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Art. I.—*Contributions to the Geology of Rhode Island: I. Notes on the History and Geology of Iron Mine Hill, Cumberland;* by B. L. Johnson. II. *The Petrography and Mineralogy of Iron Mine Hill, Cumberland;* by C. H. Warren.

Introduction.—During the spring of 1905, one of the authors (Johnson) made a geological study of the occurrence of the ultra-basic, titaniferous rock, familiar to petrographers, from the publications of Professor M. E. Wadsworth, under the name of cumberlandite. A geological map of the region and a brief petrographical study of the surrounding rocks as well as of the cumberlandite itself was made. The results of this work were presented as a graduating thesis in the geological option of the course in Mining Engineering at the Massachusetts Institute of Technology.

In comparing the results with those of other observers in the field, it was found that a fuller knowledge of the relations existing between the cumberlandite and the surrounding formations had been secured, and it was deemed desirable to place these on record. It was also noted that no satisfactory chemical analysis of the cumberlandite had ever been made, and that consequently the existing petrographical descriptions are all inadequate for so interesting and unusual a rock. Accordingly, a rather complete petrological study of the rock and its altered forms has been made by one of the authors (Warren), the results of which are also presented in the following pages.

PART I—*Notes on the History and Geology of Iron Mine Hill, Cumberland, R. I.*

Location and Topography.—The cumberlandite forms a rather conspicuous ridge, known locally as "Iron Mine Hill," situated in the northeastern corner of the state of Rhode Island, in the town of Cumberland, and about three miles in a nearly easterly direction from the town of Woonsocket. The locality is easily reached from the latter city by taking a trolley car marked "Manville" for a distance of about two miles to a point known as Chipman's Corner, and thence walking for about a mile due east. The locality may also be reached by leaving the Boston and Providence R.R., Franklin Div., at a station known as "Diamond Hill" and walking thence for about two miles along the main Woonsocket road, taking the first turn to the left and following it for a few rods.

An idea of the general topography of the region may be obtained from an examination of the Providence and Franklin quadrangles of the topographical map of the U. S. Geological Survey. The relief is not great and the hills for the most part rise to approximately the same altitude, which will not exceed much over 100 feet above the surrounding country nor 400 to 500 feet above the sea-level. The country is heavily drift-covered, and much of the present topography is due to the glacial deposits. The area is drained by the Blackstone river, which runs in a southerly direction a mile to the west.

Historical.—The existence of an entire hill composed of a rock of such high density and unusual appearance as the cumberlandite doubtless attracted attention to it at an early date. That it was a possible ore of iron appears to have been known at the beginning of the eighteenth century, for in 1703 the rock was mixed with hematite from Cranston, R. I., and smelted for iron by one Philip Brown. It is stated that his foundry was located in the town of Cumberland, but just where, the writer has so far been unable to discover. It is also said that a part of the cannon used against Louisburg in 1745 were cast at this forge.

From time to time since, mostly in the early and middle part of the present century, attempts have been made to use the rock as an ore of iron by mixing it with high grade ores at many smelters in New York, Pennsylvania, and New England. Old excavations on the side of the hill indicate that a total of at least several thousand tons has been taken out, and according to Professor Shaler, loose bowlders of the rock, which were once abundant on and about the hill, have been extensively collected and shipped away for use as ore and for other purposes. The relatively low percentage of iron (30 to

32 per cent) in the rock and the high percentage of titanium appear to have prevented any considerable use of it for the production of iron notwithstanding the enormous amount easily available.

More recently, the "Cumberland Iron Trap Rock Company" attempted to work the deposits for road-metal and erected a plant for crushing the rock, but for one reason or another the enterprise failed.

Many references to the geology, petrology, and economic aspects of the cumberlandite may be found in the literature. For a list of the more important papers the reader is referred to the bibliography which will be found at the end of the article.

Dr. Robinson, in his book entitled "A Catalog of American Minerals, with their localities," published about 1825, writes under "Cumberland, R. I., magnetic oxide of iron; two miles N.N.E. of the meeting house on the left of the Wrentham road, is an immense bed constituting a hill. Most of this ore is a metalliferous porphyry, having crystals of feldspar in the iron."

Professor Edward Hitchcock in 1833, in his report on the geology of Massachusetts, gives a brief description of the rock and its occurrence. Dr. Charles T. Jackson was, however, the first to give a description of the hill in any detail. In his report on the geology of Rhode Island published in 1840, we find the general dimensions of the hill given and a geological section along a north-south line. He also comments briefly on its origin, expressing the belief that it was "protruded through the granite and gneiss at the same epoch with the elevation of numerous serpentine veins which occur in this vicinity." He gives a chemical analysis, the first, it is believed, that is recorded.

In 1841 Professor Hitchcock expresses himself as believing that the iron ore should be looked upon as belonging to the metamorphic slates of the region, "or rather lying at their juncture with the unstratified rocks (granites, etc.)." He seems for some reason inclined to the belief that the rock will be found to be strongly impregnated with manganese.

Benjamin Silliman, Jr., in reviewing Dr. Jackson's book shortly after its publication, appears to agree with him as to its origin, and believes that in this respect it may resemble the iron ores of Missouri.

In 1869, and again in 1872, Mr. R. H. Thurston published a chemical analysis, the mean of several (source unknown to the author), and seems to have been the first to have mentioned the presence of ilmenite in the rock. Analyses of the ore by one, Dr. Chilton, were also published in the New York Tribune of 1873 and reproduced with slight changes by Mr. Holley in 1879 in the Transactions of the American Institute of Mining Engineers. He also gives figures for phosphorus, total iron, and silica, as determined at the laboratory of the Bethlehem Steel works.

The first good description of the cumberlandite was made by Professor M. E. Wadsworth in 1881. He gives its microscopical characteristics for the first time, describing it as a rock composed essentially of olivine, or its alteration products, and titaniferous magnetite, containing locally porphyritically-developed feldspar as an abnormal constituent. He concludes that it is a basic eruptive rock. A short historical account of the hill accompanies the description.

In 1881, J. D. Dana, reviewing Wadsworth's paper, concludes that the "Rhode Island magnetite is also of metamorphic origin," basing his conclusion partly on Wadsworth's statement that the nearest rock is a mica schist some hundreds of feet distant, and partly on a comparison of the occurrence with those of certain New Jersey magnetite deposits to which a metamorphic origin was assigned by Professor C. H. Cook.

In 1884 Wadsworth published his "Lithological Studies," etc., and in them he devotes considerable space to the macro- and microscopic description of the rock. He classes it as a "Terrestrial Pallasite," viz., a rock possessing a texture similar to the meteorites and composed of a sponge-like matrix of native iron, pyrrhotite, or their secondary products such as magnetite, enclosing olivine with or without other accessory minerals. He expresses the belief that the matrix, in the present case magnetite, will be found to pass in depth into the unoxidized metallic iron. He proposed the name *Cumberlandite* for this and closely similar rocks. The altered types of the cumberlandite are described in some detail in this paper as well as the feldspathic, original type. He seems here to have looked upon the feldspar as an abnormal constituent of the rock. In an appendix he gives a tabulated list of the existing analyses, but makes no particular use of them, doubtless recognizing their poor character. Dr. Wadsworth seems later to have become aware of the original rôle of the feldspar in the rock and its subsequent replacement by alteration products, for in 1889 he writes of it,—"a rock composed of a spongiform mass of titaniferous magnetite, containing abundant olivine and more or less feldspar. This is the ore in its unchanged condition as found on one side of the hill, but it passes into more altered forms on the top and other side. In the altered forms the feldspar and olivine are changed to serpentine, actinolite, and even into talc and dolomite, while the magnetite is diminished in quantity. In the hand specimens the least altered condition shows as a dark resinous, crystalline, splintery and compact mass, holding porphyritically enclosed feldspar. This, in the altered forms, passes into a rock, having the same groundmass but with the feldspar altered into patches of a dark green, fine-grained, serpentine product. By further alteration the rock changes to a dark grey, serpentinous rock, spotted with the decomposition products of iron. In the altered forms short brilliant crystals of actinolite are to be seen and the rock often shows a schistose structure."

Again in 1893 he again refers to the cumberlandite in one of his reports to the Michigan Geological Survey and gives two analyses by Professor R. L. Packard to show the general composition of the rock. These analyses are the best analyses of the rock heretofore made, and appear to be essentially correct except for certain omissions, notably the alkalis. A partial analysis of a very impure feldspar separated from the rock is also given. No statement as to the true composition of feldspar present in the rock appears in any of the papers cited, and as no attempt was made, so far as known, to determine sodium, it is inferred that the feldspar was generally supposed to be anorthite.

In the same report he states that, "the form containing feldspar was found by field observation in 1885 to pass into the form containing only greenish spots of serpentine and amphibole. Feldspars were then found showing various gradations in the alteration to the serpentinous products." In comparing the altered types with the feldspathic, the relation existing between the feldspar phenocrysts and the green spots is so obvious that it is a little surprising that so important a fact was not pointed out before.

In 1883, Professor N. S. Shaler published a paper on "The conditions of erosion beneath the deep glaciers, based upon a study of the bowlder train from Iron Hill, Cumberland, R. I." In the course of the paper he devotes considerable space to a description of the hill. He states that the dipping magnetic needle indicates that the rock mass has an extent about equal to the one assigned to it from surface showings, and that there is no evidence that similar masses exist, at least within an area of many miles about the hill. After a brief review of the facts in hand, he concludes that the cumberlandite rock mass is dike-like in its mode of occurrence and that it is an igneous intrusion. His discussion of the glacial phenomena about the hill and of the remarkable bowlder train from the hill traced as far south as the island of Martha's Vineyard, is exhaustive. He estimates from his observations that probably 300 feet in vertical thickness have been removed from the rock mass by the glacial erosion, assuming that the original area was about the same as at present. He also expresses his belief that not over six inches have been removed by erosion since. Several sketches of the hill as it appeared in 1883 and a map of the bowlder train accompany the article.

At a later date, the same writer expresses the belief that the rock might continue downward to an indefinite depth and to the north and south, beneath the drift, in the direction of its strike, an opinion shared by the present author.

Professors F. D. Adams, J. H. L. Vogt, J. F. Kemp, and Richard Beck, in the publications given after their names at the end of this paper, all mention the cumberlandite as a probable segregation from a gabbroitic stock and class it with the similar rock from Taberg, Sweden and other rocks of like origin.

General Description of the Iron Mine Hill and adjacent Formations.—The cumberlandite is a dike-like boss of igneous rock which consisted originally of olivine (hyalosiderite), magnetite, ilmenite, labradorite, and accessory spinel.

From surface indications and magnetic observations it appears to have a rudely elliptical cross section with a major axis of about 1200 ft. and a minor axis of from 500 to 600 ft. The direction of the major axis lies nearly north and south. From the position of bowlders in the drift to the west of the hill, it seems likely that the mass may extend under the drift to the north farther than is indicated by its present outcrop. There may also be a southward extension of the mass, but the nearest outcrops of adjacent rocks on the north and south certainly limit the length to a maximum of about 2500 ft. and probably a much less smaller figure is the correct one. That the maximum width is much greater than the figure given seems improbable from considerations that will appear later.

The cumberlandite is now exposed in an unaltered condition at only one point on the western side of the main ridge, a little below the middle and a few feet below the top. With reference to the probable dimensions of the rock mass as indicated above, the unaltered portion is very nearly central. It occupies an area of from 300 to 400 square feet and passes, with a relatively narrow transition zone, into the more or less altered types which constitute by far the greater portion of the present hill.

The Hill rises rather abruptly to a height of about 100 ft. above the surrounding country, and of about 60 ft. above its own base. Its upper portions, except where altered by quarrying operations, consist of rounded, irregular prominences having a dark brown to black color. Their rounded outlines are due to glacial action and many fine examples of glacial marking may be noted over most of the surface.

The hill is traversed by a nearly vertical system of main joints running nearly south and north. Roughly perpendicular to these is a system of minor joints which cut the hill up into small, rudely prismatic blocks. On the eastern side of the hill the minor jointing is rather thinly parallel in places. Many blocks have been torn out and carried away by the ice, leaving troughs and irregular breaks in the surface.

At several points along the exposed ledges on the western side, distinct inclusions of a feldspathic rock may be seen. These vary in size, so far as observed, from two to six inches in diameter. They are always much rounded in outline, evidently from alteration, and are surrounded by a variable amount of green chloritic material. Macroscopically, they resemble the gabbro noted beyond as being the nearest rock to the cumberlandite on the west, and microscopically, they were found to be practically identical with it. On a recently uncovered, glaciated surface at the northeast end of the hill, two subangular inclusions composed of a compact, greenish grey mass of chloritic material mixed with some actinolite and magnetite, were observed. Under the microscope indications of some previously existing, rather coarse textured rock were observed, and it is thought that these inclusions may also be gabbro, now strongly altered like the inclosing rock.

These inclusions, now noted for the first time as belonging to the gabbro, are the only evidence that the cumberlandite is *younger* than a portion at least of the adjacent igneous rocks.

The rock has suffered to some extent from shearing movements which have produced a schistose structure in the actinolite and chlorite commonly found along the joint planes. Many of the joints contain crystals of these minerals of considerable size, and weathered faces are sometimes thickly studded with well-developed crystals of clinochlore. Less commonly crystals of a dark glassy, amber colored olivine, the rare species *hortonolite*, are associated with the other two minerals. Veins, sometimes as much as an inch in thickness, containing varying proportions of these three minerals, cut irregularly through the rock.

As a whole the hill has resisted the action of weathering to a remarkable degree considering its mineral character. Its surface is not decomposed in general to a depth of over one-half an inch, and Professor Shaler's observation that the surface of the hill has probably not lost more than six inches by weathering alone since glacial times, seems entirely probable.

The base of the hill on its northern and western sides has a heavy covering of drift, which widens out rapidly toward the south and southwest, forming a gently rising slope. The ridge itself grows gradually lower toward the south and disappears under the drift near a road which runs across the strike at this point. On its eastern side, the foot of the ridge is marked by a rather heavy talus of large and small bowlders, beyond which a narrow strip of swampy land and a meadow extend the next ridge. Beyond the drift to the north and west, a broad stretch of low land completely isolates the hill. At the present time, the lower portions and a good part of the top are covered with a thick growth of small timber and heavy underbrush.

The cumberlandite is nowhere exposed in contact with any other rock, and is separated from the nearest outcrops by barren areas for a distance of at least 700 feet.

On the east, a ridge somewhat lower than the hill runs parallel to it. This is the nearest rock seen in place to the cumberlandite and consists of a fine-grained, green, chlorite-epidote schist. It is cut by numerous quartz veins and granite dikes. A little specular hematite may be found along the joints, and small pockets of brilliant epidote crystals are often associated with the veins. The lamination of the schist is at a steep angle and the general trend of the formation is N.W. This ridge also passes under the drift to the south. Farther to the south granite comes in with abundant inclusions of schist. The schist formation extends for some distance to the east and is succeeded by granite. On the south the granite approaches the hill to within 400 or 500 yards. It is a medium-grained, biotite granite always showing strong evidences of shearing and possesses very generally a gneissoid and in places a schistose structure. To the southwest near the road to Cumberland Hills, the granite is highly gneissoid and has a pinkish color and is suggestive of the Milford granite several miles to the north. A considerable amount of a purple fluorite is not uncommon in some parts of the granite. Just north of Cumberland Hill, three large dikes of granite or quartz-porphyry intrude the schists parallel to their schistosity. These dikes contain numerous inclusions of the schist and also of the granite. They appear to be the youngest rocks in the area. Beyond the granite on the south, a dark green hornblende schist, evidently a less metamorphosed form of the schist on the east, comes in.

On the southwest of the cumberlandite, some 350 yards distant, several large ledges of a rather coarse-grained, metamorphosed gabbro are met with. As may be seen from the map the gabbro occupies a considerable area to the west of the hill, about ½ a mile wide by ¾ long. It outcrops in a series of heavily glaciated ledges between which are considerable stretches of low land or swamp. The eastern margin of the gabbro as a whole takes a concave outline toward the cumberlandite and in one place, almost directly west, a ridge rises to very nearly the same height as the hill. It is everywhere separated from the cumberlandite by drift or by swampy land entirely devoid of outcrops. On the south the gabbro is bounded by the granite mentioned above, but the actual contact, like so many others in this region, is effectually masked by a small, drift-filled valley. The western boundary is somewhat indefinite, but judging from the position of the granite outcrops on the southwest and northwest, its position cannot be very far from that assigned to it on the map.

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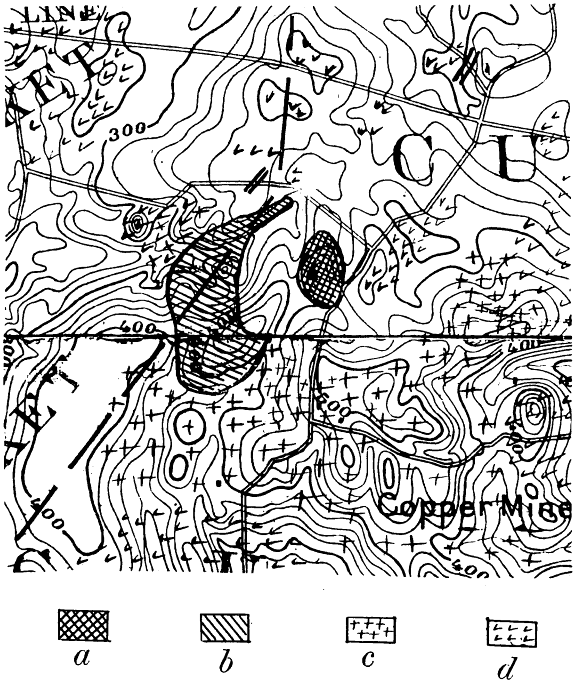

a, Rhodose (Cumberlandite). *b*, Gabbro. *c*, Granite. *d*, Metamorphic sedimentaries cut by granite and quartz veins.

The map indicates the position of the surrounding rocks as shown by outcrops.

On the north and northwest, the gabbro is bounded by metamorphic sedimentary rocks—a quartzose-biotite schist chiefly—or by granite, the latter cutting through the former in the form of dikes and larger irregular masses, and lithologically like the granite on the south. Near the contact the granite has become highly schistose and fissile. A small patch of a highly metamorphosed conglomerate, cut by quartz veins and filled with epidote in their neighborhood, outcrops in the fields just north of the gabbro. Farther east, along the road that runs by the hill, a fine, chloritic schist comes in. This is very similar to the schist on the east. At this point, also, a small outcrop of a rather coarse-grained diabase is seen. Thin sections show that this rock has been much changed from its original form, consisting now essentially of crushed and recrystallized feldspar, secondary hornblende and altered ilmenite. It has been mapped as a dike, similar in occurrence to one that comes in a little to the north and perhaps continuous with it.*

Still farther north, beyond the immediate neighborhood of the hill, schist and granite outcrop at various places through the drift, while to the west, toward the Blackstone river, a quartzite appears. The exact relations of the sedimentaries to each other are of little importance in the present connection. The schists and quartzites are placed by Woodworth in what he has termed the "Blackstone Series" supposed to be of Algonkin age, and have been named the Blackstone Quartzite and the Ashton Schist respectively. The conglomerate appears to conform to the strike of the schists and to be a bed in them. It may, however, be a remnant of the supposed carboniferous conglomerate which appears near Woonsocket.

So far as known, only one dike cuts the gabbro, and that is a short one, a few inches in width, situated near the southeastern edge of the mass. Originally this was a very fine grained trap containing porphyritic crystals of plagioclase and augite. Like the inclosing gabbro, the dike has been greatly altered, but little of the original minerals, except portions of the porphyritic feldspar, remaining fresh. So far as known no especial significance can be attached to this dike. The gabbro is not cut by the surrounding granite nor are any inclusions of the granite nor of the invaded sedimentaries known, although an examination of the contacts, were any exposed, might reveal them. There seems to be no positive evidence to show that the gabbro and cumberlandite are either older or younger than the surrounding formations. The study† of a mass of gabbro, also surrounded by schist and

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*Dr. Jackson, in an early article on the cumberlandite, speaks of the occurrence of veins of serpentine on the land of a Mr. Whipple near the hill. Careful search has been made for these veins but without success. Several good sized bowlders of a dark green, massive serpentine have, however, been found in the lots northwest of the hill. These are probably from the veins referred to by Jackson, which have doubtless been blasted out and removed in the clearing and improvement of the land carried on here in recent years. What relation these veins may have had with the surrounding formations cannot now be told.

† Private contribution from Dr. G. F. Loughlin.

granite, near Norwich, Conn., distant some eighty miles in a southwesterly direction from Cumberland, has shown that the gabbro was intrusive into the schist but earlier than the granite, which evidently found its way through the easily ruptured schists, but could not penetrate the more massive and resistant gabbro. This gabbro was intruded into the sediments prior to regional metamorphism, during which it appears to have acted as a resistant plug against which the surrounding rocks were compressed. It seems not unlikely that similar relations are true in the case of the gabbro and cumberlandite, both of which have clearly suffered from extensive metamorphism.

Finally it is to be noted that the gabbro extends around to the northeast and reaches a point about northwest of Iron Mine Hill.

The mineral composition of the gabbro is of especial interest in connection with the latter's relation to the cumberlandite. A study of the rock in the field and laboratory show that it was originally a rather coarse (millimeter) grained rock, consisting of labradorite (averaging about Ab_1An_1), a purplish augite of distinctly diabasic habit, an unusual amount of ilmenite in the form of large conspicuous grains closely associated with the augite and accessory apatite. Olivine or pyroxenes, other than augite, and original hornblende are entirely lacking. Original magnetite was very sparingly present if at all. Shearing and metamorphism appear to have affected the rock quite unevenly. The central and southern portions are the least affected. On the eastern side, along the ridge facing the hill and in the ledges which mark the northeastern extension of the mass, the rock is profoundly altered. The feldspar has gone over to a dull white saussuritic substance, the secondary hornblende and biotite formed from the first alteration of the augite and ilmenite have altered almost completely to chlorite and epidote, and the remaining ilmenite has changed to leucoxene. The rock is now somewhat schistose, the original texture having practically disappeared so far as its macroscopic appearance is concerned, although it is easily made out microscopically. The rock has assumed a greenish white color in striking contrast to the dark, greenish brown of the least altered forms. Various gradations between these forms can be seen in the field. Toward the granite and schist on the northwest, the gabbro has been severely sheared and has become a fissile green schist, while in the extreme northeast extension of the gabbro it has passed into a pale greenish white, schistose rock composed of finely crushed feldspar, saussuritic products, chlorite, epidote, leucoxene and some sericite. The light color and feldspathic appearance of the more highly altered forms of the gabbro doubtless account for its classification as a syenite by some of the earlier investigators in the region.

Conclusions as to the relations of the two basic rocks.—The presence of numerous inclusions of the gabbro in the cumberlandite, particularly on its western side, argues in favor of a not very distant contact between the two rocks. If we connect the north- and southeastern ends of the gabbro as shown on the map, it can be seen that the contact with the cumberlandite would lie near to what, from other considerations, is thought to be the western limit of the latter. If the gabbro extends somewhat farther northeast than its present outcrops show, as is very probable, the line of contact would lie still closer to the present hill. The inclusions of the gabbro in the rock of the hill show clearly the latter is the younger of the two, and that they do not grade into one another, as is the case with so many occurrences of "titaniferous iron ores" associated with gabbroitic rocks. The basic character of both, their large content of ilmenite and their occurrence as adjoining masses entirely surrounded by genetically unrelated rocks is strongly suggestive that they are offshoots from a common magma.

PART II—*The Petrography and Mineralogy of Iron Mine Hill, Cumberland, R. I.*

The Rhodose (*Cumberlandite*).—Macroscopically the typical rhodose may be described as a rock composed of colorless to white plagioclase crystals, embedded in a black, granular groundmass possessing a metallic to resinous luster and a tough, irregular fracture. The appearance either in the ledge or hand-specimen is highly characteristic and with a specific gravity of almost exactly four the rhodose is exceptional in character.

On weathering, the feldspar whitens and assumes a chalky appearance. The olivine alters readily to a reddish or brownish ferruginous clay, leaving the black ilmenite and magnetite in granular relief. The weathered layer, once formed, acts like a blanket and serves to protect the rock beneath very effectually from further action.

The groundmass is easily resolved with the aid of a lens, less easily with the eye alone, into two constituents, one, a yellowish, glassy olivine (hyalosiderite) exhibiting frequently well developed cleavage surfaces, and the other, a grayish black mass of magnetite and ilmenite. In slightly weathered specimens the olivine assumes a yellowish green to brownish color and is then easily distinguished by the eye.

The feldspar.—The plagioclase makes up about 13 per cent by volume of the rock. The crystals have generally a thinly tabular habit parallel to 010, and vary considerably in size from minute grains up to individuals 2 or 3^{mm} thick by 2^{cm} square. The average, and likewise the most common size, is perhaps about 2^{mm} thick by 1^{cm} square. By the very general segregation of two or more of the feldspar crystals together, the rock assumes what may be termed a "cumulophyric" texture.[*] A more or less distinct parallel (fluidal) arrangement of the feldspars may be noted in portions of the ledge and in individual specimens, but no single direction of orientation has been made out in the rock as a whole. The direction, therefore, which any particular surface of the ledge or of a hand-specimen makes with the local direction of flow, taken in connection with the tabular habit of the feldspar, determines very often the apparent abundance or paucity of the feldspar phenocrysts on the surface in question. In some of the bowlders found on the edge of the swamp to the west and believed to have been loose bowlders taken from the old talus or drift about the hill, the feldspars have a very marked parallel arrangement. While a careful study of the outcrop shows that the feldspar is more abundant in some places than others, it seems highly probable if not certain that the feldspar had a fairly uniform distribution in the rock as a whole.

Although the characteristic tabular habit of plagioclase is strongly developed it is rather surprising to note, particularly in thin section, that the crystal outlines are always rounded toward the minerals of the enclosing groundmass. The rounded ends may be sometimes seen buried in an olivine or ilmenite-magnetite[†] grain and actual inclusion of small feldspar anhedrons by the olivine are not uncommon. On the other hand, the margins of the feldspars are indented by the groundmass grains, and as noted by Wadsworth, small "tongues" of feldspar run out into the groundmass. Occasional irregular pieces of feldspar may also be seen in the interstices between the olivine and ore. Olivine and ore grains are also imbedded in the feldspar, but so far as observed, these are always situated either on the contacts between individuals, along fracture lines, or in fractured portions of the feldspar near the border. Their mode of occurrence has led to the conclusion that they have reached their present positions not through crystallographic inclusion but by mechanical means. The feldspar crystals are bent, broken, the parts deorientated and recemented; again they are jammed into other feldspars as well as into the surrounding groundmass. Everywhere there is abundant evidence of movement.

[*] See The Texture of Igneous Rocks, Jour. Geol., vol. xiv, No. 8, 1906.

[†] The ilmenite-magnetite will for brevity hereafter be generally referred to simply as *ore*.

Some idea of this texture may be obtained from the accompanying sketch.

The feldspars are beautifully twinned after the albite and carlsbad laws, rarely after the pericline. Extinction angles measured in sections perpendicular to the albite lamellæ after the method of Michel Lévy, indicated a labradorite, varying in composition from Ab_1An_1 to Ab_3An_4. Plates parallel to *b*, 010, show the emergence of a bisectrix inclined to the normal. Extinction angles measured on basal cleavage plates gave values of from 5 to 8 degrees. Homogeneous fragments of the feldspar free from inclusions sank in the Thoulet solution from 2·687 to 2·706, an average of 2·69.

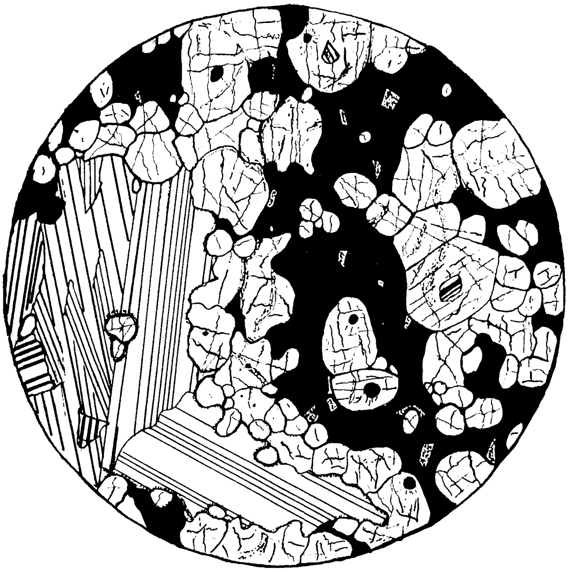

Fig. 2. The sketch shows the textural relations of the minerals in the rhodose. The feldspar is ruled to show the position of the twinning lamellæ and the peculiar arrangement of the deorientated parts. The black represents the ore with inclusions of olivine and spinel (dotted). The olivine is shown with inclusions of ore and feldspar.

The chemical composition of the feldspar as calculated from the rock analysis is that of a labradorite Ab_3An_4, a figure in agreement with the composition indicated by the optical properties and the density. A well marked although somewhat irregular zonal structure has been noted in sections cut parallel to (*b*)010. The variation in the optical properties of the different zones is, however, very slight and the variation in chemical composition must, therefore, be also small. No orthoclase has been observed.

Along the fractures in the feldspar crystals some alteration material is noticeable. This consists largely of actinolite mixed with some kaolinite and a little calcite or dolomite; otherwise the feldspars are quite fresh. Where the plagioclase comes in contact with the groundmass, a characteristic reaction rim is always developed. The reaction material consists essentially of pale green to colorless actinolite needles orientated perpendicular to the contact. When in contact with the ilmenite-magnetite, shreds of biotite frequently make their appearance and sometimes constitute the entire rim. The biotite often lies next the ore, as a narrow border, and a change into actinolite may sometimes be seen on the side towards the feldspar. The width of the reaction rims appears to be somewhat greater about the ore than about the olivine, but in any case they are exceedingly narrow, varying between approximately $\cdot 003^{mm}$ and $\cdot 01^{mm}$, rarely exceeding the latter figure. The rims are too narrow to in any measure account for the rounded character of the feldspar outlines. The formation of the reaction rims appears to have been quite distinct from the more extensive metamorphic alteration which replaced the feldspar with chloritic material.

A few crystals of biotite, exactly like the biotite shreds associated with the actinolite in the reaction rims, are met with throughout the rock. They are always associated with the ore and are clearly secondary. This suggests, at least, that the biotite observed in the closely related rock from Täberg, Sweden, may also be secondary.

Enclosed in one or two of the feldspar crystals, several irregular grains, of a colorless to brownish, highly refracting, isotropic substance were observed. They have not been positively identified, but are thought to be garnet.

The groundmass.—A polished surface of the rock serves admirably to bring out the texture of the groundmass. The ore, if looked at directly, possesses a grayish black color, but if viewed at an angle, shows a peculiar and characteristic bronze tint. It forms a more or less continuous network through the rock and serves as a matrix for the olivine. No crystallographic outlines have been identified with certainty in the ore. The olivine occupies somewhat more than one-half of the surface, possesses a dark, glassy appearance, in sharp contrast to the ore, and is characteristically rounded in outline.

The ore.—On etching the polished surface with hydrochloric acid, a delicate reticulate structure is developed in the ore. With a direct illumination under the microscope, this structure is seen to consist of an intersecting series of bright gray, narrow bands or lamellæ enclosing dull black depressions. This structure extends everywhere through the ore except over occasional small areas which have a smooth surface and are identical with the bands in appearance and presumably in composition. The lamellæ are frequently observed to cross at angles of nearly or exactly 60 degrees; again they form a nearly rectangular grating. This structure taken in connection with the well known tendency of ilmenite to develop a reticulate structure parallel to the rhombohedral planes, suggests at once that the lamellæ are ilmenite enclosing the more easily dissolved magnetite. The change in direction of the bands in different parts of the ore matrix is the only indication of the existence of individual grains in the ore.

The ratios derived from the rock analysis show conclusively that the two molecules, $R^{II}TiO_3$ and $R^{II}R^{III}_2O_4$, are present, and in about equal proportions. The magnetic susceptibility of particles of the ore, free from olivine and feldspar, was found to be intermediate between that of pure magnetite and ilmenite. It appears, therefore, that the ore matrix consists essentially of an intimate intergrowth of magnetite and ilmenite with an occasional grain of what is probably pure ilmenite. The parallel intergrowth of members of the spinel family with ilmenite has long been familiar to mineralogists and a similar intergrowth has been suggested by a number of petrographers to explain the composition of the "titaniferous magnetites" of many rocks. Quite recently Hussak[*] has shown by the study of etched surfaces that intergrowths of ilmenite and spinel minerals, particularly magnetite, are very general in the titaniferous ores of Brazil. He also gives a full bibliography of the literature on the subject. It would be extremely interesting to extend the study of titaniferous magnetites still further and ascertain to what extent, if at all, an intergrowth like the one described in the present instance exists in other occurrences. There is still, in spite of the considerable amount of investigation which has been carried on upon "titaniferous-magnetites," much uncertainty regarding the exact relations of these two mineral molecules when occurring together.

Spinel.—Examined in thin section the edges of the ore show a fine granularity under high powers. Numerous small crystals of a dark green, feebly transparent, isotropic mineral of an angular or sub-angular habit are enclosed at random in the ore. They are never found outside of it. A few of the grains have distinct crystallographic outlines suggestive of isometric crystal sections, and many are crossed by sharp, straight (cleavage?) cracks. The crystals vary in size from exceedingly minute individuals up to those measuring $0{\cdot}45^{mm}$ long by $0{\cdot}12^{mm}$ wide. They occur

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[*] Jahrb. f. Min., etc., Bd. I, Heft II, 1904, pp. 94-113.

more commonly, however, as roughly equidimensional grains from 0·10 to 0·20^{mm} in average diameter. They were called glass by Wadsworth and were thought to be hercynite by Geo. H. Williams, to whom they were submitted by Wadsworth for examination. The crystals are very refractory to chemical decomposition since a few were found undecomposed by sulphuric and hydrofluoric acid in some of the ferrous iron determinations made on the rock. They are undoubtedly spinels (pleonaste), an identification substantiated by the ratios derived from the rock analysis given beyond. Spinel is lacking in sections cut from some of the bowlders previously referred to, but appears, however, to have been generally present in the rock of the hill, and its absence in the bowlders probably indicates only a local variation in the composition of the magma.

The olivine.—The olivine is nearly colorless in thin section with but a slight brownish or yellowish tint, and is remarkably fresh throughout. Fractures are abundant, and the basal and brachy-pinacoidal cleavages are better developed than with ordinary olivine. Between crossed nicols the olivine is broken up into a mosaic of anhedral grains, showing all gradations in size from mere points up to individuals 5^{mm} long and 2·5^{mm} wide. In a few instances an olivine grain has been observed with a distinct crystallographic outline against the ore, but in general the olivine, like the other constituents (except the spinel), are conspicuously lacking in crystallographic outlines. Single olivine anhedrons are everywhere to be seen *enclosed* in the ore, and throughout the rock the latter acts always as the matrix.

The olivine anhedrons are often separated from one another by strongly marked black borders, consisting of minute opaque, black grains, accompanied by some that are reddish or brownish by transmitted light, and very similar in appearance to the inclusions in the olivine. These borders are commonly *continuous* with the ore matrix.

As previously noted, the olivine anhedrons are traversed by many fractures. These often extend through several individuals, and more rarely form a series of rudely parallel fractures, extending across the entire section. In the latter case they are sometimes filled with granulated material of the mineral, through which they pass, and are more or less discolored with serpentinous matter. More commonly they are filled with the same black, finely granular material that lies between the crystals. In several slides examined, numerous fractures were observed, radiating outward into the surrounding olivine from an ore grain. It appeared as if the olivine had been shattered against the ore and the resulting fractures filled with oxides derived from it. The *olivine* crystals *very generally enclose* small anhedral *ore* grains, and are rich in other inclusions. These consist in part of minute black particles and in part of cavities. Many of the latter contain ferruginous matter. While the cavities occur at random through the crystals, they are commonly arranged along curious, wavy, ribbon-like lines which do not, so far as observed, follow any crystallographic directions and often extend across more than a single individual. In form the cavities are similar to those noted by various authors in the olivine from other rocks—round, elliptical, or irregular, branching and amœba-like in shape. Their general appearance and their ferruginous filling point to their being solution cavities formed, perhaps, along old healed-up fracture lines. Many of the opaque particles have the same shape and mode of occurrence, and are, perhaps, cavities entirely filled with ore derived from the matrix. It is possible that others are true crystallites of magnetite and ilmenite included by the olivine. It is noticeable that the strings of inclusions and the material distributed along the fracture lines, like those between the crystals, tend to merge to a greater or less extent into the main body of the ore matrix. Although part, perhaps most of these perplexing inclusions, are probably of secondary origin, it is impossible to escape the feeling that many of them, like the larger included ore grains, represent crystallizations from the magma which were caught by the rapidly crystallizing olivine.

The mean index of refraction of the olivine was found by the immersion method to be about 1·712, which is considerably above that for ordinary olivine, as is also its specific gravity, 3·728, as determined by the pycnometer at 20 C. on carefully selected material separated from the crushed rock by magnetic treatment.*

A chemical analysis (by Warren) of this material gave the following results:

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*Several hundred grams of the crushed rock, from which the finest dust had been removed by washing, was passed through an 80 mesh screen and subjected to a magnetic treatment by which three fractions were made:—No. 1 ilmenite-magnetite mixture; No. 2 olivine; No. 3 feldspar and other non-magnetic materials. Fraction No. 2 was again fractioned with great care, using a magnetic field of varying intensity, until a small fraction of clear yellowish olivine grains was obtained, which showed under the microscope almost none of the ferruginous material so abundant in the greater proportion of them. The material thus obtained was used for the analysis. The mean index of refraction of this material was found to be the same (by the immersion method) as that of the olivine taken out with a weaker magnetic flux because of included ore, indicating that the olivine is of uniform composition.

	I	Ratio		II Calculated to 100%	III Kaiserstuhl
SiO_2	37·16%	·619	·619	37·3	36·72
TiO_2	·07				
Fe_2O_3	·12				
FeO	31·38	·436	1·220	31·5	29·96
MnO	·40	·005			
CaO	tr.				
MgO	31·16	·779		31·2	31·99
Feldspar Insoluble	·34				
	100·63			100·0	98·67

The ratio $RO : SiO_2 = 1·97 : 1·0$, or very nearly 2 : 1.

The olivine of the rock is, therefore, a *hyalosiderite*, or iron rich variety, and corresponds very closely in composition to that of a hyalosiderite (see column III above) given by Dana (p. 453, Analysis No. 32), from a basalt described by Rosenbusch from the Kaiserstuhl.* The specific gravity of the latter is given as 3·566, which is considerably lower than that of the one just described. An estimate of the specific gravity of an olivine of this composition based on the specific gravity of fayalite, fosterite and certain common chrysolites, gave 3·70, which is in good agreement with the value found experimentally in the present investigation. It would therefore seem that 3·7 represents the true specific gravity of an hyalosiderite of about the above composition.

The Crystallization of the Rhodose.†—The unusual mineral composition of the rhodose and its peculiar texture raise many interesting questions regarding the manner of its crystallization from a molten condition which are deserving of careful consideration. The cumulophyric arrangement of the feldspar and the undoubted inclusion of crystals of the latter within the olivine indicate that the feldspar was the first mineral to separate from the magma. In order for the feldspars to have attained so large a size and to segregate into isolated groups, a considerable degree of molecular mobility is demanded, which could have hardly obtained if the surrounding minerals, con-

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* Jahrb. f. Min., etc., p. 50, 1872.

† The writer is fully aware that he is not in possession of the thermal data, and other physical constants, nor of a knowledge of the possible equilibrium conditions that might exist between the various components of the magma, so essential for an exact and satisfactory discussion of its consolidation. The purely petrographical evidence in the present case is of such a character, that notwithstanding an insufficient basis, a guarded discussion of the problem will be entered into, believing that it may contribute something of value to the more general problem of rock crystallization.

stituting by volume upwards of 85 per cent of the solid rock, were in the act of solidifying or had already done so. Whether the feldspar did separate first or not, its final outlines were determined by the surrounding minerals. It is to be noted that the feldspar exists only as the pure phase-feldspar—and is not seen in any relation to the other minerals which can be interpreted as a eutectic structure. Feldspar is not seen within the body of the ore.

The ore, although it consists of three distinct minerals, so far as its textural relations to the other minerals are concerned, behaves as a textural unit and will be looked upon as such. Within the olivine are included ore grains of some size not to mention the finer grained inclusions which may be in part secondary. Besides inclosing the olivine collectively as a matrix, the ore contains many single crystals of olivine inclosed in the body of its substance. Nevertheless the ore and the olivine have as a whole separated from each other and the olivine has clearly dominated the situation, forcing the ore into the rôle of a containing matrix. Here again there is nothing that suggests a eutectic structure.

The constituent minerals of the ore matrix also bear very interesting relations to one another. The spinel, or a part of it, and a little of the ilmenite crystallized first. The remainder consolidated as an intimate intergrowth of ilmenite and magnetite in which the ilmenite acted as the host. To those familiar with the solidification of alloys or salts, this intergrowth suggests by its appearance a eutectic mixture of ilmenite and magnetite. The exact quantity of spinel which exists as a pure phase has not been estimated, but it is likely that some of the spinel molecule remains in isomorphous relations with the magnetite. Whether the intergrowth is a true eutectic mixture or not can of course only be told by experiment, and so far as the writer is aware, no experimental study of the system ilmenite-magnetite has ever been made. It seems likely that such a study would throw not a little light on the character of "titaniferous magnetites" and steps have been taken toward carrying one out. It may be remarked in passing, that the relatively low consolidating temperature of eutectic mixtures compared with those of the individual constituents is in keeping with the fact that the ore was the last portion of the rock to consolidate.

It appears clear to the writer that the feldspar was the first mineral to separate from the magma and that the olivine and the ore then separated in some manner from each other and crystallized. The crystallization of so large a proportion of the magma (ore plus olivine nearly 85 per cent) must have given rise to a considerable evolution of heat, in amount perhaps sufficient to again raise the feldspar above its melting point. It has been shown by Day and Allen* in their paper on the "Isomorphism and Thermal Properties of the Feldspars," that a plagioclase crystal of acid composition if raised to a temperature somewhat above its true melting point, persists for a time as a metastable phase without the crystal as a whole undergoing molecular deorientation. The crystals in such a condition behave like hyperviscous liquids and are capable of yielding to mechanical deformation. If then the feldspar in the rhodose were in such a condition, the crystallization of the olivine and ore under pressure might reasonably be expected to cause marked changes in the outlines of the feldspar crystals. Add to these conditions the effect of movements in the mass, even if slight, and we have a very probable explanation of the relations between the feldspar and the groundmass minerals. The indentation and molding of the feldspar outlines by the other minerals, the occurrence of small crystals of olivine and ore within the feldspar substance along boundaries, between crystals, near the margins and along fractures, the bending, deorientation and recementing of parts of the feldspar crystals, in short, all the peculiar textural features of the feldspar crystals and their relations to the other minerals as seen in thin section are what might be expected if such a state of affairs as outlined above had obtained.

One can hardly escape contrasting the conditions of stable equilibrium which obtained in this rock with those existing in the much better understood systems of salts and alloys of the laboratory. The phases found here are, plagioclase, olivine and ore, the latter, as pointed out, existing texturally as a unit although it is made up of three distinct minerals. We have in the rock no textural evidence of the existence of eutectic structures nor of solid solutions between the phases. The ore alone bears a possible analogy to the cases of salts and alloys. In the case of the feldspar it is perhaps not difficult to understand how it might develop relatively large crystals or groups of crystals in a comparatively mobile magma, such as the molten olivine and ore would make when melted. The feldspar is apparently entirely immiscible in the magma, or the solid phases resulting from the latter's consolidation, by the time it has reached its freezing point. With the ore and olivine it is more difficult to see how they could have separated in the way they have if the separation

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* This Jour. (4), xix, 1905. It is assumed by the writer that the high viscosity of the plagioclase Ab_1 An_1 would be sufficient to cause it to behave in a degree like the more highly acid feldspars.

was wholly a part of the act of crystallization. Whether the olivine preceded the ore in time of crystallization or whether the two crystallized at the same time, we have to explain how a material in the act of orientating its molecules can forcibly expel another and move it through a molecularly great distance. If the expulsion is a part of the act of crystallization then it must have begun about a great number of irregularly situated centers and proceeded gradually outward, the growth of the one mineral (in the present case the olivine) forcing the other toward the surrounding centers until finally the expelled material from the many centers would necessarily occupy an interstitial position with reference to the first mineral. If the interstitial material were still liquid it would then solidify when its own freezing point was reached. The position and character of the ore is quite in keeping with such a procedure. Another supposition which is possible is that the minerals become immiscible before their freezing point is reached and being then in a relatively mobile condition they would segregate readily, and subsequently solidify independently, their textural relations to each other being in such case determined by their individual freezing points, their relative velocity and power of crystallization, and their relative volumes. The inclusion of ore grains, as well as that of the minute opaque particles, a part of which may reasonably be considered as primary crystallizations, within the olivine crystals and along their boundaries, is quite in keeping with either of the above suppositions. The inclusions are merely a portion of the ore which was prevented from segregating with the rest by the decreasing mobility of the crystallizing olivine.

This last supposition involves the idea of liquid immiscibility in silicate melts. This has been proposed by some to explain rock differentiation,* but there appears to be no convincing evidence, certainly not experimental,† of immiscibility in molten silicate mixtures. Nevertheless, the mechanical difficulties involved in the segregation of the various minerals into the positions occupied by them in the rhodose (as well as of the minerals in many other rocks) seem to be considerably less if liquid immiscibility can obtain, than would be the case if the separation took place during crystallization, at which time one would expect, in most instances, great resistance to freedom of motion and the minerals might be expected to crystallize as a fine-grained, intimately mingled aggregate such as is the case with eutectic mixtures. The idea of liquid immiscibility seems at least worthy of careful consideration.

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*See H. Bäckström, Jour. of Geol., vol. i, 1893, p. 778.

†See Vogt, Die Silicatschmelzlosungen, vol. i, p. 100, vol. ii, p. 228, and A. L. Day and E. S. Shepard, Econ. Geol., vol. i, 1905, p. 286.

Chemical Composition and Quantitative Classification.—Material for chemical analysis was obtained by breaking off a large number of good-sized fragments from the parts of the ledge where quarrying had exposed a comparatively fresh surface. These fragments were broken into smaller pieces and of these about 3 kilos were crushed in a chilled steel mortar, care being taken to avoid pieces showing any signs of alteration. The entire lot was then sampled so as to yield a product representative of the average composition of the rock.

The presence of so much titanium* makes the analysis of this rock of more than usual difficulty, and accordingly especial pains were taken to insure the correctness of the various determinations. The results of the analysis with the molecular ratios and their apportionment to the various "normal" minerals are as follows:—

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* The writer is indebted to Professor Henry Fay of the chemical department of the Massachusetts Institute of Technology for the details of a highly satisfactory method, both in point of simplicity and accuracy, for the determination of the titanium. The principles involved present nothing new, but the exact details of the method do not appear to be known to petrographers at least, and for the benefit of those who may have occasion to analyze rocks rich in TiO_2 the directions for the carrying out of this method are given herewith. By observing these carefully, excellent results will be obtained. Where extremely accurate determinations are desired, a third repetition of the separation may be made. In two made during the present investigation, only one one-hundredth of one per cent of iron could be detected in the TiO_2 precipitate. Aluminium and manganese are probably included to about the same amount.

Fuse 0·4 to 0·6 gms. of finely ground ore with 6 to 8 times its weight of sodium carbonate. Extract the mass with hot water, and decant the solution through a filter. Boil the residue with 25 cc. of sodium carbonate solution, filter, and then wash the residue on the filter paper several times with dilute sodium carbonate solution. Ignite the filter and residue in a platinum crucible at a low temperature until the filter paper is burned. Fuse with 12 to 15 parts of dry acid potassium sulphate for one-half hour. The temperature of the fusion should be so regulated that the mass is kept in the molten condition, but fumes of sulphur trioxide should escape only when the lid of the crucible is removed. Cool and remove the fusion from the crucible by means of a platinum wire. Suspend the fusion in 200 cc. of *cold* water to which has been added 100 cc. of sulphurous acid and allow to stand in a cool place until solution is complete.

Filter if necessary. To the solution add 125 cc. of acetic acid (sp.gr. 1·04) and dilute to 800 cc. in a liter beaker. Add 20 gms. of sodium acetate dissolved in a small amount of water and boil from 3 to 5 minutes, adding *just before the boiling point is reached* an additional 25 cc. of sulphurous acid. Allow to stand in a warm place for one-half hour and then filter by means of a siphon through a 9^{cm} paper.

Wash the precipitate with 5 per cent acetic acid solution until most of the sulphate has been removed and then ignite the paper and precipitate and fuse with acid potassium sulphate again. Proceed exactly as before, wash thoroughly, finally igniting and weighing the precipitate as TiO_2. The latter in the writer's experience always has a light to dark gray color.

	Per cent	Mol.	Ilmenite	Magnetite	Orthoclase	Albite	Anorthite	Olivine	Spinel
SiO_2	22·35	·372			·006	·042	·040	·284	
Al_2O_3	5·26	·051			·001	·007	·020		·023
Fe_2O_3	14·05	·088		·088					
V_2O_3	·18	·001		·001					
Cr_2O_3	tr.								
FeO	28·84	·400	·125	·089				1·86	
MgO	16·10	·402						·377	·025
CaO*	1·17	·020					·020		
Na_2O	·44	·007				·007			
K_2O	·10	·001			·001				
H_2O-	·42								
CO_2	·02								
TiO_2	10·11	·125	·125						
P_2O_5	·02								
S	·38	·012							
MnO	·43	·005						·005	
Zn*	·71	·010							
Cu	·08	·001							
(Co&Ni)	·08	·001							
Pb	tr.								
Total	100·74								

In the non-magnetic residue obtained in isolating the olivine previously described, some sphalerite and chalcopyrite as well as a few galena and pyrite grains were identified. The sulphur is therefore not all present in the sphalerite and chalcopyrite. Some of the zinc may also enter into the spinel molecule. The amount of sulphides found may be in excess of the amount really in the normal rock. Since the analysis was completed a minute vein of sulphides has been observed in a specimen similar to those used for analysis, but no trace of sulphide has been noted in the rock outside of this vein. It is possible that such a vein slipped unnoticed in to the sample analyzed. In such case, however, the classification is not materially affected thereby. The classification is as follows:

Or	0·56	
Ab	3·67	9·79 sal.
An	5·56	
Ol	45·70	
Mt	20·65	90·05 fem.
Ilm	19·00	
Spinel	3·55	
Sulphides	1·15	
	99·84†	

$$\frac{\text{sal}}{\text{fem}} = \frac{9\cdot79}{90\cdot0} = 0\cdot10 = 5, \text{ Perfemane.}$$

$$\frac{P+O}{M} = \frac{45\cdot70}{39\cdot65} = 1\cdot1 = 3, \text{ Rhodare.}$$

$$\frac{(MgFe)O+CaO}{K_2O+Na_2O} = \frac{807}{8} > \frac{7}{1} = 1, \text{Rhodase.}$$

$$\frac{MgO}{FeO} = \frac{402}{405} = 0\cdot99 = 2, \text{ Rhodose.}$$

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* Sphalerite 0·004 Chalcopyrite 0·004

† After the completion of the calculation it was noticed that the dropping off of fractional parts in several instances had resulted in reducing the total of the norm and making a small discrepancy between it and the total of the

The rock is therefore perfemic, polmitic, permirlic, and magnesiferous, its coördinates in the quantitative classification being 5, 3, 1, 2. Furthermore it falls in section 5 of its order, and in section 1 of its rang, and may therefore be further defined as perolic and permiric. As there is as yet no name in the quantitative classification for either the order or rang in which this rock falls, it is necessary to choose a name. Rhodare* and Rhodase (-ose) have been chosen, using the name of the state in which the rock occurs for a stem to which the appropriate termination may be affixed. This has been chosen in place of Cumberland—since the latter is the name of an obscure and almost unknown town and might be confused with Cumberland, England, a well known locality.

The rock finds a place in the classification in which there are practically no heretofore adequately studied rocks and is therefore of particular interest.

As the olivine is the only one of the groundmass minerals whose exact chemical composition has been determined directly, it was assumed, in apportioning the FeO, MgO, and MnO between the four modal minerals, olivine, magnetite, ilmenite, and spinel, that the magnetite is represented by the formula $Fe^{II}Fe_2^{III}O_4$, the spinel by $MgAl_2O_4$, and that the remaining MgO and the small amount of MnO are contained entirely in the olivine and ilmenite. It seems unlikely, however, that any considerable error is involved in this assumption. Adjusting, therefore, the above mentioned oxides between the olivine and the ilmenite in accordance with the ratios obtained from the mineral of the olivine, we obtain the following as the true composition, or mode, for the rock :

	Mode.		
Mineral.	Per cent. by weight.	Per cent. by volume to 100%.	Sp. gr. used.
Orthoclase	0·56	0·8	2·55
Labradorite Ab_3An_4	9·23	13·7	2·69
Olivine (hyalosiderite)	46·08	49·4	3·73
Magnetite	20·65	15·9	5·17
Ilmenite	18·63	15·2	5·0
Spinel	3·55	3·9	3.6
Sulphides	1·15	1·1	4·1
	99·85	100·00	

Composition of the ilmenite calculated to 100%.	
TiO_2	53·6
FeO	42·5
MnO	1·3
MgO	2·6
	100·00

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analysis (less H_2O = 0·42 per cent). It does not affect dependent figures materially and it has not been thought worth while to recalculate the whole for so trifling a matter.

* The use of the name Rhodare, etc. was first suggested by Professor L. V. Pirsson, to whom the writer's thanks are due.

A computation of the specific gravity of the rock, from its percentage composition and the specific gravities of the individual minerals given above, gives 4·003, which is in close agreement with the figure obtained experimentally, 4·005, by J. E. Wolff, quoted by Wadsworth, and of 3·92 by the writer.

With regard to the volume percentage (see above table) of the different minerals, it is to be noted that the olivine makes up one-half of the volume of the rock, while the magnetite and ilmenite occupy, relative to each other, almost exactly the same space, and make up a total of 31·1 per cent. In the last column of the above table is given the percentage composition of the ilmenite calculated to 100 per cent.

Transition Type.—In going either north along the ledge from the exposure of the unaltered rock, or downward and to the west (outward), within a few yards one comes upon what is a transition into the more highly altered types of the hill. The transition zone seems to be of variable width, but never exceeds a few yards in actual measure. The rock is distinguished macroscopically from the original by the presence of a dark green, amorphous border of alteration material about the plagioclase crystals. This border is the first indication of a change, and as one goes farther from the unaltered rock it grows broader, spreading out irregularly into the groundmass, while at the same time the core of feldspar grows smaller.

As seen in thin sections without crossed nicols, the alteration border is apparently homogeneous except for occasional specks of actinolite or ore, and differs in appearance from the core of unaltered feldspar in being less transparent, in possessing a pale yellowish-green discoloration, a somewhat higher index of refraction and consequently a different surface. That its index is higher than the feldspar was proved by observing the total reflection phenomena at the contact between the two after the method developed by Van der Kolk and elaborated by F. E. Wright* and also by the well-known method of Becke. Between crossed nicols the border is resolved into two distinct substances.

One is seen directly in contact with the feldspar and is clearly the first product formed. The structure is more or less confused but may be described as semi-compact to sub-fibrous and often shows a divergent structure (plumose). Distant from the feldspar the structure becomes still more confused but at times approaches a granular texture. As near as can be told, the extinction is parallel to the elongation, as is also the direction of vibration of the slower ray (C). The interference colors have never been noted higher than yellow of the first order in sec-

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* This Journal, No. 167, vol. xvii, pp. 385–7, 1904.

tions about 0·03^{mm} thick. This would indicate a double refraction a little higher than the feldspar.

The second substance is in part enclosed in the first in the form of irregular patches. It replaces the first substance entirely toward the margins and where the feldspar has entirely disappeared it occupies the center of the area. With high powers between crossed nicols it is seen to consist of an aggregate of minute fibers and crystal plates often closely thatched. Individual crystals have a distinct cleavage or lamination parallel to their length, to which the extinction is parallel and which is also the direction of the vibrations of the faster ray (A). The interference colors are a peculiar dull, dusty gray, for 0·03^{mm} thickness. With low powers the aggregates appear almost isotropic. The characters of this mineral indicate that it belongs to the chlorite family, probably near the variety clinochlore. This identification has been repeatedly confirmed by study of the same mineral, more coarsely crystalline, in the altered types described beyond, and is strongly supported by chemical considerations (see later) as well as by the occurrence of clinochlore in the veins which cut the rock of the hill. The identity of the first mineral substance is not so clear, but its easy passage into the chlorite as the alteration progresses points to a very close relationship between the two. The identification of chlorite, previously supposed to be serpentine, adds not a little interest to the chemical aspects of the alteration process.

Enclosed in this pseudomorphic material, at or near the feldspar, are occasional irregular apparently isotropic bodies of a brownish color and a high single-refraction. They have not been positively identified. More or less actinolite in the form of minute prisms and a few black particles are scattered through the chlorite.

About the spaces originally occupied by the feldspar, the ore is more or less frayed out and finely granular, and clearly shows the effects of alteration. Here too the olivine grains are to a greater or less extent replaced by the chlorite. This replacement begins at the borders, and while there is a well marked tendency for the fibers to follow the direction of the basal cleavage, their direction is often irregular. This chloritic replacement is often either accompanied by, or immediately followed by an *actinolitic* one. The latter is strongest in the neighborhood of the chloritic areas, but occurs to a variable degree elsewhere. Olivine crystals surrounded by a border of chlorite may be seen containing one or two well-developed crystals of actinolite, or the crystal, within the border, may have been wholly replaced by one, two, or a greater number of actinolite crystals. The actinolite retains many of the original inclusions of the olivine, which have, however, undergone more or less rearrangement and recrystallization. Between the olivine, which is now very often somewhat discolored, and the ore, and sometimes between the olivine crystals where these are near the ore, there is everywhere developed a narrow band of chlorite crystals. The continuity of the ore matrix is now somewhat broken, probably along the boundaries of individual grains, and the breaks are filled with chloritic material. The spinel is also replaced by chlorite, and can be seen in various stages of alteration. Although the ore has clearly contributed to the formation of the secondary minerals, the olivine and the feldspar have furnished by far the greater portion of the materials.

Altered Types—"Chloritic."—Beyond the transition type we find the plagioclase phenocrysts entirely replaced by the dark green, amorphous material. The greater part of the olivine is still unaltered, and is easily detected macroscopically. Crystals of a pale green to yellowish actinolite are now conspicuous in the rock, and are particularly numerous in the neighborhood of the pseudomorphic areas of chloritic material. Freshly broken specimens of the rock have a greenish black color, broken by the occasional bright cleavages of olivine, or actinolite, and indistinctly mottled by the chloritic areas. On smooth glaciated surfaces recently cleared of soil, the appearance of the thickly scattered chloritic spots whitened by exposure is strikingly suggestive of the cumulophyric texture of the original rock. Surfaces long exposed to weathering become deeply pitted where the soft chloritic spots wear away and the olivine rusts out, leaving the ore in relief. This type, which we will designate the "*chloritic type*" for convenience, as near as can be told from the exposures, makes up the greater portion of the present hill. It is most typically exposed in the large old quarry on the western side.

An examination of thin sections of this type shows that the first formed product of the alteration has entirely disappeared. Different pseudomorphic areas differ more or less in detail, but all consist essentially of chlorite and a variable amount of actinolite in the form of minute prisms. The latter are apt to be segregated particularly toward the center, which then gives a lighter color to the green areas in the hand specimen. The chlorite crystals vary considerably in size, but are on the average larger than in the previous type and show their distinctive properties more clearly. A well-developed cleavage may be seen and many crystals are twinned. There is rarely a feeble pleochroism visible. Some areas consist throughout of a finely thatched mass of chlorite, others consist of a granular aggregate of chlorite and actinolite centrally, surrounded by a much finer grained border. Traces of the original feldspar cleavage and twinning structures are often preserved in the arrangement of the secondary minerals. On the whole the areas appear to have enlarged somewhat and to have suffered more or less recrystallization and rearrangement within their borders.

The olivine is now commonly filled with a brownish dust, and has suffered from chloritic and actinolitic replacement as in the previous type, except that the process has gone further. Many olivine crystals about the chloritic areas have been entirely replaced by chlorite as well as actinolite, and fine examples showing various stages of replacement may be seen. The continuity of the ore-matrix is more often broken in this

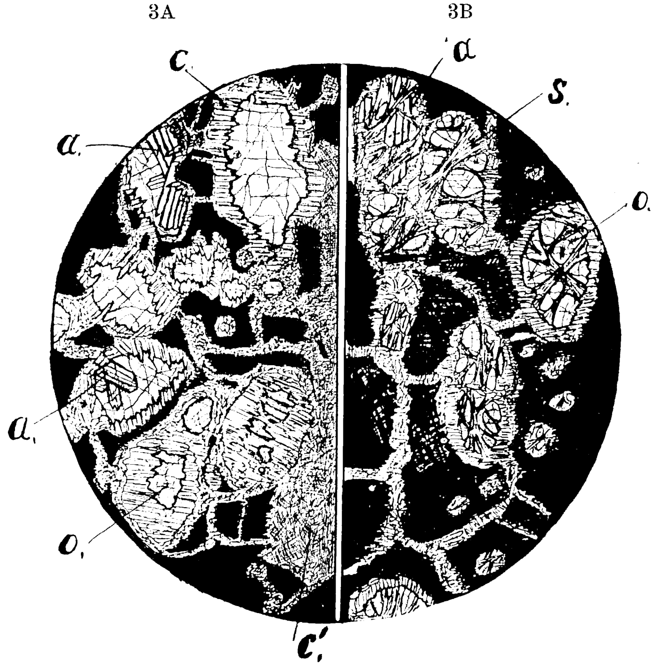

FIG. 3A. The sketch shows the relations of the minerals in the chloritic type. *o*, Unaltered olivine. *c*, Chlorite lamellæ replacing olivine; commonly lie parallel to the basal cleavage. *c'*, Fine chlorite aggregate replacing the plagioclase; only the edge of the area is shown. *a*, Actinolite prisms replacing the olivine. The black is the ore; note that the continuity of the ore is broken.

FIG. 3B. This shows the olivine (or actinolite) with the border of chloritic material lying between it and the ore, being replaced by a fibrous or lamellar serpentine, (*s*.) Here again the ore is broken and in places shows its reticulate structure.

type, and the chloritic border between the ore and the olivine is more pronounced than before. Minute veinlets, similar in character to the larger veins of the hill, are occasionally seen macroscopically and in the slides. The accompanying figure (3A) will illustrate the relations of the various minerals as seen in thin section.

Actinolitic Type.—By a considerable increase in the amount of actinolite, we pass into what may be called the "*actinolitic*" type. So far as quantity goes, it is much less important than any of the other types. It occurs locally in irregular patches or streaks through the hill. Compared with other types, specimens of it are lighter and more yellowish in color and possess also more glistening surfaces, by reason of the presence of abundant actinolite crystals of a pale yellowish green color and with highly developed cleavages. The ore is much less conspicuous as a rule. In fact, in extreme cases it is hardly noticeable, and the rock then consists practically of actinolite and the compact chloritic material. The chloritic areas seem to be rather more abundant, somewhat less distinct in outline, and show a tendency to merge into one another. The actinolite crystals rarely exceed 2 or 3^{mm} in length.

In thin section the green areas appear much the same as in the previous type. In their neighborhood the olivine is strongly replaced by chlorite as before. The actinolitic replacement, however, reaches a maximum development and frequently displaces all of the olivine. The ore-matrix, although considerably broken, preserves very well its original outlines. The chloritic borders about the olivine grains persist even where the olivine has been entirely replaced by the actinolite. Whether or not the latter mineral is affected by the chloritic alteration has not been definitely made out, but if such is the case, the process has gone on only to a very slight degree. Except in extreme cases the texture of the rock in section differs but little from that of the preceding type, and in general appearance they are also similar—actinolite lying in the place of the olivine.

The actinolite possesses a very pale greenish pleochroism and a rather high extinction angle, 20 degrees measured on the prismatic cleavage cracks. It was found by comparison (immersion method) with the vein actinolite described beyond that the two possess practically the same index of refraction. Fragments of the actinolite from the rock sank in the Thoulet solution a little more readily than that from the veins, although this may be accounted for by the presence of included ore particles without which the mineral from the rock could not be obtained. For this reason no attempt was made to analyze the mineral. The rock and vein minerals appear, however, to be essentially identical, and no great error can be made by looking upon the composition of the vein actinolite, given beyond, as representing closely that of the mineral from the rock.

Serpentine type.—Both the chloritic and the actinolitic types by the replacement of the remaining olivine, or of the actinolite, by serpentine, pass gradually into what will be called the *serpentine type.* This represents a more advanced stage in the alteration and is the predominant type at the northern end of the hill. It is also found along the eastern side, locally on top, and was probably characteristic of the peripheral portions of the mass. In appearance it resembles the chloritic type, from which it can be distinguished by its somewhat greener color and by noting with a lens the presence of a leek-green, foliated serpentine in place of the original olivine of the groundmass. The ore preserves its characteristic appearance, but has a more noticeable bronzy tint on broken surfaces than the unaltered rock.

Thin sections show that the chlorite and actinolite of the pseudomorphic areas are much the same as in the other types, although the crystals of the chlorite are commonly larger and occasionally show a delicate plumose texture while the actinolite is more strongly segregated. A variable amount of finely crystalline serpentine and ore, the latter both residual or secondary, is now mingled with the other constituents. The areas themselves appear to have encroached on the groundmass more extensively than elsewhere except perhaps in extreme cases of the actinolitic replacement.

The olivine is seen in all stages of replacement by a finely lamellar to fibrous serpentine having a beautiful divergent texture. The serpentine starts at or in the chloritic borders and shoots out at random into the olivine grains, which here are filled with a brown dust. The serpentine shows gray polarization colors, a parallel extinction and a positive elongation. The actinolite crystals seem to have undergone replacement in the same manner as the olivine. In most of the slides examined considerable residual olivine and actinolite remain in the interstices between the serpentine lamellæ, and form, with their brilliant polarization colors, a striking contrast to the dull gray serpentine.

Although the ore matrix has suffered some absorption and removal during the serpentinization, and its continuity has been more or less broken, it still retains its original outlines and therefore preserves to a remarkable degree the peculiar texture of the unaltered rock. Few rocks if any that have come under the writer's observation show phenomena of alteration and replacement in so beautiful and convincing a manner. Figure

3B will serve to give some idea of the relations of the different minerals.

Professor Wadsworth has noted the occurrence of talc and dolomite as extreme alteration products of the rock. These minerals seem, however, to be exceptional and are certainly not characteristic of the alteration as now exposed.

Conclusions regarding the alteration process.—The profound alteration which has taken place in the rhodose appears to have been affected by the long-continued action of waters from the surface. It is most severe in the peripheral portions of the rock mass and its progress seems to have been gradually inward from the margins.

The first change effected in the rock was the destruction of the plagioclase and of the olivine and ore immediately adjoining. The first product formed in the place of the feldspar is of uncertain composition, but very readily changes into chlorite and actinolite; at least these two minerals appear almost immediately. The chlorite can derive its aluminium *only* from the *feldspar*, its *magnesium* from the *olivine;* its *iron* may and undoubtedly does come from both the *olivine* and the *ore.* The *lime* from the *plagioclase* goes to form *actinolite* whose other bases seem to come principally from the *olivine* since it is the olivine that is replaced by the actinolite. The alkalies and a part of the lime have been removed. The titanium has either remained in the form of ilmenite or else has passed into the composition of the chlorite. It is perhaps remarkable that rutile* or other oxides of titanium are characteristically absent from all of the altered types.

That the solutions carrying the alumina, lime and soda and other products were diffused very generally through the rock is proved by the bands of chlorite almost everywhere developed between the ore and the olivine, as well as by the presence of actinolite distributed through the rock. The veins carrying actinolite, chlorite and hortonolite also bear evidence that material was being actively transported. That these solutions should deposit a mineral belonging to a group of minerals so characteristic of igneous origin is of especial interest.

The greater abundance of actinolite in certain portions of the hill may be accounted for by supposing that the feldspar was there more abundant and the supply of material for secondary minerals therefore more abundant. On the other hand, it is supposable that the actinolitic portions represent merely places where the mineralizing solutions were for some reason more abundant.

After the series of reactions which gave rise to the chlorite and actinolite were completed, *further alteration* resulted

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* In one or two instances reddish grains associated with the ore have been noted which may be rutile.

chiefly in the replacement of the remaining olivine and actinolite with *serpentine.*

The magnetite-ilmenite matrix seems to have been the part of the rock least affected.

For the purpose of checking in a general way the conclusions reached through microscopic study as to the mineral and chemical changes that have taken place in the rock, two partial chemical analyses have been made, one of the "chloritic" type, and the other of the "serpentinic," the later showing very little actinolite. A single specimen cannot of course be expected to represent the exact altered product of a rock of the composition of the representative sample taken for the original type, and an extensive sampling of the altered types, had there been time and opportunity to do it, would undoubtedly have yielded more satisfactory results. Nevertheless the two analyses given in the accompanying table, together with that of the unaltered rock, serve to sustain the conclusions already reached, and are instructive in showing the general character of the chemical changes which have taken place.

	Unaltered type	*Chloritic type	Serpentine type
Sp. Gr.	4·005–3·92	3·85–3·80	3·65–3·56
SiO_2	22·35	20·89	19·98
TiO_2	10·00	9·57	9·76
Al_2O_3	5·26	6·93	6·75
Fe_2O_3	14·05	17·81	19·25
FeO	28·84	26·04	21·42
Fe met.	(32·26)	(32·71)	(30·13)
MnO	·43	....	·40
MgO	16·10	15·65	16·83
CaO	1·17	·96	†lost
K_2O	·10	none	tr.
Na_2O	·44	tr.	tr.
H_2O	·42	2·71	4·77
	99·26	100·54	99·32

Comparing the three analyses we see that there has been comparatively little material actually removed from the rock during the extensive alteration process. The alkalies, some lime and silica, have been removed, and also some of the iron in the serpentine type. The iron has suffered some oxidation. The alumina seems to have increased relatively, and its presence

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* This analysis was made by Mr. J. W. Shaw, formerly assistant in the department of Geology.

† The amount of lime ppt. was very small indeed.

points conclusively to the presence of *chlorite* so generally looked upon as serpentine heretofore.

The Vein Minerals.—As noted in Part I, small veins of varying sizes, sometimes attaining a width of an inch, and consisting essentially of actinolite, clinochlore, and hortonolite, are found following the directions of the joints and also cutting irregularly through the rock. Furthermore, these veins are confined in their occurrence to the "chloritic" and "actinolitic" types of the partially altered rock and must be looked upon as one expression of the alteration phenomena of the rhodose. The vein minerals are quite irregular in their arrangement and start immediately from among the grains of olivine and ore in the wall rock. They appear to have formed along joint or fracture lines which afforded easy channels for the mineral-bearing solutions.

The Actinolite.—The actinolite is the most abundant mineral and its crystals attain a relatively large size, being often from 1^{cm} to 2^{cm} in length. It is light green to yellowish green in color, prismatic in habit, and is conspicuous by reason of its highly perfect prismatic cleavages. Terminal crystal planes are lacking. Fragments of it under the microscope show a feeble pleochroism from pale to yellowish green and an extinction angle of 15 degrees measured in fragments lying on their cleavage faces. The specific gravity was found with the pycnometer to be 3·062 at 20 degrees. A chemical analysis was made of selected crystals of the actinolite which, after crushing to a small grain and handpicking, had been digested in dilute hydrochloric to remove ferruginous matter. The material thus prepared showed no trace of impurity. The analysis and ratios derived from it are given below in column I. It is interesting to note that the ratios bear a close resemblance to those derived by Penfield* from the analysis of actinolite by Stanley, especially to No. III (p. 32), an actinolite associated with talc from Greiner in Tyrol. For comparison these are given below:

	SiO_2	:	$R^{III}_2O_3$	:	$R^{II}O+(F.OH)$	SiO_2	:	$R^{II}O+(F+OH)$
Greiner	·938	:	·017	:	·935	1		·997
Cumberland	·933	:	·010	:	·916	1		·982

No determination of fluorine was made in the case of the cumberland actinolite but intense ignition in a hard glass tube gave some slight trace of etching, indicating that fluorine is probably present to a slight extent in this actinolite as in all of those studied by Penfield and Stanley.

The Clinochlore.—The clinochlore is found in the form of psuedo-hexagonal or rhombic tables penetrating the other minerals and not uncommonly attaining a diameter of from 2 to 5^{mm}.

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* This Journal, xxiii, 1907.

They are of a dark green to almost black color. Many of them are twinned after the characteristic manner of the chlorite group. Under the microscope the crystals show a strong pleochroism, brownish red parallel to c' (C), dark emerald-green perpendicular to c'. The crystals show an optically positive interference figure with an axial (2E) angle varying considerably but running as high as 23 degrees according to an approximate measurement made with the aid of a Schwarzmannische Axenwinkel scale. Several exposed and strongly rusted joint surfaces are thickly studied with these clinochlore crystals. In such cases the other minerals have either entirely weathered away or were originally absent.

The Hortonolite.—In examining one of the best exposed of the veins, situated on the western side of the hill somewhat south of the center, Professor Charles Palache, of Cambridge, discovered a dark resinous-looking mineral associated with the actinolite and clinochlore which he correctly referred to the olivine group and which subsequently proved on analysis to be hortonolite. The material collected by Professor Palache was very generously placed by him at the writer's disposal for investigation and has proved the best so far obtained. No crystallographic outlines have been noted on the hortonolite and its relations to the other minerals are distinctly xenomorphic. It possesses two well-marked cleavages at right angles to each other, and, when fresh, small fragments have a light yellow color by transmitted light. The mineral tends to decompose readily to a reddish brown, ferruginous earth with an accompanying discoloration of the actinolite and eventual disintegration of the vein. An examination of a large number of specimens, collected from different veins, shows that the hortonolite is very generally present, and when not actually seen the characteristic ferruginous alteration material indicates that it was originally present. It is, therefore, to be looked upon as a normal constituent of the veins of the hill. With the aid of a miscroscope a sufficient number of clear yellow particles were picked out with considerable labor from some of the larger fragments, and analyzed. The results are given in column II. The specific gravity was found with the pycnometer to be 4·054 at 20 degrees C.

The ratio $SiO_2 : RO$ is very nearly 1 : 2, the olivine ratio, and the composition is close to that of the hortonolite from Munroe, Orange Co., N. J., analyzed by Penfield and Forbes* and given in column III. The occurrence of this rare mineral species at a new locality as a distinctly secondary mineral in veins traversing an ultrabasic olivine rock is of special interest to mineralogists. The occurrence of a member of the olivine group as a vein mineral has been noted and described by E.

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* This Journal, No. 151, p. 132, 1896.

Weinschenk* in veins associated with antigorite, diopside, calcite, amianthus and magnetite, traversing both the unaltered and altered portions of a peridotite (Stubachite) which originally consisted essentially of olivine with some antigorite, the later said to be of primary origin. Weinschenk ascribes the origin of this secondary olivine to the action of deep-seated, pneumato-hydro-metamorphic processes following the volcanic period during which the intrusion of the peridotite took place.

Serpentine Veins.—At the northern end of the hill near the foot of the ledge, a few narrow veins of a grayish-green, fibrous, and rather brittle serpentine were observed. Small magnetite grains are embedded in the serpentine.

I. Actinolite Analysis (Warren).

		Ratio	
SiO_2	56·00%	·933	·933
TiO_2	tr.		
Al_2O_3	1·00	·000	·010
Fe_2O_3	·10	·001	
FeO	7·14	·100	
MnO	·10	·001	
CaO	14·03	·250	
MgO	20·52	·513	·916
K_2O	tr.		
Na_2O	·50	·008	
H_2O	·80	·044	
F	?	?	
	100·19		

II. Hortonolite Analysis (Warren) Cumberland, R. I.

		Ratio	
SiO_2	33·27%	·554	·554
TiO_2	tr.		
Fe_2O_3	·37		
FeO	49·32	·685	
MnO	1·50	·018	1·105
MgO	16·08	·402	
H_2O	undet.		
	100·54		

III. Hortonolite Analysis (Penfield and Forbes.) Munroe, Orange Co., N. J.

SiO_2	33·94
FeO	47·32
MnO	4·32
MgO	13·74
H_2O	·48
	99·80

Laboratory of Mineralogy
Massachusetts Institute of Technology, Boston, Mass.,
Sept., 1907.

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* Beiträge zur Petrographie der östlichen Centralalpen, u. s. w., Abh. Kgl. bayer. Akad. Wiss., II, Cl. 1894, 18, 651; also shorter papers—Zeitschr. für Kryst. und Min., No. 26 and Neues Jahrb. f. Min. u. s. w., 1895, Bd. 1.

BIBLIOGRAPHY.

1825(?) Robinson (Samuel)—A Catalogue of American minerals with their localities.

1833.5 Hitchcock (Edward)—Report on the geology, mineralogy, botany and zoology of Massachusetts. Amherst, 1833, 700 pp. (1st edition). (See pages 22, 54, 154, 359-360.) Also, 2d edition, 1835, 702 pp. (See pages 33, 64, 160, and 357.)

1840 Jackson (Charles T.)—Report on the geological and agricultural survey of the State of Rhode Island. Providence, 1840, 312 pp., 2 maps. (See pages 42-43, 52-54, 84, 105.)

1841 Hitchcock (Edward)—Final report on the geology of Massachusetts. 1841. (See pages 195, 380, 553-554.)

Silliman (Benjamin, jr.)—Review of Dr. C. T. Jackson's Report on the geology of Rhode Island. This Journal (1), xl, 182-194, 1841.

1843 Reports of the first, second, and third meetings of the Association of American Geologists and Naturalists, at Philadelphia in 1840 and 1841, and at Boston in 1842. Embracing its Proceedings and Transactions. Boston, 1843, 544 pp (See page 28.)

1861 Hitchcock (Charles H.)—Geology of the Island of Aquidneck. Proc. Amer. Assoc. Adv. Sci., xiv, 112-137, 1860, Cambridge, 1861. (See page 133.)

1872 Thurston (R. H.)—Iron-making in Rhode Island. Eng. and Min. Jour., xiii. 386, June 18, 1872.

1873 New York Daily Tribune, October 15, 1873.

1876 Report of the Rhode Island Commission to prepare a plan for a thorough geological and scientific survey of the State. Presented to the General Assembly at its January session, A. D. 1876. (See page 11.)

1881 Wadsworth (M. E.)—A microscopical study of the iron ore, or peridotite, of Iron-Mine Hill, Cumberland, Rhode Island. Bull. Mus. Comp. Zool., Harvard College, vii, 183-187, 1881. Abstracted in Proc. Bos. Soc. Nat. Hist., xxi, 195-197, 1881. Contains Historical sketch.

Dana (James D.)—Iron ore of Iron Mine Mill, Cumberland, Rhode Island. This Journal (3), xxii, 152, 1881.

Salisbury (Chas. M.)—Geology of the valley of the Narragansett. Science Advocate, 1881.

1883 Wadsworth (M. E.)—Meteoric and terrestrial rocks. Science, i, 127-130. 1883.

1884 Eddy (E. B.)—Porphyritic iron ore of Cumberland. Random Notes on Natural History, i, No. 4, 1884.

Wadsworth (M. E.)—Lithological Studies. Harv. Coll. Mem. Mus. Comp. Zool., xi, 208 pp., 8 pls., 1884. (See pages 74-83, table III, pp. xvi-xvii, and plates 1 and 2.)

Wadsworth (M. E.)—The theories of ore deposits. Proc. Bos. Soc. Nat. Hist., xviii, pp. 197-208. 1884. (See page 207.)

1885 Wadsworth (M. E.)—Descriptive catalogue of one hundred thin sections of American and foreign rocks. (See page 5.)

1887 Wadsworth (M. E.)—Preliminary description of the peridotytes, gabbros, diabases and andesytes of Minnesota. Geol. and Nat. Hist. Survey of Minnesota, Bull. No. 2, St. Paul, 1887, 158 pp., 12 pls. (See pages 65 and 90.)

1889 Wadsworth (M. E.)—(Letter to the editor.) Bulletin American Iron and Steel Association, Nov. 20, 1889.

1893 Wadsworth (M. E.)—A sketch of the geology of the iron, gold and copper districts of Michigan. Report of the State Board (of Michigan) Geological Survey for the years 1891 and 1892. Lansing, 1893, pp. 75-186. (See pages 90, 95-96, 97.)

Shaler (N. S.)—The conditions of erosion beneath deep glaciers, based upon a study of the bowlder train from Iron Mine Hill, Cumberland, Rhode Island. Bull. Mus. Com. Zool., Harvard College, xvi, pp. 185-225, pls. 1-4, and map, 1893.

1895 Adams (Frank D.)—On the igneous origin of certain ore deposits. Journal of the General Mining Association of the Province of Quebec. 1894–1895, ii, pp. 35–53. (See page 38.)

Shaler (N. S.)—The geology of the road-building stones of Massachusetts, with some consideration of similar materials from other parts of the United States. U. S. G. S., 16th Ann. Rept., pt. 2, 1895, pp. 277–341, pls. xviii–xxiv. (See page 321.)

1896 Vogt (J. H. L.)—The formation of eruptive ore deposits. Min. Industry for 1895, iv, pp. 743–754, New York and London, 1896. (See page 745.)

1898 Engineering and Mining Journal, lxvi, 768, 1898.

1899 Shaler (N. S.)—General geology (of the Narragansett Basin) U. S. G. S., Mon. 33, 1899, pp. 1–90. (See pages 72–73, 75–76, 88–89.)

Kemp (James Furman)—The titaniferous iron ores of the Adirondacks. U. S. G. S., 19th Ann. Rept., 1897–98, Part 3, 1899, pp. 377–422. (See pages 384, 388–389, 390, 391, 401, 419).

Kemp (James Furman)—A brief review of the titaniferous magnetites. Columbia School of Mines Quarterly, xx, 323–356, 1899, and xxi, 56–65, 1899. (See pages 349–351.)

1903 Kemp (James Furman)—The ore deposits of the United States and Canada, 1903, 481 pp. 5th edition, New York, 1903. (See pages 57, 63, 61, 66, 173 and 181.)

1905 Beck (Richard)—The nature of ore deposits, translated by Walter Harvey Weed. 1st edition, 1905. (See pages 21–25.)