A fine-grained dark brownish rock, composed of small feldspars and a darker material. Many of the feldspars appear pinkish. A very few small porphyritic plagioclases are present.

Mic. Small lath-shaped *plagioclases* and an abundance of *augite* and *magnetite*. The augite is largely still quite fresh. A hematite stain has penetrated the rock and is more abundant in the vicinity of the magnetite grains.

One section.

Age. Cabotian. U. S. G.

No. 72. Sandstone. *(Pyroclastic grit.)*

Mouth of Lester river, east of Duluth. This river was called Passabika by Dr. Owen.
Ref. Annual Report, ix, page 22.

Meg. Apparently a granular clastic fine-grained rock, of a brown or reddish color, homogeneous and thinly bedded. The amygdaloidal structure does not pervade the sandrock, but it pervades the cement or rock which fills the angular openings between the pieces of the breccia.

Mic. The section made from the clastic rock shows a fine grain, the individual grains being both rounded and angular, and of different sorts. The most evident and conspicuous are angular limpid fragments of quartz. These are covered with a coating which is now stained as by hematite. Other grains which now consist

essentially of quartz, are secondary after glass. They are rounded, and are dimmed by many inclusions of opaque substance. Still others are angular plagioclase fragments, their twinning being perfectly apparent by reason of the banded extinctions. These are embraced, over large areas sometimes, by calcite which like the Fontainbleau crystals presents a single orientation.

One section.

Age. Cabotian.

Remark. This rock may be compared with Nos. 17, 24 and 30. It occurs as angular inclusions in a vesicular lava, No. 72A. The rounded outlines and the uniformity of size of the most of the grains seem to be due to beach friction, for it is hardly possible that such forms can be produced by volcanic explosive action. The grains of silicified glass are comparable with the matrix of some of the aporhyolytes of the region. N. H. W.

No. 72A. Amygdaloid. *(Calcitic.)*

Mouth of Lester river, east of Duluth. The cementing material of the foregoing breccia.
Ref. Annual Report, ix, page 22.

Meg. A dull, much changed, fine-grained rock, containing amygdaloidal cavities mostly occupied by calcite.

Mic. Minute trachytic feldspars are distributed throughout the matrix. The ferro-magnesian silicates are wholly changed to serpentinous or chloritic elements, which also fill certain amygdaloidal spaces. No calcite amygdules appear in the section. The chloritic amygdules are blue between crossed nicols, but sometimes have a green border surrounding the blue.

Age. Cabotian.

Remark. It is a common feature to find these clastic masses in the midst of the vesicular lavas of the region. It is as yet unexplainable. Such association may have resulted from the rupture of old clastic strata in the ejection and flow of the lava, or from cotemporary erosion and sedimentary action of the ocean's waters on the lavas of the same or nearly the same date as the amygdaloids in which they are found. N. H. W.

No. 73. Diabase. *(Fine grained.)*

East side of the mouth of Lester river. Becomes brown along some of the joints, and in some large areas. Extends one and one-half miles, with a line of low exposure. Runs under No. 74.
Ref. Annual Report, ix, page 22.

Meg. A fine-grained, compact, dark-gray rock. Small feldspars are the only crystals that can be distinguished.

Mic. The section is composed of small lath-shaped *plagioclase* in a background of *augite*, *magnetite*, *plagioclase* and some secondary products. In structure this rock differs some from the usual diabases. The lath-shaped plagioclases are not all

idiomorphic, and all gradations can be found from idiomorphic to granular plagioclases; and with these granular plagioclases and between the lath-shaped crystals are grains of augite. Thus the augite is not in the usual plates common to diabases, and in that respect this rock has gabbroid characters. It would seem that after the usual lath-shaped plagioclases were formed there was still a considerable amount of feldspathic material in the magma which crystallized at about the same time, or perhaps slightly previous to the augite. A few areas of magnetite and chlorite are present which perhaps represent old olivines. The augite, which is clear and colorless when fresh, has altered in places to a more or less fibrous greenish substance which often can be distinguished as *hornblende*. There are also some small areas of yellowish or brownish pleochroic hornblende which may be the greenish grains cut in another direction, but these yellowish grains are not so distinctly fibrous as most of the green ones. All of this hornblende is probably secondary after the augite.

One section.

Age. Cabotian. U. S. G.

No. 74. GRANITE. *(Red.)*

Rock next east of No. 73, extending for some distance.
Ref. Annual Report, ix, page 22; Annual Report, xiii, page 100 (No. 153), 102; Bulletin viii, page xxxiii.

Meg. A brick-red, granitic rock of fine grain, composed of red feldspar and quartz. A few cleavage faces of feldspar one-tenth of an inch across are seen scattered through the rock, but the usual grains are much smaller than this.

Mic. Rock composed of *feldspar* and *quartz*, about two-thirds feldspar, which is of the usual red, almost opaque, variety common to the acid rocks of the Cabotian. It rarely shows any effect on polarized light. Judging from the analysis of the whole rock, given below, we would expect the feldspar to be largely *anorthoclase*. Some of the larger feldspars show evidence of an original zonal structure. The quartz is in rather large areas embracing the feldspars poikilitically, and often penetrating and replacing in part the feldspar grains. The rock furnishes a good example of the coarser micropoikilitic structure. The feldspar enclosed in the quartz has frequently a tendency to an idiomorphic development. A few areas of a dull brown, granular, isotropic substance, with dark borders, are present. These may represent an old ferro-magnesian constituent. Scattered abundantly through the rock in grains and specks and stains is *hematite*, and the presence of this mineral is also clearly evident from the analysis.

One section.

Scoria. Diabase.]

Chemical analysis. This analysis was made by Prof. J. A. Dodge and first published in the Thirteenth Annual Report, page 100 (No. 153):

SiO_2	65.56
Al_2O_3	10.06
Fe_2O_3	14.40
FeO	.23
CaO	.96
MgO	.73
K_2O	2.88
Na_2O	2.25
H_2O	.86
Total	97.93

Age. Cabotian. U. S. G.

No. 75. Scoria. *(Acid, volcanic.)*

East of Lester river. S. E. ¼ sec. 34, T. 51–13. At this locality there has been an unusual disturbance, the strata dipping in different directions, or at a high angle to the north, the strike being nearly east and west. This point cannot be far distant from an ancient volcanic crater. (See figure 109, page 576, vol. iv.)

Ref. Annual Report, ix, page 22.

Meg. The rock varies from a brownish red amygdaloid to a flesh-red scoria, the latter represented by the samples examined. This is porous, and even spongy but the vesicles are elongated and flattened. Through the rock runs a considerable calcite in veins and patches.

Mic. The sections show that the rock consists essentially of devitrified glass and of glass, embracing vesicular openings. There are many crystallites which are apparently biaxial, and others evidently of quartz though they do not exhibit hexagonal shapes. They are clear and quick to extinguish between the nicols. But these are embraced, frequently, in a substance which is nearly isotropic. Yet, between the nicols other faintly luminous spots appear, indicating the arrested formation of other crystallites. In other words, the glass is but imperfectly devitrified. This fact is in keeping with numerous observations on the tuffaceous rocks of the region, in which sub-glassy grains have been seen distributed through a clastic mass.

Two sections.

Age. Cabotian. N. H. W.

No. 76. Diabase *(with olivine and thalite).*

Directly overlying No. 75, interbedded in No. 75, but still runs under No. 77.

Ref. Annual Report, ix, page 22. Compare No. 91B.

Meg. Has a trappous aspect, contains laumontite amygdules and nodules of calcite and fluorite.

Mic. The aspect is that of an ophitic rock, the bright microlites of *feldspar* being numerously embraced in some of the large *augites*. There is no evidence of an earlier generation of augite.

The *olivine* is much crowded with magnetite accumulations, and in many grains is so lost that its form is the only remaining evidence of its former existence.

In several irregularly shaped areas occurs a finely fibrous, yellowish green mineral, which has much the appearance of that seen in No. 140 (7). It is in the form of undulatory and mammullated layers, the fibres of which are perpendicular to the layers and have parallel extinction and positive elongation. The name of this mineral is not yet determined, but appears to be thalite. The mineral referred to in No. 140 (7) is much harder than thalite.

One section.

Age. Cabotian. N. H. W.

No. 77. Amygdaloid *(with laumontite.)*

Overlies No. 76. A coarse amygdaloid, with laumontite and calcite, containing some copper, wrought slightly for copper at one time. Color, brown.

Ref. Annual Report, ix, page 23.

The fragile *laumontite* nests are of various shapes and sometimes two inches in larger dimension, the fibres radiating from points; color, light flesh-red. The fibres are optically negative, and have extinctions at 6° to 24°. The rock is a fine olivinitic diabase in which the augite preceded the feldspar and was then corroded.

One section.

Age. Cabotian. N. H. W.

No. 78. Diabase.

Forms the bite of Crystal bay east of Lester river. Bluffs fifteen to twenty feet in hight.

Ref. Annual Report, ix, page 23; Annual Report, x, page 38.

Meg. Firm, brownish red, much jointed, disintegrating and falling in large masses, weathering light red or pinkish; containing nests of calcite crystals.

Mic. The section shows a fine-grained diabase now considerably altered and impregnated by iron oxides, apparently both magnetite and hematite. The plagioclase laths are usually still distinct, though clouded. One of these, cut nearly perpendicular to the axis of least elasticity, gave an extinction angle of 21°, indicating *labradorite.* Secondary *quartz* in small grains is common. There are some pseudamygdaloidal areas filled with *chlorite* and quartz.

One section.

Age. Cabotian. U. S. G.

No. 78A. Calcite. *(Crystals from No. 78.)*

Ref. Annual Report, ix, page 23.

These nests are sometimes eighteen inches across, but generally less than ten. The forms are sometimes perfect, with double terminations. They are impacted in a fine red clay, which doubtless has infiltrated through the loose rock from the surface above, where a continuous sheet of the same red clay covers the country.

N. H. W.

Porphyryte. Prehnite. Diabase.]

No. 79. Porphyryte. *(Amygdaloidal.)*

Eastward from Crystal bay, similar rocks extend for a mile or more. These are brownish or black and basaltiform outwardly, and are doubtless a continuation of No. 78, though exhibiting in the field considerable variation of dip and of structure. They are sometimes compact and sometimes amygdaloidal, and are associated with fragmental rock in a confused manner, the latter being brecciated, and transversely and falsely bedded like some sandrocks. The bluffs are generally low, three to ten feet, with interruptions.

Ref. Annual Report, ix, page 23.

No section.

Age. Cabotian. N. H. W.

No. 80. Prehnite.

From the old copper shaft about a mile up French river. This mineral fills and lines numerous cavities of various ramifying shapes, in the rock No. 81. Rolled pieces of this mineral are found in the gravel of the beach, and metallic particles of copper are frequently embraced in them.*

Ref. Annual Report, ix, page 23.

Meg. This prehnite is associated with another form of gangue, both carrying metallic *copper*. This form of the gangue is a siliceous rock of a light, reddish-brown color, apparently fragmental, which, according to the field descriptions, runs in irregular veins and crevices in No. 81. It is hard, like a quartzyte, and dense, but it plainly embraces fine grains of a darker mineral than quartz. The rock has a color-banding which is somewhat flexuous, simulating a fluidal structure, suggesting the silicification and other devitrification of a glassy eruptive.

Mic. On making a thin section of this peculiar gangue rock, it is seen to be a fragmental rock, consisting very largely of rounded fragments of prehnite, quartz, epidote(?) and of devitrified glass, with an abundant deposition of secondary quartz. Some of the glassy fragments are hardly devitrified, but remain dark constantly between the nicols. They occasionally take the forms of elongated shreds and strings, and show a rhyolitic structure.

Two sections.

Age. Cabotian.

Remark. This rock seems to illustrate, in its origin and manner of occurrence, the clasolyte of Wadsworth. (Report of the State Board [Michigan] of Geological Survey, for the years 1891 and 1892, page 130). N. H. W.

No. 81. Diabase *(with olivine)*.

Banks of French creek, from the lake shore northward for about half a mile or more.
Ref. Annual Report, ix, page 23.

Meg. A dark, fine-grained, heavy rock.

Mic. Ophitic, with *augite* and *feldspar*, the *olivine* grains being fine and of a reddish brown color. *Biotite* is also brown and quite abundant. Some of the vesicles are filled with *calcite* and some with *chlorite* of the variety *pennine*, judging from the bluish interference color between crossed nicols.

One section.

*For an account of this mining enterprise, see *Minnesota Historical Collections*, vol. ii, p. 181, by H. M. Rice.

Age. Cabotian.

Remark. This rock undergoes variations between the lake shore and the old French River mining location, becoming amygdaloidal, and also in other places finer grained, even aphanitic, as if it had been glassy. Of two sections made from the rock at the old mine, on the veinings of which prehnite forms coatings, one is permeated with *prehnite*, as well as having small vesicles that are completely filled with the same mineral. N. H. W.

No. 82. Diabase *(with olivine)*.

French river, one half mile from the lake. An amygdaloidal portion of No. 81.
Ref. Annual Report, ix, page 23.

Meg. A dark brownish rock of very fine grain. Contains amygdules of laumotite, prehnite and a dark mineral (chlorite). The rock also has small indistinct black areas, which are probably largely of chlorite.

Mic. The section is almost exactly the same as the first section described under No. 81, and so needs no further descriptions. The feldspars are perhaps a little larger than in No. 81.

One section.

Age. Cabotian. U. S. G.

No. 83. Diabase. *(Altered.)*

French river.
Ref. Annual Report, ix, page 24.

Meg. There are two hand specimens. One is a dark purplish rock, similar to Nos. 81 and 82. It contains amygdules, veins and geodic cavities of prehnite. The other hand sample is part of a geodic cavity filled with coarsely crystallized laumontite and some prehnite. Part of the rock surmounting the geode is present; this is similar to the other sample, but is redder and decayed.

Mic. The section shows a rock which was undoubtedly originally very similar to Nos. 81 and 82, but is now highly altered. The outlines of the small lath-shaped *feldspars* are sharply preserved, but the whole rock, except the areas of iron ore and some opaque substances, has been replaced by *prehnite*. From the hand sample, which is apparently quite fresh, one would not suspect that so profound a change had been wrought in the rock.

Two sections.

Age. Cabotian. U. S. G.

No. 84. Amygdaloid. *(Laumontitic.)*

A mile and a half up French river. Allied to the series of traps and amygdaloids already described at this place.
Ref. Annual Report, ix, page 24.

No section.

Age. Cabotian. N. H. W.

No. 85. Diabase. *(Coarse.)*

Two miles up French river.
Ref. Annual Report, ix, page 24.

Meg. Considerably shattered and deeply decayed, but evidently one of the heavier surface flows or sills of the region.

Mic. A coarse ophitic structure is at once apparent. *Olivine* is only shown by the usual independence of the areas that now are filled with the products of decay. *Magnetite, quartz, chlorite* are conspicuous.

One section.

Age. Cabotian. N. H. W.

No. 86. Diabase. *(Amygdaloidal.)*

French river, two miles from its mouth.
Ref. Annual Report, ix, page 24.

Meg. A dark brownish, medium-grained diabasic rock containing a few small amygdules of *chalcedony* and *quartz.*

No section.

Age. Cabotian. U. S. G.

No. 87. Diabase.

French river, three miles from its mouth.
Ref. Annual Report, ix, page 24.

Meg. A fine-grained diabase with some black blotches, which are pseud-amygdules of chlorite.

Mic. Lath-shaped *feldspars, augite, magnetite, hematite, chlorite* and alteration products. The chlorite forms pseud-amygdules. Probably some olivine was originally present.

One very poor section.

Age. Cabotian. U. S. G.

No. 88. Olivine Diabase.

S. W. ¼, sec. 10. From the round point which bounds Sucker bay on the west.
Ref. Annual Report, ix, page 24.

Meg. Fine-grained, dark and heavy trap.

Mic. The feldspars are microlitic and ophitically embraced by the *augite,* which in some cases encloses ten or fifteen of them. The *olivine* is in small grains and much changed to a fibrous substance which is usually green, but which becomes so charged with iron that it is also largely opaque.

One section.

Age. Cabotian.

Remark. The coarse diabases Nos. 85 and 87, and the gabbroid characters of No. 73, are believed to be due to the greater proximity, both areally and chronolog-

ically, of the chief gabbro mass which lies further north. The lavas and clastic rocks along the shore seem to be the more distant representatives of these coarse diabases. How many of the surface outcrops of these coarse rocks away from the lake shore, belong to sills, and how many are of massive surface flows, there is at present no way of knowing. N. H. W.

No. 89. Diabase.

Just east of the creek crossing sections 9 and 10, east of the mouth of French river, and near Sucker bay.
Ref. Annual Report, ix, page 24; Annual Report, x, page 36.

Meg. A massive, homogeneous, fine-grained diabase-like rock, non-amygdaloidal, but having large geodic concretions of calcite, with an interior of laumontite. The joints, as seen in the field, are lined with a mineral Norwood styled heulandite. Compare Nos. 515 and 516.

Mic. An ophitic diabase of the usual characters, lath-shaped feldspars, *pyroxene* much changed, *magnetite*, *olivine*, *hematite*, *chlorite*, a little *quartz*.

One section.

Age. Cabotian. N. H. W.

No. 90. Diabase *(with olivine, coarse)*.

From the east point of Sucker bay; a massive, heavy bedded, dark rock, sloping up from the water's edge, similar to Nos. 1 and 49; continues to Knife river; also forms Knife islands.
Ref. Annual Report, ix, page 24; Annual Report, x, page 139; Proceedings American Association for the Advancement of Science, vol. xxx, page 162; Bulletin ii, page 99.

Meg. A rather coarse-grained, granular "sugary" appearing rock, which is made up of plagioclase, weathering white, and black materials.

Mic. The following is Dr. Wadsworth's description (Bulletin ii, page 99):

"One section is composed of numerous grains of olivine and masses of augite arranged irregularly in the feldspar which is sometimes in aggregations of crystals, and sometimes in divergent lath-shaped blades dissecting the augite. The feldspar contains the remains of an included globulitic base, so commonly seen in the plagioclase of modern basalts.

"The olivine is much fissured and more or less altered to a greenish serpentine. Greenish and yellowish brown secondary products, showing aggregate polarization, are common in the section. In another section of the same rock the feldspar contains much of the altered globulitic base, while that mineral is largely in rounded and tabular aggregations of crystals. The olivine is here altered, not only to the greenish serpentine, but also to a brownish yellow form."

Two sections.

Age. Cabotian. U. S. G.

Remark. This, perhaps, is in continuation of the coarse diabases Nos. 85, 87, and they are probably all closely related with the great gabbro mass seen at Duluth. N. H. W.