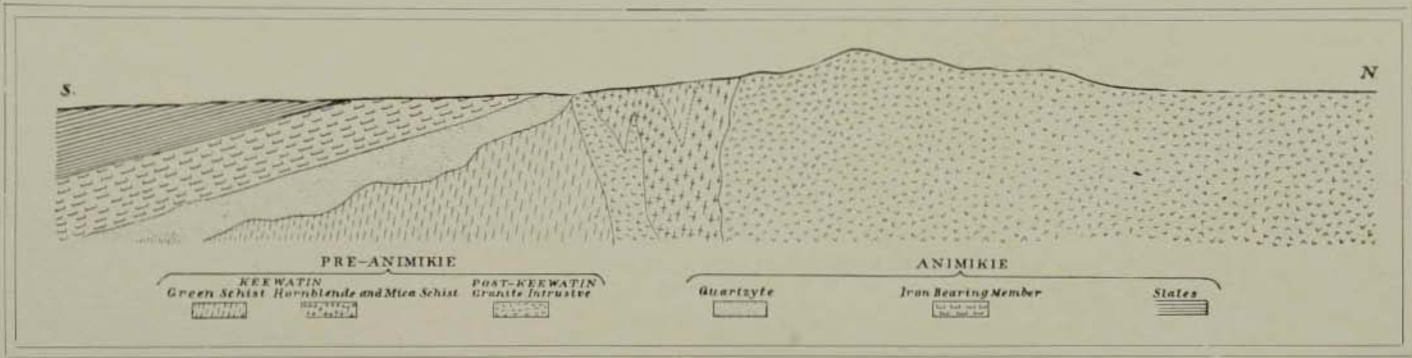

FIG I.—SECTION ACROSS THE MESABI RANGE.

DRAWN NORTH AND SOUTH THROUGH THE CENTRAL PARTS OF TOWNSHIPS 58-18 AND 59-18, THUS PASSING THROUGH THE TOWN OF MOUNTAIN IRON.

Horizontal Scale ⅔ mile=1 inch. Vertical Scale three or four times exaggerated.

This section shows the typical stratigraphy of the Western Mesabi range.

GEOLOGICAL AND NATURAL HISTORY SURVEY OF MINNESOTA
N. H. WINCHELL, STATE GEOLOGIST.

BULLETIN NO. X.

THE IRON-BEARING ROCKS

OF THE

MESABI RANGE

IN MINNESOTA.

BY J. EDWARD SPURR.

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PREFACE.

In this bulletin the writer has endeavored to add to the knowledge of one of the most perplexing and fascinating fields in American geology. At the same time, some apology must be offered for the incompleteness of the work. Both time and opportunity have been too scanty for a thorough study and analysis of all of the problems which have presented themselves. New modifications of old principles, and new principles, will be found to have been active in other areas, apart from that especially studied; and, not improbably, in this area itself. Economic geology in these departments is as yet rudimentary; but it is hoped that the main points here presented will prove sound, and can safely be made the basis for more advanced work.

In the preparation of this subject, aid of the greatest value has been rendered by many friends in Massachusetts and Minnesota. The writer is especially grateful to Mr. H. V. Winchell of Minneapolis, to Professor J. E. Wolff and Dr. R. T. Jackson of Harvard University, and to Professor N. H. Winchell and Dr. U. S. Grant of the Minnesota survey.

J. E. SPURR.

Minneapolis, April 30, 1894.

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CHAPTER I.

GENERAL STRUCTURE OF THE MESABI RANGE IN THE IRON-BEARING REGION.

THE KEEWATIN SERIES.

The lowest rocks of the iron-producing region are in part certain greenish schists which are profoundly metamorphosed. For this reason it is difficult to decide in any given case what was the original nature of the rock, for most of the original mineral characters have disappeared. It seems clear, however, that some of them are derived from clastic rocks—slates, quartzytes, graywackes, etc., while others have an igneous origin. All of these rocks have been changed and brought to resemble one another in some degree by dynamic forces, which have induced re-crystallization and the development of certain minerals common to all. One of the most marked effects of these disturbances is a regional cleavage, which is nearly uniform,—in trend, about N. 70° E., in hade approaching the vertical. (See Fig. 1.)

These Keewatin schists are exposed upon the south slope of the Giant's range of hills, or that region which goes under the name of the Mesabi Iron range, to a limited extent only. In general terms, they form a narrow strip, somewhat less than a mile in width, running in a north of east direction from the middle of the extreme southern part of T. 59-18 to the Embarras lakes and eastward. They there seem to disappear, but reappear again in the same position further east. West of range 18 they are found only in isolated patches, along the line which is given by the continuation of the principal strip. There is an exceptional occurrence in T. 58-17, where a tongue of the Keewatin* schists runs southwest across the town, quite to its

*The terms Keewatin and Animikie are used by the Minnesota survey to designate formations which correspond in general to the Huronian of the United States survey,—the Keewatin being in the Lower, the Animikie constituting the Upper Huronian.

southern border, and just enters the northern limit of T. 57-17.

The most common phase of these schists upon the Mesabi range, is that which goes by the common name of "green schist." This has a fine texture and is chiefly distinguished by the development of sericite and kindred minerals along the cleavage surfaces, and hence generally throughout the rock. Along the northern edge of the Keewatin area, these schists come in contact with granite, and here, in many cases, there has been a more complete crystallization, resulting in the formation of limited areas of hornblende and mica schists, sometimes coarsely crystalline. On the extreme southern limit, on the other hand, there is less change, as in the southern part of the area which runs across T. 58–17. Here, in many cases, the schists resemble closely little-altered sedimentary rocks.

GRANITE.

Next in order of age is the granite, of which the highest part of the Giant's range consists. South of this ridge of hills it is not found to any extent, but it runs north, making for some distance the northern slope of the divide. In shape, the granite area is long and narrow, constituting a belt which traverses nearly the whole Mesabi region in Minnesota. The width of this strip averages perhaps nearly ten miles, and the direction is about N. 70° E., or about the same as the trend of the schistosity in the Keewatin rocks. The relation of the granite to the schists is plainly intrusive. It cuts the schists at the contact, and sends small stringers into them; near the edge of the granite area there are imbedded numerous fragments of the schists, more or less profoundly metamorphosed and re-crystallized, according to the size of the fragment, and the distance from the contact; and along the contact, and especially where some slight irregularity in the course of the granite runs, so as to partly surround a fragment of the Keewatin, portions of the main body of the schist have been metamorphosed, as before stated, into more perfectly crystalline hornblende and mica schists. The same proofs of the intrusive nature of the granite have been found, and stated by Dr. U. S. Grant, for the region further east.* So it is quite proper to speak of the Giant's range granite as a dike, which

*Twentieth Ann. Rep., Geol. and Nat. Hist. Survey of Minnesota, "Field Observations on Certain Granite Areas," pp. 35-95. Twenty-first Ann. Rep. pp. 36-37 came up nearly vertically into the Keewatin rocks. The age of this dike is not closely fixed, except that it is, of course, younger than the Keewatin period, and far older than the lowest rocks of the overlying Animikie strata. In the tongue of Keewatin rocks which runs down into township 58-17, there are found two lenticular masses of the granite, surrounded by the schists. Of these the smallest is farthest from the main body of granite, being situated in sections 20 and 21, T. 58–17. It has a length of about three-quarters of a mile, and a width of a few hundred yards. The larger one has a length of nearly three miles, and a width at the middle of about three-quarters of a mile. It crosses the range line between T. 58–17 and T. 58–16, in the northern part of the townships. The longer axes of these two masses are in a common direction, and correspond with the general trend of the main body. They are undoubtedly the surface exposures of apophyses from the main dike.

Petrographically, the granite of the Giant's range is a hornblende granite, which in various parts of the field is modified by the varying increase or diminution of any of the constituents. Besides the variations of mineral composition, there are also great differences of texture, due in the main to the relative proximity of the Keewatin rocks. Near this contact the granite becomes fine-grained and gneissic; but it grows coarser as the distance increases, and becomes often coarsely porphyritic. The granite of the apophyses is of the same mineral composition as the rest, and in its finer texture corresponds exactly to the common fine-grained phase found at the contact of the main dike with the schists.

THE ANIMIKIE SERIES.

Unconformably upon the folded and schistose rocks of the Keewatin and the granite lies the Animikie series. The comparison of these two formations shows the immense time-break which this unconformity represents. None of the forces which have changed the Keewatin have operated upon the Animikie series, for here there is neither any marked folding nor schistose structure, nor any other evidence of great disturbance. The Keewatin rocks were altered to their present condition quite completely before the lowest of the Animikie strata were laid down. Thus, between the deposition of the rocks of these two formations, there intervened vast periods of disturbance, producing intricate and complex folds, the intrusion of the granite, and the development of the regional schistosity. But since the beginning of the Animikie period, this region has been left comparatively undisturbed by dynamic forces.

The main part of the Animikie series in Minnesota, and all that part which includes the known iron-bearing region, lies to the south of the granite of the Giant's range, and constitutes, for the most distance, the immediate southern slope of the divide. It thus forms a belt which extends from the Mississippi river to the extreme northeastern part of Minnesota, at Pigeon point, and into Canada, to Thunder bay. In length it is over two hundred miles, although in the central part of this belt the rocks are disturbed and often hidden by the later igneous rocks of the Keweenawan. It is almost always less than ten miles in width, and very often no more than two or three miles.

The stratigraphy of the Animikie rocks is nearly uniform throughout the whole extent of this belt, except where locally disturbed, as stated. In general, they are arranged in a gentle monocline, which dips south, with often a decided east-of-south tendency, at a slight angle, which perhaps averages from ten to fifteen degrees. In the northeastern part of the state the strata thus disappear beneath the Keweenawan rocks; in the western part, the continuation to the south is hidden by a great thickness of drift. Other than this uniform and slight monoclinal tilting and the accompanying disturbances, there have been no regional changes in the position of the Animikie series. There has been no folding of importance, nor even any marked development of induced slaty cleavage in the argillaceous rocks which form a great part of its thickness. The disturbances which took place between the end of the Keewatin and the beginning of the Animikie period were thus in this region incomparably greater than the changes of all succeeding time.

For present purposes the Animikie series may be divided into three chief members;—the basal quartzyte, the iron-bearing member, and the upper slates.

THE PEWABIC QUARTZYTE.

So far as is yet definitely known, the quartzyte which is here called Pewabic lies at the base of the Animikie rocks in Minnesota. It is tolerably uniform throughout its extent, varying in texture from an extremely fine-grained variety to a very common sort, where the small pebbles of translucent quartz average perhaps an eighth of an inch in diameter, and are very closely crowded together, and finally to a rare conglomeratic phase, in which the pebbles are still almost entirely of quartz. This conglomeratic phase is supposed to represent the extreme base.

The only change of importance which has overtaken the quartzyte since its deposition has been the filling of the interstices with silica by enlargement of the grains of sand. Ordinarily, these enlargements are of crystalline quartz, like that of the original grains, and the additions have been made without any change of the crystallographic axes; but occasionally, especially near the top of the formation, specimens are met with where the filling has been made with aggregate or cryptocrystalline silica. The source of this secondary silica will be shown to be the disintegrating iron-bearing member above.

THE IRON-BEARING MEMBER.

The rocks which contain all of the ores of importance along the Mesabi range constitute a strongly marked horizon, presenting as a whole no resemblance to the quartzyte member or the slate member. In places where these three most important members of the Animikie series of the iron-bearing region occur together, the boundary which separates the iron-bearing member from the others, above and below, is distinct. Its lithological characteristics will be discussed and described in detail further on.

Distribution of the Iron-Bearing Rocks.

The iron-bearing member is known to extend in Minnesota from Pokegama falls, on the Mississippi river, as far as Gunflint lake, on the Canadian boundary. From this point the Animikie series continues eastward to Pigeon point, along the international boundary, and thence into Canada, where it is best known around Thunder bay. In Minnesota the existence of the iron-bearing member is not known east of the Gunflint Lake region, where it is well shown, and where most of the observations upon it have hitherto been made. At Pigeon point it is not found, although the rocks of the Animikie series are well exposed. Neither does it seem to occur at Thunder bay, although the discovery of iron in this region, comparable with the deposits of the Minnesota part of the series, has been predicted by some Canadian geologists. But this belief seems to have been founded simply on the recognition of the Animikie series as a whole, as the rocks associated with ore deposits; and appears to be inaccurate, from failure to distinguish the iron-bearing member as the only one which contains ore in appreciable quantity. Irving,* in describing the rocks of the Thunder bay region, did not recognize the existence of the iron-bearing member. Following are extracts from his description:

"Around Thunder bay the rocks of this series, which are chiefly black slates, graywackes, argillaceous quartzytes, interstratified diabase, and gabbro layers, which are many in number, and individually often have a considerable thickness, are exposed on a large scale.

"So far as it is developed along the international boundary line, the lowest layers of the Animikie series in sight are those on Gunflint lake. The highest layers are those in the vicinity of Grand Portage bay, the whole succession between these points being some thousands of feet in thickness. The iron-bearing horizon at the base of this succession is lithologically identical with that of the Penokee series of northern Wisconsin and Michigan, while the black slates, graywackes, etc., which succeed the iron-bearing horizon, are in turn the counterparts of those which form the middle and upper portions of the Penokee series."

At present, therefore, we must consider the iron-bearing member to be limited, at its western extremity, by Pokegama falls, on the Mississippi river, and on the east, by the vicinity of Gunflint lake. It is found for some slight distance west of the Mississippi river; † and at its eastern limit it is well-developed both on the American and the Canadian shores of Gunflint lake. Its length is thus nearly one hundred and fifty miles.

Stratigraphic Relations.

The iron-bearing member occupies a definite and constant position with regard to the other members of the Animikie series. From Pokegama falls to the region of the Embarras lakes, it is for the greater distance known to rest directly upon the quartzyte, and to be overlaid by the slates. In this region these three members are persistent and constant in their relations, and they are not disturbed or modified by any other rocks. From the Embarras lakes region to the vicinity of Gunflint lake the relations of the strata have not well been made out, owing to the confusion arising from the presence of the great gabbro of the Keweenawan, which conceals the Anim-

*U. S. Geol. Survey, Seventh Annual Report, pp. 420-422; on the Classification of the Early Cambrian and pre-Cambrian Formations, by R. D. Irving. Quoted in Tenth Annual Report, p. 403; The Penokee Iron-bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise.

†Twentieth Ann. Rep.; Minn. Geol. and Nat. Hist. Survey, p. 116. The Mesabi Iron Range, by Horace V. Winchell.

ikie strata, or disturbs their positions and apparent relations. As far as can be ascertained, however, the association of the iron-bearing member with the other two grand divisions of the series, especially with the underlying quartzyte, do not strictly hold for this region. In township 60 north, range 13 west, section 13, it has been found resting directly upon the granite of the Giant's range. A drill-hole sunk under the direction of the Longyear Company in this place passed through one hundred and ninety feet of hard "jaspery taconyte" banded with ore. The bands of ore were five or six inches thick, and the iron was hard, black, and nearly always magnetic. At Gunflint lake the lower quartzyte, according to Irving* and others, is not found, but the iron-bearing member lies directly upon the unconformable schists of the Keewatin. A few miles west of Gunflint lake it was found to lie on the granite, as reported by the professors Winchell.† Further east than this its relation is not known since it does not appear in the horizon of rocks exposed.

Divisions of the Mesabi Iron Range.

It will thus be seen that the Animikie of Minnesota may be separated into three geographical regions, of about equal length and marked by differences sufficiently great to make a division desirable. The first division, which we may call the Western Mesabi region, extends from the Mississippi river to the neighborhood east of the Embarras lakes. The second division, which may be called the Eastern Mesabi region, extends from the vicinity of the Embarras lakes to the neighborhood lying south and west of Gunflint lake. The third division, which may be called the International Boundary region, extends from Gunflint lake eastward into Canada.

Broadly speaking, the Western Mesabi region is characterized by the persistent occurrence of the three main divisions of the Animikie as described for Minnesota, and the absence of later disturbing rocks like the gabbro and traps of the Keweenawan. The Eastern Mesabi region is marked chiefly by the predominant influence of the traps and gabbros above mentioned, together with the other features, which will be shown to be probably the direct result of their invasion: the obscuring of the true stratigraphy; the predominant magnetic condition of the iron, and the more crystalline state of the accompanying

*Loc. cit.

†Sixteenth Ann. Rept., pp. 80, 266-268.

silica; and the absence of iron, so far as yet shown, in bodies large enough for profitable mining. This region is also marked by the subordination in importance of the lower quartzyte, and its final disappearance. The International Boundary region also is characterized by the constant occurrence of igneous rocks within the series, but in less quantity, and occasioning less confusion than on the Eastern Mesabi; by the subordination in importance of the iron-bearing member, and the great development of the upper slate division. The Mesabi iron-bearing formation is thus separated into two divisions, the Eastern and Western Mesabi.

For the reasons above mentioned, the Western Mesabi offers the most attractive field for study upon the causes and conditions governing the formation of the great ore deposits which lend the chief economic interest to this series. Not only are the strata little disturbed and the rocks less altered than in any other part of the Animikie series of Minnesota or even than the rocks of any other of the iron regions of Lake Superior, but it is here that the formation of ore has been accomplished on the most magnificent scale. Within this district all of the paying mines and promising explorations so far discovered on the Mesabi are located; and in the amount and quality of the ore already developed, it compares favorably with the richest of the older ranges.

The known ore-bearing district at the present time is marked, in its highest development, by the Hale mine on the east, situated in the northeast corner of T. 58-16, and on the west by the Mesabi Chief mine, situated in the eastern part of section 23, of T 57-22. East of the Hale no paying mines have been developed, and west of the Mesabi Chief but one mine is found, which, however, is one of the oldest on the range,—the Diamond, in T. 56-24. While it is probable that other bodies of ore will be discovered outside of these limits, especially in the region between the Mesabi Chief and the Mississippi, yet it is here that at the present time there are the greatest opportunities for acquaintance with the phenomena of the occurrence of ore. In the course of the explorations for iron within this area many hundred test-pits have been sunk, which serve in the place of outcrops and are of the greatest value to the geologist. It is in this district that most of the field work, the results of which are embodied in the present report, has been done; and the specimens which have served for laboratory study, and on which many of the conclusions are based, have been collected from the same region.

Thickness of the Iron-Bearing Member.

On the Western Mesabi the iron-bearing member is exposed in a strip which varies in width from half a mile or less up to two or three miles. In the narrowest parts the dip is frequently as great, locally at least, as thirty degrees. The most usual width is about one mile, and here the dip averages about ten degrees. The wider strips always occur in districts where the dip is on the average very slight. So we may estimate the thickness of the member as between 500 and 1,000 feet, with an average of about 800 feet. In several places, as in the basin of Embarras lake and that before mentioned in T. 60–13, drill holes have passed through nearly 200 feet of the iron-bearing rock. In the drilling at Embarras lake, the bottom of the formation was not reached, but in the case last mentioned the thickness represented the whole extent of the member in that place.

THE UPPER SLATES.

Above the iron-bearing member lies a series of fine-grained detrital rocks, of uncertain but probably great thickness. So far as the Minnesota territory is concerned they are at the top of the Animikie. These slates consist mainly of siliceous materials which are apparently derived from the erosion of the Keewatin rocks. There is, however, at least one marked exception to this in the lowest horizon, which lies directly upon the iron-bearing rocks. This horizon is, when least changed, an impure limestone; and it seems to be nearly continuous over a large part of the Western Mesabi.

A typical locality of this limestone is found in the pit on the south side of the road between Virginia and Mountain Iron, in the northwest of the northeast quarter of section 7, T. 58–17. This is dark gray in color, and shows an apparently original bedded structure. Specimen 76 is from this locality. The alternating layers are of different shades of gray. The rock effervesces freely with cold dilute hydrochloric acid. Under the microscope, the structure is seen to be that of an impure, little-altered limestone, consisting mainly of grains of calcite, very small, but of nearly uniform size, with which are intermixed chloritic material and iron-oxide dust. Scattering fragmental grains of quartz are also found.

In other parts of the field this calcareous layer has undergone important modifications, for, while it still remains a carbonate, yet the original calcium has been replaced, to a greater or less extent, by other bases. Thus, near the contact between this layer and the iron-bearing series, in section 4, T. 58–16, the rock, which is seen to be identical in structure with section 76, under the microscope, is found by the analysis to have been almost completely dolomitized. This rock is de-described as 53--2, in the chapter on the microscopic examinations of thin sections, and the analysis of an impure portion of it is there given. In the specimen analyzed, which was obviously greatly more impure than that examined under the microscope, the remaining carbonate is seen to be almost wholly magnesite, while the ferruginous impurities have increased, owing to the immediate proximity of the rocks of the iron-bearing member, till they form the larger part of the rock.

In other parts of the field this calcareous layer seems to have undergone a ferration. This may also be ascribed to the influence of the solutions derived from the iron-bearing member, which in many places happens to lie topographically above it. Where this ferrated limestone is found, the contact between the upper slates and the iron-bearing rocks cannot be distinctly located; for the rock has not only become ferrated, but in some degree silicified; and so its structure is hardly distinguishable from some of the phases of the iron-bearing member. An example of this class of ferrated slaty rocks is specimen 112, from the northeast of the southeast of section 17, T. 58–19. Under the microscope this is very fine-grained, and consists of an intimate mixture of green chloritic matter and the carbonates, without observable arrangement, but having, on account of the uniform texture, a fragmental appearance. In the hand specimen this is a nearly black slate, without distinct slaty cleavage or well-marked planes of actual bedding. Little can be learned of the original nature of the rock through this microscopic study, but in structure it is nearly identical with the impure limestone of specimen 76, and therefore the carbonates seem to have altered from the condition of calcite without great change of form. An analysis of this rock was made with the following results.

ANALYSIS OF SPECIMEN 112 BY A. D. MEEDS (CHEMICAL SERIES 240).

Silica, SiO_2	23.80	per cent.
Sesquioxide of iron, Fe_2O_3	5.97	" "
Protoxide of iron, FeO	32.21	" "
Alumina, Al_2O_3	7.95	" "
Lime, CaO	4.67	" "

Magnesia, MgO	5.89	"	"
Soda, Na_2O	.29	"	"
Potash, K_2O	.18	"	"
Manganese, MnO_2	trace.		
Water, H_2O	4.28	"	"
Carbon dioxide, CO_2	11.84	"	"
Loss on ignition*	3.35	"	"
Total	100.43		

The results of this analysis are in accord with the suggestions of the microscopic examination. A part of the carbonates still consist of the calcite which is peculiar to this horizon. None of the rocks from the undoubtedly iron-bearing series have been found upon analysis to contain more than a very small quantity of lime. Thus what is here found probably represents the residue of the original limestone; the amount of magnesia represents the effects of the dolomitization, as represented in specimen 53-2, while the majority of the rock has been ferrated and changed to siderite. Two other important points of difference between this rock and the rocks of the iron-bearing member which have been analyzed suggest themselves. The first is the large amount of residual organic matter, in which respect this is identical with 53-2. The second is the presence of a trace of manganese. In none of the analyses of the iron-bearing rocks, save in profoundly altered phases, has even a trace of manganese been reported.

The thickness of this lowest and typically calcareous layer of the upper slates is not great; it grades gradually into the siliceous slates above, and the thickness may be estimated as between ten and fifty feet, varying in different localities. So far as is known on the Western Mesabi the slates above this are uniformly siliceous.

THE TILTING OF THE ANIMIKIE.

It has been stated that the only important disturbance which has befallen the Animikie strata since their deposition is the monoclinal tilting. There is a slight wrinkling of the strata into gentle undulations, and some accompanying faulting, but these phenomena seem to be connected, and may be provisionally assigned to a single period of disturbance.

It is probable that there is some connection between this disturbance and the igneous rocks which belong to the Kewee-

*Loss on ignition above the amount of H_2O and CO_2 probably represents organic matter.

nawan. Upon the middle part of the Mesabi in Minnesota these rocks have cut across the belt of Animikie strata, and thus in many places there results great change of position, steep dips and confusion of stratigraphy. Going east the angle of the dip almost steadily diminishes, the rocks at Thunder bay being often nearly horizontal.* To the west the same thing happens, the dip growing less as the distance from the central area, and in this case from the whole Keweenawan region, increases. Over the greater part of this district the direction of the dip is southward, or southeastward. In the region immediately west of the Keweenawan area there has been some slight faulting and folding, but this disturbance seems to die out as the distance from the igneous rocks increases. It is probable, then, that the weight of the Keweenawan rocks has produced a sinking of the area south of the Animikie, and that this has produced the tilting. The process of subsidence was probably slow, and was not accomplished until later Keweenawan or post-Keweenawan time, for in many places the Keweenawan rocks themselves are tilted in the same direction as are the Animikie strata, and so have participated in the movement.

*U. S. Geol. Survey, 7th Ann. Rep., pp. 420-422. On the Classification of the Early Cambrian and Pre-Cambrian Formations; by R. D. Irving.

CHAPTER II.

MINOR STRATIGRAPHY OF THE WESTERN MESABI.

The Animikie series of the iron region shows a freedom from disturbance by outside dynamic forces that is wonderful, considering the great age of the strata. The general structure of a gentle monocline is often quite undisturbed, even by slight variations; and when these modifications occur, they are generally of no great importance.

TOPOGRAPHY.

On the western part of the range the topography is least bold. Here the rugged elevation of the Giant's Range hills further east is softened down to a gentle slope, the summit of which, forming the divide as before, is often scarcely to be recognized, save from the course of the sluggish streams. Here the effect of the different underlying rocks on the topography is not great, and the change from one formation to another is marked by no sharp changes in the surface features. The highest point in the divide is not always strictly in the granite area, although it maintains itself in that neighborhood. Thus, where the divide crosses the southeast corner of T. 58-21, the summit is marked by a ridge of the quartzyte, and at the very highest point of this ridge, which is in sec. 35, and is somewhat over 1,700 feet above the sea, this contour line includes a part of the iron-bearing member itself.

The dip of the Animikie strata in this region is very gentle, often seeming to the eye to be nearly flat. As a consequence of this the iron-bearing member occupies a more uniformly broad strip than it does further east, and, mainly by reason of the more even erosion, the quartzyte comes to the surface in a continuous strip, lying between the iron-bearing member and the granite. This strip is tolerably uniform through townships 57-21, 58-21, and to the center of T. 58-20. Here it narrows to a wedge and disappears, save for a local reappearance here and there further east, from under the overlapping iron-bearing member. At this point the summit of the divide definitely passes into the granite area; the hills become steep, and are strongly contrasted with the even slope of the Animikie rocks to the south. From here to the southern part of T. 59-18, the iron-bearing member generally abuts directly at the surface against the granite, the quartzyte appearing only in occasional patches. Then the Keewatin schists come in between the granite and the Animikie rocks, and continue as an important feature of the geology of the range as far as the eastern limit of the Western Mesabi. Against this area of Keewatin schist the iron formation often rests.* This is seen not only in the field, from plotting of outcrops, but is proven by test-pits, as at the Hale mine and vicinity.

MINOR STRATIGRAPHY IN RANGES 18-21.

As we go east the exposed width of the iron belt shows a gradual decrease. Through ranges 21, 20, 19 and 18, the average width is probably not far from two miles. In T. 58-17 the average is between a mile and a mile and a half, and on the western side of the township it is not more than a mile. As the belt passes into township 58-16 it becomes still narrower, so that on the whole it is perhaps not more than three-quarters of a mile wide. At the extreme eastern end, at the Hale mine and vicinity, the width is probably less than half a mile in places.

This diminution in width of the iron-bearing member in ranges 16 and 17 is attended by other striking differences which make a minor stratigraphical distinction between this district and that comprised within ranges 18 to 21 inclusive, which has just been described. The structure in this latter region may be summed up as a uniform, gently sloping monocline, with, so far as yet made out, few irregularities of any importance.

*Twentieth Annual Report Minnesota Geological Survey, p. 160.

MINOR STRATIGRAPHY IN RANGES 17 AND 16.

The chief irregularity is to be noted in T. 58-17, 59-17, 58-16, 59 16, and somewhat in 57-17. For nearly all the length of the Western Mesabi, the contact of the granite and of the older schists with the Animikie rocks, runs slightly north of east; and though there are slight swings and variations, yet these are never abrupt, and the angle between the extremes of trend is probably not less than 30°. This uniform trend, which probably averages about N. 70° E., conforms with the general course of the Giant's range granite, with the planes of schistosity of the Keewatin rocks, and with the trend of the Giant's range divide. It obtains as far east as range 17, and the eastern part of range 18.

Following its regular north-of-east trend, the line of contact passes into township 59 in the extreme southeastern corner of T. 59-19. About the middle of T. 59-18 it turns, and runs nearly due east. Passing into T. 59-17 it turns still further, and for the first time begins to run south of east. Thus the contact between the Keewatin schists and the iron-bearing member crosses into township 58 again, on the line between sec. 34, T. 59-17, and sec. 3, T. 58-17. From here it runs due south for a mile and a half, through sections 3 and 10; it then turns and runs nearly due southwest for over two miles to the south line of section 20; then due south again, through sections 29 and 32, for over two miles, to the township line between 58 and 57, and into the northern part of sec. 5, T. 57-17. At this point it describes a large angle, and begins to pursue an almost due northeast course again. It keeps upon this with uniformity for some distance, crossing into T. 58-17 again at the southeast corner of section 33, and passing through sections 33, 27, 23, and 13, into T. 58-16; here it passes through sections 18, 7, 8, 5 and 4, to the northeast corner of 4, very near the boundary line between 58-16 and 59-16. At this point it turns again and runs east, with an increasing tendency to a north-of-east trend, along the northern border of 58-16. After this it resumes the normal north-of-east course.

It will thus be seen that the regular E. N. E. trend of the contact between the Animikie and the older rocks, and of the course of the iron belt, is broken abruptly in ranges 16 and 17, by two local lines of trend, which have no relation to the usual line, and yet are persistent for seven or eight miles. Of these the more western line is the more variable in direction, but has a general course of N. N. E., thus making an angle of about forty-five degrees with the normal trend; while the more eastern has a more uniform course of N. E., making an angle of about twenty-five degrees with the normal trend; locally, however, the parts of these lines make right angles with each other. The two extraordinary lines are in some places nearly parallel, but in general converge towards the south, so that they meet in the northern part of T. 57–17.

This break of trend is also marked by a corresponding break in the topography. In the most of the iron belt, the contour lines, marking the southern slope of the divide, have a general north-of-east course; but here they swing around and follow the course of the extraordinary lines of contact. The area included between these converging lines becomes much higher, not only than the immediately adjoining country, but also than any other part of the Giant's range. The elevation of the highest points of the divide on the Western Mesabi, from ranges 16 to 21, outside of these lines, scarcely varies more than one hundred feet, and even these changes are not abrupt, but rather gradual. The highest contour line in range 21, occurring in Ts. 57-21 and 58-21, is 1,700 feet. This marks the greatest elevation for the greater part of range 20 also. On the line between 20 and 19, the elevation rises to 1,800, and maintains this height up to the more western of the two lines which have been indicated, with the exception of a small area in sec. 26, T. 59-18, which falls within the 1,850 line. To the east of the eastern line, the same observation holds good, the greatest elevation being in T. 59-16, and is marked by the 1,750 foot contour. But in the area comprised between the two extraordinary lines, the elevation rises, in T. 58-17, secs. 20 and 21, to over 1,900 feet, and in secs. 28 and 33, over 1,950, and in one place nearly to 2,000 feet. This is 150 feet higher than the highest point on the range outside of this area. These hills form a striking contrast with the surrounding country which lies south and just outside this line. From the section line, between 28 and 33, the elevation drops in a mile and a half to a uniform plain of 1,450 feet, a difference of 550 feet for the two sides of the dividing line of contact.

This break in the uniformity of the topography marks also the area included between these contact lines when they are produced to the north, past the point where they begin to swing around to the normal direction; and the area where the divergence disappears is also that of the return to the normal topography. That part of the granite belt which lies within these lines constitutes by far the highest land of the Western Mesabi region. In Secs. 28, 59-17, granite hills rise to the hight of 2,150 feet above the sea. Just west of this hill is a valley, about a mile broad, where the elevation for some distance is not more than 1,600 feet. In this valley lies the prolongation of the western of the two lines. On the other side of the valley the land rises to 1,850 feet, which we have already noted as the highest part of the Mesabi outside of the area under consideration. Thus this area is at this point three hundred feet higher than any other part of the range. Between Secs. 35 and 36, in the same township, the elevation becomes greater than 2,000 feet, and on the line between Sec. 36, T. 59–17, and Sec. 31, T. 59–17, it is still 1,900 feet. To the east of this latter eminence lies the valley of the Pike river, which is about a mile and a half broad, and has an elevation near the river of about 1,500 feet. In this valley, and along the course of the river, lies the prolongation of the eastern of the two lines. Further east the land rises from the valley, but the highest point attained is only somewhat above 1,700 feet.

From these comparisons it is seen that this area rises from 200 to 500 feet above the highest points in the adjacent country, which lies west of the western line and east of the eastern one, and that these highest points are separated from the area by profound valleys of no great width, in which the extensions of these lines lie. For convenience this elevated region will be called the Virginia area, from the city of Virginia, which is situated near it, in T. 58–17, and is the most important town of the vicinity.

THE VIRGINIA UPLIFT.

The Virginia area encloses as its center the largest body of Keewatin rocks found on the Western Mesabi south of the granite. Indeed, its bulk is nearly twice as large as that of all the rest. Surrounded by the schists are two lenses of granite, representing the ordinary granite of the Giant's range in its more finely crystalline phases. These lenses are found nowhere on the Western Mesabi save in the Virginia area. Against this central core the rocks of the iron-bearing member lie, forming a broad fringe, and passing down under the slates on their outer edges.

The character of the Virginia area, as described, points to the suggestion that it has been brought up above the surrounding rocks by a process of faulting. The fault lines may be supposed to correspond roughly to the lines which limit the region geographically, and are marked by the deviation of the ordinary trend of contact and the change in the topography. They were two in number, differing in trend from 30 to 45 degrees. On the south they converged and were lost in the north part of T. 57-17, and their northern ends, beginning to diverge widely, passed up into the granite belt,—the valley of the Pike marking the course of the eastern, and the valley through which the southern part of the range line between ranges 17 and 18 passes that of the western line,—and are lost in the granite belt lying north of the divide. The faulting marked by these lines seems to have affected only the Virginia area, for east and west of this a tolerably uniform relation of the strata obtains.

Evidence of the Fault at Virginia.

In the northeast of the southeast quarter of section 8, nearly at the summit of the hill which rises steeply to the east of the town of Virginia, and along which the assumed fault-line runs, a peculiar, dark, sometimes flinty phase of the iron-bearing member is found, forming the capping of the hill in this place. This rock is dark, sometimes nearly black. It is ordinarily extremely siliceous, and frequently presents the physical appearance of chert. In other bands it has more of the appearance of an ordinary indurated slate; in some places it is filled with small rhombic crystals of siderite, in others it shows a multitude of small concretion-like forms, which are a frequent characteristic of the rocks of the iron-bearing member, and will be fully described later. Going southwest down the slope of this hill, from the brow, this rock disappears, and in its place is found a deep and broad deposit of soft hematite. Near the foot of the hill the iron ore deposit ends, and at the foot a pit sunk reveals the same peculiar rock as at the brow of the slope. The horizontal distance between the two places is about six and seven hundred paces, and the difference in elevation at the surface about one hundred and thirty feet. The boring at the foot of the hill has gone down one hundred and fifty feet from the surface, without finding much difference in the rock, while that at the top has not penetrated far below the surface. In all points, however, the rocks from the two places are identical.

As will be shown, these special phases of the iron-bearing rocks are not certainly known to occupy any definite stratigraphical position, and do not form always continuous bodies, extending over a large part of the formation, so that we cannot assign these two rocks to the same horizon with the certainty that we might have if the reverse were the case. On the other hand, it is certain that these phases, and especially the slaty, flinty phase, with which we are dealing, do extend over considerable areas, sometimes as much as a mile in diameter, without greatly altering their appearance, and without great intermixture of other phases. The edges of these areas, moreover, do not terminate abruptly, but grade off into other forms of the iron-bearing rocks. So we may have reason for believing that these two rocks, so much alike, and in such close neighborhood, were originally connected, forming one body, and that the rather abrupt break between them indicates, not a gradual change, but a mechanical fracture. The dip of the rock at the top of the hill seems to be very nearly level, but with a slightly western inclination; but this inclination is sufficient to account for only a small part of the difference of elevation between the rocks at the top and at the bottom of the hill.

In this case, we have here a normal fault with a vertical throw of at least three hundred feet, and an easterly offset of a thousand feet or more. The width of the offset is mainly occupied by the deposit of iron ore, and also in the midst of it, by the only deposit of manganese ore of workable dimensions known on the range.

Fault-plane and Breccia.

A few hundred paces north of here, following along our fault-line, test-pits sunk on the Lone Jack and the Missabe Mountain properties have encountered, in the midst of the soft ore, a deposit of peculiar character. This deposit has the form of a wall of no great thickness, the exact dip of which is not as yet known, and the strike of which seems to follow in a general way the strike of the slope. Test-pits sunk in this show it to be made up of many fragments of hard hematite, averaging perhaps three-quarters of an inch in diameter, enclosed in a cement of light red porous, friable, limonitic nature, mixed with finely divided siliceous stuff. In shape these fragments are often perfectly rounded, but they are usually sharply angular, and the edges of these prismoidal fragments show no traces of attrition whatever. This material was encountered in a vertical shaft for about sixty feet. Below this the shaft encountered a layer of white and red silica-kaolin, varying in depth from a few inches to twelve feet. The origin of this substance will be explained during the consideration of the rocks of the iron-bearing member. Below this soft blue hematite is found. Other pits sunk on either side of this fragmental material encounter at once, immediately below the glacial drift, the same blue hematite, sixty feet nearer the surface.*

This phenomenon can only be satisfactorily accounted for by the supposition that it represents a breccia along a fault-plane. It has been supposed to represent a stream-eroded preglacial gorge, but, although the rounded shapes of some of the fragments suggest water-worn pebbles, yet the sharply angular forms of the larger part forbid this conclusion. The freedom of the material from foreign fragments is also another significant feature; and it is difficult to imagine a stream eroding a narrow gorge, with perpendicular walls, to the depth of at least sixty feet, and then refilling this gorge quite to the surface with a conglomerate of which the pebbles were composed only of hard hematite, and the cement mainly of soft ore. In the process of mining, this structure will probably be fully exposed, and an examination of it will be of great interest.

Ore-deposits Near Virginia.

This western line of the Virginia area is marked by a great number of extensive deposits of iron ore, which, taken together, make up what is undoubtedly the richest region of like extent on the Mesabi. The most valuable of all are perhaps those in the immediate vicinity of Virginia, which we have been discussing. Here are clustered together mines like the Franklin, the Norman, the Commodore, the Lone Jack, the Missabe Mountain, the Minnewas, and others. But all along the line, as we go south, we find equally valuable mines, such as the Iron King, the Great Northern, and the Great Western, till in section 31 we find the enormous ore body of the Adams mine and the adjacent properties. This continuous line of ore deposits certainly indicates somewhat unusual conditions, such as would follow the development of an extensive mechanical fracture along this line. The method of formation of the ore-bodies of the Mesabi, as will be seen later, is largely dependent upon such accidents for their large development, for it is by these means that the oxidizing agents which are necessary for the deposition of the iron are permitted to penetrate the

*Twentieth Annual Report, Minnesota Geological and Natural History Survey, p. 132. The Mesabi Iron Range, by Horace V. Winchell.

rocks extensively and thoroughly. The same remarks apply to the deposit of manganese ore, chiefly pyrolusite, which is found on the Moose property, on the southeast of the southeast quarter of section 8. Here in prospecting, one hundred tons of ore have been taken out, and the deposit promises to be of value. The occurrence of manganese mixed with the hematite is common in the ore of this vicinity, on other mining properties. The occurrence of comparatively pure manganese ore lying by the side of comparatively pure iron ore, moreover, is a phenomenon the explanation of which suggests a mechanical fissure. According to R. A. F. Penrose, such separation ordinarily indicates somewhat freely moving waters bearing the two minerals in solution, and free access of oxidizing agencies to secure their separate precipitation. The following quotation is from his work on manganese:*

> If the waters from which the precipitation took place were moving, the iron and manganese, according to the difference in oxidability as stated above, would be laid down in different places, resulting in the formation of deposits of pure iron ore and deposits of pure manganese ore, occupying different positions along the plane of the same geologic horizon. Such occurrences are seen in the iron region of the Appalachians, where there are often found, in different places along the same ore belt, deposits of iron and deposits of manganese in positions similar with relation to the enclosing rocks.
>
> These conditions of moving water might also cause the interstratified condition of the two ores already described in still water deposits: this would result if iron were deposited in a certain place at one time, and if later, on account of some increased facility for oxidation, iron were deposited before it reached that place, and the manganese, being less easily precipitated, were carried on and laid down upon the first deposit of iron.

These conditions would be in no way satisfied by waters slowly percolating through a porous rock, but would be amply fulfilled by waters making their way along the broken rocks of a great fault-plane.

The Eastern Limit of the Virginia Area.

The eastern line of the Virginia area is also marked by ore-deposits, but they are not so many nor so large as those of the western border. Still, in sec. 34, T. 58-17, and on the Towanda and the McKinley properties, in T. 58-16, we find deposits of value.

The Animikie rocks do not recover their uniformity, even when they are to the east of the supposed course of the fault-

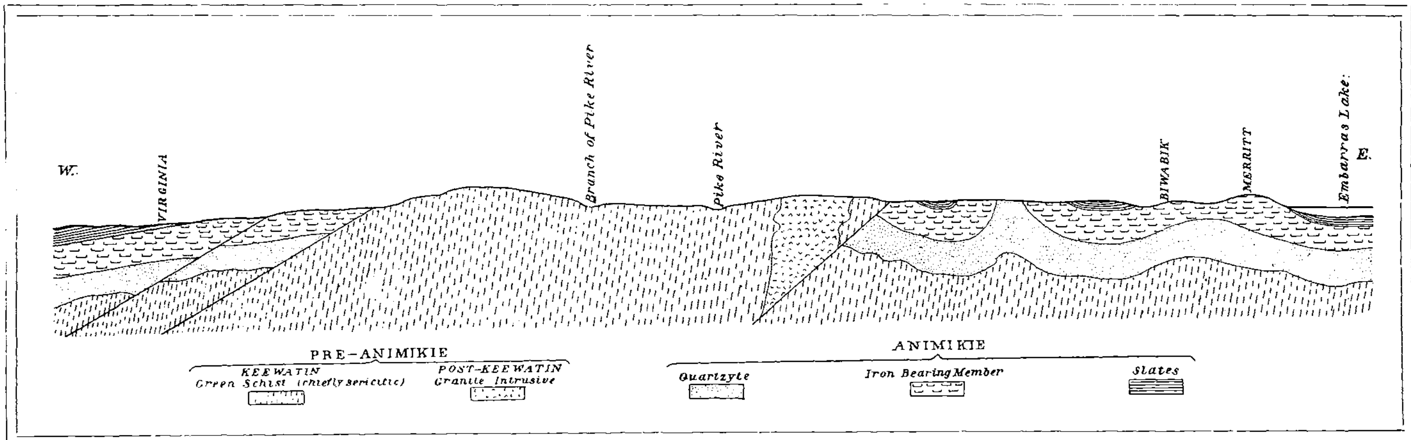
*Ann. Report, Arkansas Geological Survey, 1890. Vol. 1, p. 571.

line up the valley of the Pike. Their course in T. 58-16, from its western limits to Embarras lake, is marked by a gentle but distinct crumpling. The effect of this is to make the boundary of the iron-belt very irregular, especially on the south, as will be seen on the map. In place of the regular, broad strip of the western part of the range, there are sweeping curves, giving the belt at one place the width of over a mile, and in others near by a width of one-third of a mile or less. Attendant upon this is the wrinkling of the strata, resulting in slight elevations and corresponding depressions. An example of this is seen in sec. 4, T. 58-16, where a slight anticlinal dome is surrounded by a synclinal trough. The erosion of this structure has brought to the surface, in the centre, an area of the basal quartzyte, over half a mile in diameter, from which the upper rocks fall away on all sides. The surrounding synclinal trough is represented by a ring of the upper slates, which leaves the main body, and stretches up to surround the island of quartzite. Several smaller patches of quartzite, surrounded by the iron-bearing member, are scattered throughout the length of the iron belt on the eastern line of the Virginia area, and here, also, indicate a greater disturbance of the strata than is ordinary. But in sec. 4, it is much more strongly pronounced than anywhere else; and it must be noted that through the extreme western border of the crumpled area passes the more eastern of our two fault-lines.

The disturbed district, lying between the Virginia area and the Embarras lake is, as we might expect, marked by a signal development of extensive ore deposits. The group of mines near Biwabik and Merritt are perhaps second only to the Virginia group in importance. The explanation is the same as for the Virginia area. The disturbance of the strata was followed by freer access of percolating waters, and of oxidizing agencies with them, and thus ore-deposits were formed in favorable places.

Dip of the Animikie Strata in the Virginia Area.

On the Western Mesabi, west of the Virginia area, the dip is apt to be slight, but is almost uniformly somewhat east of south in direction. In sec. 20, T. 58–19, the ore is nearly flat; in sec. 10, 58–19, it dips about 25° S. E. This dip is probably only local. At Mountain Iron the ore dips almost imperceptibly to the southeast; in sec. 6, 58–17, it is to the southeast; in a pit on section 5, same township, it is 30° S. E. This brings us to



SECTION OF THE VIRGINIA UPLIFT AND VICINITY.

FROM THE SOUTH-WEST CORNER OF SECTION 6, TOWNSHIP 58-17, TWELVE MILES DUE EAST TO THE SOUTH-EAST CORNER OF SECTION 1, TOWNSHIP 58-16.

Horizontal Scale ⅔ inch=1 mile. Vertical representation of strata twice or three times exaggerated; of topography, five or six times exaggerated.

The section represented is that of the only area on the Western Mesabi which is known to have suffered important disturbance since the Animikie period.

the western limit of the Virginia area. Once across this line there is a marked divergence. At Virginia, as seen in the rock-cut at the Ohio mine, the dip is seen for the first time to be to the west. On the cliffs of iron-bearing rock between secs. 20 and 29, T. 58–17, the rocks seem to lie horizontally. At the Adams mine the dip is slightly south, as it is in sec. 5, T. 57–17. On the eastern side of the Virginia area it again becomes south-east. At a shaft of the Towanda near McKinley, the dip is nearly 45° S. At Iron Cliff, sec. 36, 59–17, the rock appears to be usually horizontal, although locally it dips 30° S. E. In the area between the Virginia area and the Embarras lakes it is still south and southeast, although the dips are rather steeper than to the west of the Virginia area, owing to the crumpling. On the Chicago property, in sec. 4, T. 58–16, the dip is about 30° S.; at the Biwabik mine the ore dips 30° S.; at the Hale it is in places as much as 45° S.

The dips as given are taken from the iron-bearing member, and refer to the banded and bedded structure, when present; or from the horizontal parting or slaty cleavage which is developed parallel to this banding and bedding. No one of these features, however, was possessed by the rock in its original condition, as will be shown later, and so the differences of position cannot be taken to mean actual differences in the positions of the rocks, without some hesitation. It will be shown that the banding and other structures which roughly simulate stratification have been developed in planes which correspond roughly, as a rule, to the position of the overlying and underlying strata, thus giving the impression of conformable stratification; but it will be shown that tensions have been developed in the iron-bearing member, resulting in folding, and changes in the direction and angle of dip, which did not extend to the adjacent strata. So, unless we assume that this banding and cleavage from which we have taken our dips was developed at about the same time, and represents nearly the actual relation of the rocks at the present time, they are of little value. If we do assume this, then the slight westward dip on the western border of the Virginia area, as contrasted with the uniform south and southeast dip of the rocks on the rest of the range, indicates a disturbance, not great enough for a fold, but such as we might expect along a fault-line.

Concerning the nature of the fault-line on the eastern limit of the Virginia area, we do not know, but two circumstances indicate that it may have been a reverse fault, and so was nearly parallel to the plane, as well as the trend, of the western fault. The first is the constantly narrower width of the iron-bearing belt on the eastern side of the area as compared with the western side. This difference may be estimated as on the average between 500 and 1,000 paces. Had the eastern fault been normal, like the western, there should be a strip of nearly equal width on both sides, while if the eastern were a reverse fault there would result from the overlapping the diminution of the width of the belt that actually exists. The second circumstance is the crumpling that is shown east of the eastern fault line, especially in its immediate vicinity, as contrasted with the total freedom of disturbance west, and in the vicinity of the western line. This shows that in both cases the thrust was in the same direction, towards the east. Had both faults been normal, there need not have resulted any great disturbance outside of the faulted area, on either side, and what folding took place would be in the faulted area itself; but with a reverse fault on the eastern border, the eastern thrust of the whole body of the faulted area would produce the disturbance in the adjacent rocks that we find.

SUMMARY.

The Virginia area has been faulted up from the main body of rocks, and thrust in a southeasterly direction. The two fault-planes that limit this area are roughly parallel, both in trend and hade, for a considerable distance. In the south, however, they converge so as to meet, and in the north they diverge and are lost. The upthrow has been probably not less than 500 feet, and the offset to the southeast between 500 and 1,000 feet. The movement caused the slight crumpling of the strata immediately to the east of the area. Along these fault-planes, but especially along the line of the normal fault, extensive iron-ore deposits have been developed. (See Plate II.)

DATE OF THE FAULT.

The faulting of the Virginia area and the crumpling of the strata east of it having been shown to be probably of the same age and caused by the same force. We may suppose, pending evidence to the contrary, that the slight tilting of the less disturbed Animikie strata was accomplished at the same period. The Keweenawan has already been suggested as the age of this movement, and the heaping up of the Keweenawan traps and lavas as the cause. The fragments of hard hematite in the breccia at Virginia show that at the time the faulting took place, there was already considerable iron in the rocks, and on the hypothesis (which will be shown to be correct) that none of the iron existed in the original rocks in the condition of massive hematite, the concentration of this indicates the lapse of a considerable period of time. But the formation of the great deposits of soft ore, considered as dependent on and subsequent to the faulting, shows what an immense time has elapsed since that accident. This is indefinite, but it does not militate against the supposition that the Keweenawan was the period of disturbance.

CHAPTER III.

MACROSCOPIC STUDY OF THE ROCKS OF THE IRON-BEARING MEMBER.

Although the iron-bearing member is a unit in all respects, yet no description can be framed that will apply to all of the phases of its rocks. In appearance, in habit, in structure, and in chemical composition, they vary within the widest limits. So unlike are the different phases that they have generally been taken to represent different horizons. These conclusions have been based on the observations of a large body made up with some uniformity of a single phase; in which case the connection with another large body of a totally different phase does not at first seem apparent. In places these bodies attain considerable size, if conditions are favorable, and the diameter of the largest may be perhaps about a mile. Such bodies, representing only closely allied phases, are scattered all over the iron-bearing belt.

These large accumulations, however, form only a small part of the entire bulk of the rocks Through the greater part the different phases are found more closely associated. A test-pit may within a few feet pass through representatives of all the important varieties of the rock, and a single hand-specimen may comprise half a dozen distinct and widely differing phases. It is when the rocks are thus closely associated that the true relationship of one type to another may be successfully studied, and by comparison of these types of which the relation has been worked out with the larger, isolated, less varied bodies, these latter may with certainty be identified, and put in their true positions as regards one another.

The study of the hand-specimens brings out the fact that the specimens are not so hopelessly multitudinous as first seems; that specimens may exist in many different localities which are in every respect identical; and that an enumeration and a classification of the different phases is very possible. It also brings out the important fact that while the phases which are mostly strongly contrasted with one another frequently occur in close proximity, yet oftener the changes are not so abrupt, and one phase may be seen passing into another by an easy transition.

With a view to assigning each of the different phases to a definite type, more than two hundred specimens, collected in the field with this special object in view, were examined, and the phases described by their outward appearance, with no microscopic or chemical aid. The result was as anticipated by observations in the field. Many of the types thus observed and described differ but slightly from one another, yet are described separately in order that the list may be full, and that there may be no danger of error from an erroneous identification of types, which, while they resemble each other, may yet have a different origin. For example, the different forms of iron ore are described as six types,—magnetite, hard crystalline hematite, friable granular crystalline hematite, earthy hematite, hard limonite, and earthy limonite or göthite. This elaboration is hardly greater than that used in describing the other types, and every variety found within the iron formation is thus described. Yet it was found that these types, as thus described, easily fell under about thirty heads. The list as worked out is given below, without any attempt to arrange the types in any order, for that order was worked out by subsequent comparisons, which will be described later. So any application of this would be premature, and would obscure the process of investigation as actually conducted.

PHASES OF THE IRON-BEARING ROCK.

1. Color dark gray, finely mottled with light gray. Luster mottled, vitreous and metallic. Texture granular. Fracture irregular. Heavy.

2. Color light gray, mottled with dark. Luster mottled, vitreous, metallic, and earthy. Texture granular, sometimes porous. Fracture irregular. An indistinct rough parallel parting. Specific gravity medium.

3. Color dark gray. Streak gray. Hard. Texture fine and compact. Luster metallic. Heavy. *Magnetite.*

4. Color light gray or pink. Luster vitreous to earthy. Texture porous and friable.

6. Dark brown. Friable, often hardly cohering. Grains crystalline, non-magnetic. Luster metallic. *Granular hematite.*

7. Color brown. Luster metallic. Hard; non-magnetic; texture close and compact. *Hard hematite.*

8. Color yellow. Friable; earthy. Limonite or göthite.

10. Brown, yellow, red or gray. Luster vitreous, (sometimes earthy). Hard; texture fine and compact. Fracture conchoidal.

12. Gray or white powder. Very fine-grained and friable.

13. Color blue, brown or red. Luster earthy to metallic. Texture powdery. Feel greasy or granular. Grains hardly or not at all cohesive. *Earthy hematite.*

14. Dark gray or green. Fracture conchoidal; luster vitreous; very hard. *Chert.*

15. Fine gray or green siliceous ground, mottled with soft spots, white and red.

16. Like 15 in structure, but with ground colored dark red, brown or yellow, and mottled with red or dark gray.

17. Color green or gray, well-developed slaty cleavage. Lustre earthy to silky. Medium hard; irregular fracture.

18. Like 17, but heavier, darker, and with metallic luster.

19. Color green, gray, brown, or red. Fracture irregular. Luster earthy to sub-vitreous. In texture fine-grained and compact; moderately soft, and cohesive.

20. Color red or brown. Cleavage well-developed. Luster metallic. Heavy. Is like 18, but contains more iron. *Hematite slate.*

21. Color white, red, gray, or black. Resembles somewhat 10, but as vitreous, frosty luster, and is harder. "*Jasper.*"

22. Color green, gray, white, or red. Luster earthy. Soft; mottled with white or red spots. Resembles a clastic rock.

23. Is like 16, structurally, but has a light green ground, mottled with black.

24. Is like 23 or 16, but has soft white ground, mottled with red.

25. Any color—black, white, green, gray, red, yellow, etc. Passes directly into 12. Soft; luster earthy; brittle. Cleavage very well developed. "*Slates.*"

26. Any color. Luster vitreous. Fracture granular. Hard; appears homogeneous to the naked eye.

27. Derived from 16 by leaching. Red. Regular hollow pores have been formed by the dissolution of the red spots of 16. Resembles 2.

28. Hard limonite. Compact.

29. Color green or gray, faintly mottled with lighter spots. Fracture irregular; luster vitreous; texture granular.

30. Color red-brown. Luster vitreous to pearly; structure crystalline.

31. Color green. Luster pearly. Fracture irregular. Is mottled like 22.

32. Color green; fracture irregular; luster earthy to vitreous; texture granular. Bears a general resemblance to 29.

It will be seen that these classes are so connected that they easily fall into a few larger divisions, which suggest themselves; thus Nos. 1, 2, 15, 16, 22, 23, 24, 27, 29 and 31 are all spotted cherty rocks, much resembling one another; 17, 18, 20 and 25 are all fine-grained slaty rocks; 10, 14 and 21 are fine-grained unspotted rocks, consisting almost entirely of silica; 4, 12 are light, porous and pulverulent; 32 is a green unspotted rock, not eminently siliceous; and 3, 6, 7, 8, 13 and 28 are all ores of iron. Thus all are disposed of except 19 and 30, and the characters of these two make their relationship sufficiently clear,—the first to the group of fine-grained slaty rocks, and the latter to the group which is represented by 32.

As before said, these different phases grade into one another, ordinarily showing no dividing line; and their relation is such as generally to place it beyond a doubt that one is derived from the other. In nearly every one of the specimens examined this process of change was clearly shown. The relationship of two phases in the same specimen is sometimes shown by their physical resemblance, and nearly always by the irregular, ragged nature of the boundary between them, and by the gradual change from one to another. In most cases the change is simply one of weathering, the weathered rock constituting one phase, and the fresher rock another. Then the weathered portion is found distributed along the joint-planes or other places where oxidizing agents have freest access; and the fresher rock remains within this as a ragged residuary fragment, its boundaries corroded and invaded by the weathered portion. Sometimes the weathered rock closely resembles, save for a little bleaching, the rock from which it is derived, as is the case in the transitions from one to another of many of the spotted cherty rocks; but in other cases the two phases are so entirely different that their relationship would with difficulty be established, were it not for their association. An example of this is the decomposition of a fine-grained dark, gray chert to a light, banded pulverulent rock, often quite white in color. This change may be frequently observed. In this case not only the total change in color and texture, but also the banded appearance of the decomposition product, as contrasted with the massive structure of the primary rock, operates to destroy the resemblance between the two.

The different phases are often interbanded, sometimes quite regularly. Ordinarily, however, these bands are seen on close inspection to be by no means comparable with the alternating sedimentary layers which they have been sometimes supposed to be. In the first place, they are generally marked only by the presence of a greater or less amount of iron oxide, and in all other respects may be identical with the rest of the rock. That this iron is an impregnation may usually be plainly seen, as marked by the irregular course of the band and often by the existence of the channel by which the iron penetrated the rock, this channel being often at a considerable angle with the banding. Again, the band, after running for some little distance in a straight line, generally bends, describes a curve or even an angle, and runs in a different direction; or again, it forks, and the branches separate widely, or again converge and meet; or the band may stop suddenly and entirely. It is rare that in any specimen from the rocks of the iron-bearing member the evidence against any sedimentary nature of the banding is not clear; and in these rare cases the true secondary nature may always be discovered by study of other specimens from the same place.

The relative age of the different phases, where they occur together, is usually evident. The original rock exists not only in a compact body, but also as residual fragments, large and small, surrounded by the secondary rock. The discovery of the residual fragments establishes at once the relation of the two rocks. These are angular as a rule, sometimes rounded, and their boundaries are irregular and not firmly marked. When the process is one of weathering, and the resulting rocks still resemble one another, that phase which follows the joint, cleavage or fracture planes may be taken as the secondary phase, and its appearance is usually an additional guarantee that this is the right conclusion. (See Figs. 3 to 9 inclusive.)

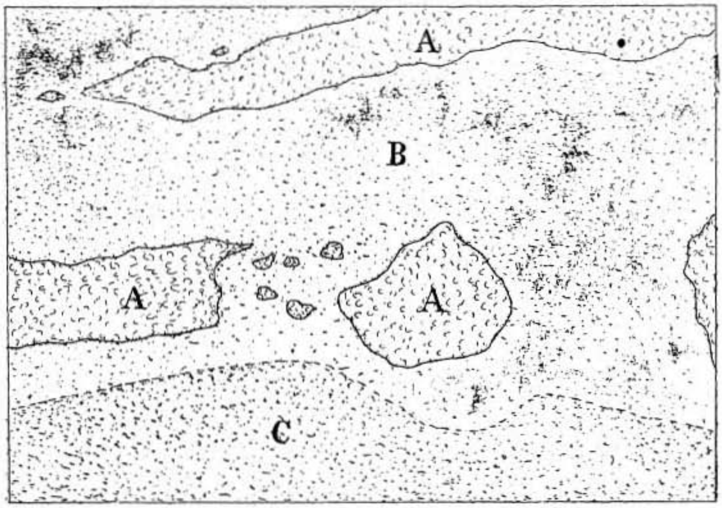


FIGURE 2.

Sketch of Specimen A. (*slightly enlarged.*)

A. Residual fragments of very light gray rock, of granular texture. Upon the light gray background there are numerous thickly clustering rounded bodies which are still lighter in color.

B. Harder rock, with a tendency to a conchoidal fracture and a finer texture than A. In color a nearly uniform rich brown. B is derived directly from A, chiefly by staining with iron oxide.

C. Very dark brown, highly ferruginous rock, locally passing into pure hematite. Is derived from B directly, by a continuation of the process of impregnation by iron oxide.

This specimen shows the destruction of the regular banding, by the advancing processes of change; and the formation, by division of the bands, of isolated residual patches. In the figure the former existence of two unbroken bands of the least altered rock (A) can be observed. These bands originally connected the separated fragments, but have been altered to their present state by the invasions of the altering agents. In the next stage A will entirely disappear. Finally, with greater change, B will also disappear, passing into C, which in turn may alter into some slightly differing phase.

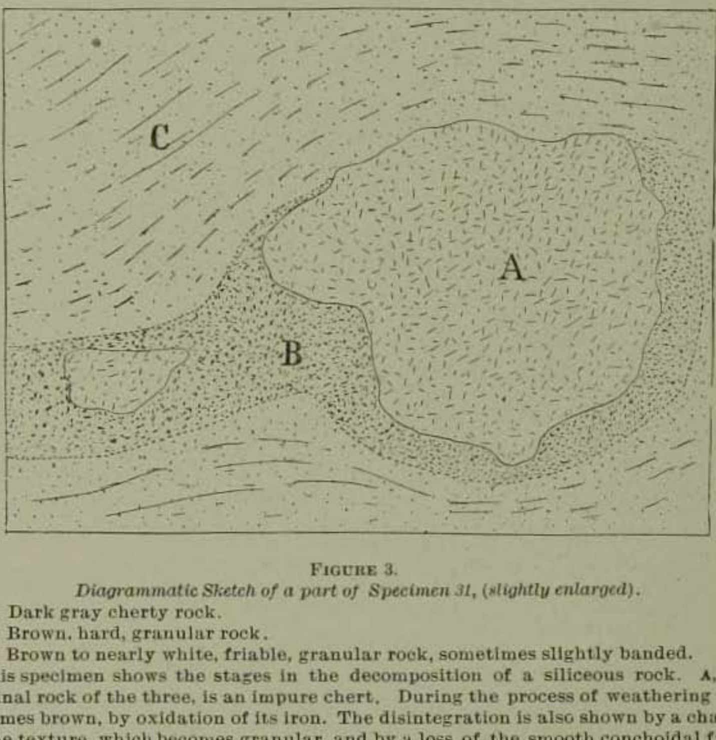


FIGURE 3.

Diagrammatic Sketch of a part of Specimen 31, (slightly enlarged).

A. Dark gray cherty rock.

B. Brown, hard, granular rock.

C. Brown to nearly white, friable, granular rock, sometimes slightly banded.

This specimen shows the stages in the decomposition of a siliceous rock. A, the original rock of the three, is an impure chert. During the process of weathering this becomes brown, by oxidation of its iron. The disintegration is also shown by a change in the texture, which becomes granular, and by a loss of the smooth conchoidal fracture. This stage, represented by B, is transitional between A and the completely altered rock, which is represented by C. C is almost entirely disintegrated; is leached of most of its iron, and is rapidly approaching the condition of a residual silica powder. Here, again, it is evident that the two fragments of the original cherty rock were once connected, so as to form a single band; and the area occupied by B is that which the original material last occupied.

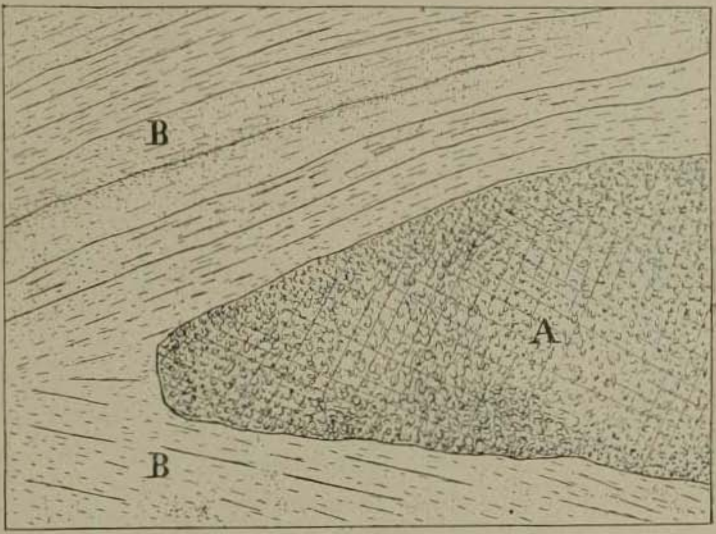


FIGURE 4.

Diagrammatic Sketch of a part of Specimen 28, (slightly enlarged).

A. Residual fragment of, red, siliceous rock; massive, with the characteristic spotted appearance, granular texture and conchoidal fracture.

B. Fissile slaty rock, banded, light and dark gray. The darker bands are highly magnetitic, the lighter ones siliceous and chloritic.

The decomposition of a hard, siliceous and ferruginous rock, to form a banded slaty rock, is well shown in this specimen. The process seems to be that of simple weathering along joint-planes; and the contraction of each successively weathered zone, due to the loss of its more soluble constituents, has produced the slate-like cleavage. The removal of iron from certain of these decomposition zones, and its concentration in others, has produced the banded appearance of the resulting rock. Most of the rock in the pit from which this specimen was taken was thus changed, and the resemblance to a somewhat altered slate is very deceptive.

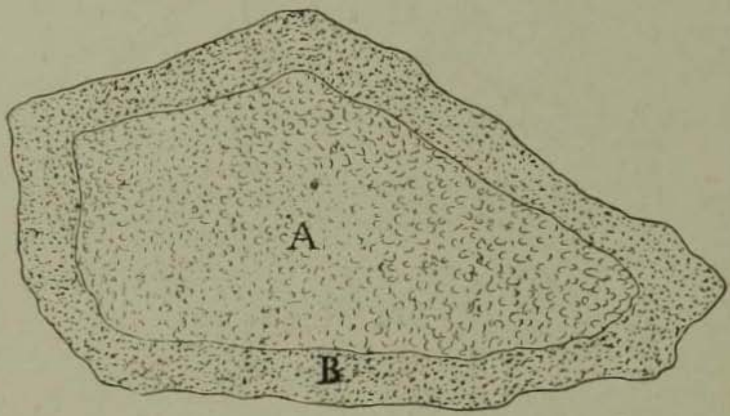


FIGURE 5.

Diagrammatic Sketch of Specimen 212, (actual size).

A. Light gray, granular rock.

B. Dark brown, granular rock.

This specimen shows the alteration of the original rock A to the dark brown phase B, chiefly by impregnation with iron oxide, with the attendant removal of silica. The shape of the specimen is the same as when found, and its outlines correspond to joint-planes which bounded it in its original position. Along these planes the agents of alteration entered, and penetrated the rock, progressing slowly inward. Thus a wide and well-marked border has been formed. In other specimens phases corresponding exactly to A and B are found in somewhat regular horizontal bands, alternating one with another; and in these cases the method of formation of the darker bands from the lighter must be the same as for the corresponding areas in the figure.

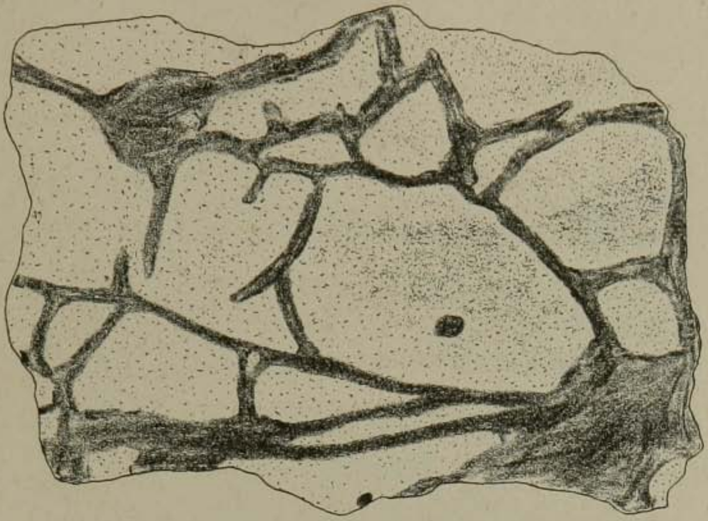


FIGURE 6.

Diagrammatic Sketch of Specimen 134, (actual size).

This sketch is made of a surface parallel to the horizontal parting or jointing of the rock. A very irregular arrangement of the darker seams is shown, and one which shows well the conditions which give rise to this structure. The lighter portions of the cut are of a light gray, granular, porous and friable rock, consisting almost entirely of silica. The dark reticulated seams are deeply stained, dark brown, with iron oxide; and often this process is carried so far that pure hematite results, especially in a narrow strip in the very centre of these darker portions. It is clear that the structure has been brought about by the infiltration of iron oxide in solution into crevices; and from the distribution of these crevices the contraction of the rock seems to have been the force which produced them.

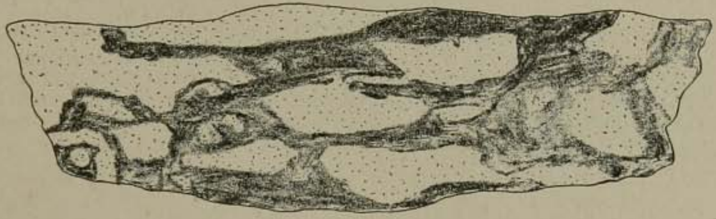


FIGURE 7.

Diagrammatic Sketch of Specimen 134, (actual size).

This is from the same specimen as figure 7, but is made at right angles to the horizontal planes of easiest division. The upper and lower outlines of this figure show the unequal course of the actual surfaces of separation. As in figure 7, the lighter parts represent porous and somewhat disintegrated siliceous rock; while the darker portions are stained by iron oxide, or are completely changed into hematite. The course of the ferruginous seams is very irregular, but the tendency to a horizonta arrangement, suggesting the banded structure which is the most usual occurrence, is very evident. The iron oxide is so distributed as to include patches of the original light-colored material; and with the continuation of the process of ferration these will be reduced in size and number, thus constituting scattered residual fragments in the midst of the highly ferruginous rock; and finally will be marked only by spots poorer in iron than the rest.

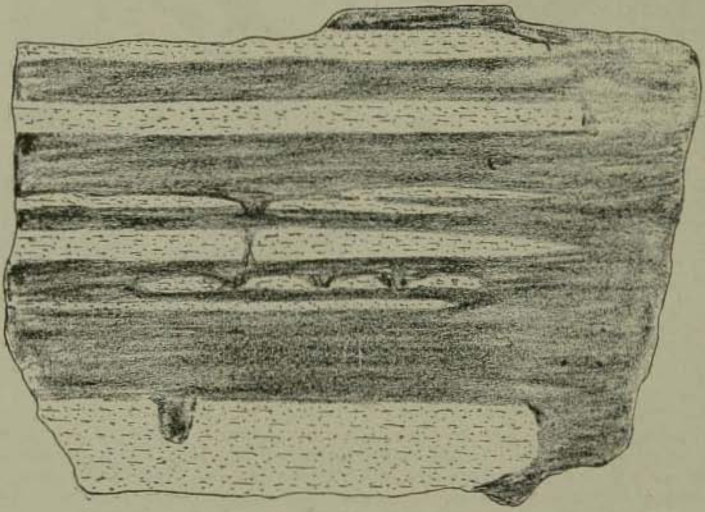


FIGURE 8.
Sketch of Specimen 148 (actual size).

The pit from which this specimen was taken contains rock which in general is beautifully banded, often without any noticeable irregularity. This specimen was selected as showing irregularities in the banding which explain the manner of its formation. The lighter parts of the cut represent a light gray, granular, porous and friable rock, with very fine banding of lighter and darker gray. The darker parts represent portions which have in general the same characters, but are harder, and dark brown in color.

That the darker portions have been produced from the lighter by deposition of iron oxide from infiltrating waters is shown by the irregularities of the banding. The right hand side of the cut represents a portion which was adjacent to a crevice, and in this vertical zone the whole rock has been stained. Most of the horizontal bands are regular and continuous, but often the channel by which the ferruginous solutions have leaked down from one band to another are shown.

For the purpose of discovering what order there was in the transition of certain phases into certain others, the specimens collected have been carefully studied in the hand specimen, and the changes noted in them tabulated, as given below. The numbers used refer to the different phases as described and numbered above:

TRANSITIONS OBSERVED IN THE HAND SPECIMENS.

Spec. No.	*Transitions of Phases.*
10.	1.
11.	1 to 2, 2 to 3.
12.	4 to 5 (4 is probably derived from 2.)
13.	6 to 8, 7 to 8. (Probably 7 is derived from 5, hard by.)
14.	32 to 3.
17.	29.
18.	9.
19.	1 to 10, 10 to 11, 1 to 12, 10 and 11 to 13. (Cavity forming.)
20.	1 to 3, 1 to 10, 10 to 12.
21.	14 with 10.
22.	10 to 2; 2 to 3, 6 and 8; 3 to 6 and 8.
24.	1 to 3, 3 to 7 and 13.
26.	7 to 8 and 13.
27.	15 to 16, 16 to 14, 14 to 17, 17 to 12.
28.	15 to 17, 15 to 18, 17 to 18, 15 to 12, 19 to 18.
29.	19 to 18, 18 to 20.
30.	18 to 6.
31.	16 to 10, 10 to 19, 19 to 12, 19 to 13.
32.	16 to 10.
33.	15 to 16.
34.	15.
35.	1 to 7 and 13.
36.	1 to 7 and 13.
37.	?
38.	?
39.	?
40.	21 to 7.
41.	16.
42.	1 to 7.
43.	12.
53.	?
64.	16 to 22, 12, 10 to 12.
65.	16 to 22, 12, 10 to 12.
66.	22, 12, 10 to 12.
68.	16, 2, 14 to 10, 10 to 19.
70.	12.
71.	2 to 10, 10 to 19.
73.	15 to 16, 15 and 16 to 12, 16 to 10.
74.	16 to 12.
75.	16 to 12 and 22.
78.	16.
79.	14, finely banded white and gray. Breccia.
80.	14 to 12, 8 and 13; 14 to 17.
81.	2 to 18.
82.	16.
83.	23.
85.	16 to 24, 24 to 22, 22 to green and to red 25.
89.	19–25.
90.	19–25.
91.	25 green, to 25 white and yellow.
92.	19 to 25.
93.	14 to 10, 10 to 19.
97.	21.
99.	Black 14, with pyrite; 20 to 6.
100.	16 to 6.
101.	25 (gray.)
103.	25 (gray.)
107.	1 to 8 and 13.
108.	16 to 2, 16 to 1, 16 to 6 and 3, 16 to 12.
109.	26 (26 to 27?), 27, 27 to 10.
110.	26 (26 to 27?), 27, 27 to 10.
111.	16 to 27, 16 to 10, 16 to 25, 16 to 19.
115.	14 to 19.
116.	14 to 19.
117.	14 to 19.
119.	19-14 to 19, 19 to 25.
120.	14 to 19, 19 to 25, 25 to 12.
121.	14 to 19, 19 to 25, 25 to 12, 25 to 5.
122.	14.
123.	1 to 27, 27 to 12, 12 to 25, 25 to 7.
124.	3 to 28.
125.	29 to 3, red 10 to 3. Pyrite.
126.	7 and 28, 28 to 8.

127. 14 to 10, 10 to 19.
128. 29 to 15, 15 to 10, 29 to 27, 29 to 7, 10 to 12, 29 to 12.
129. 1, derived from 29.
131. 32 to 30, 30 to 4.
132. 32 to 30, 30 to 4.
133. 29 to 2, 29 to 4, 4 to 3; 3 to 7, 28 and 8.
134. 26 to 4, 4 to 3; 3 to 7, 28 and 8.
135. 16 to 1; 1 to 3 and 8.
136. 16 to 27, 27 to 23, 23 to 12, 23 to 3.
137. 31 to 3; 3 to 7 and 8.
138. 25.
143. 2 to 7.
147. 2 to 10, 10 to 12 and 8.
148. 19 to 3 and 7.
150. 2 to 10, 10 to 25.
151. 2 to 10, 10 to 8, 10 to 7.
152. 25.
153. 25.
154. 18.
155. 14.
156. 31 to 2, 2 to 3 and 7.
157. 15 to 16, 16 to 18, 18 to 20.
158. 19 to 20.
159. 15 to 16, 16 to 19, 14 to 2.
160. 19 to 20.
161. 16 to 2.
162. 7 to 8.
164. 14 to 21. Pyrite.
166. 16 to 14. Pyrite.
170. 25.
171. 15 to red 10.
185. 23 to 14-19; 14-19 to 7.
204. 7 to 8 and 13.
208. 2 to 7.
210. 14 to 19.
211. 2 to 10, 10 to 7.
212. 2 to 5.
213. 10 to 7, 30.
214. 2 to 10.
215. 2 to 7, 26 to 7.
216. 2 to 5.
217. 29 to 3.
219. 31 to 1, 31 to 3, 3 to 8. Pyrite.
218. 10 to 7, 7 to 8 and 13.
220. 26 to 3 and 7.
221. 19-25.
222. 14-19-25, 14 to 19, 19 to 25.
223. 25.
225. 19 to 25.
224. 2-10.
229. 12.
230. 12.

By collecting from this list the different changes which each rock has undergone, we may make out the following table. This shows after each phase as enumerated and described above, the phases into which it has been seen to pass by a gradual transition, the circumstances in each case observed being in general such as to show that one was derived immediately from the other.

TRANSITIONS FROM ONE PHASE INTO ANOTHER.

From Phase *1* are derived Phases 2, 3 (twice listed), 7, 8 and 13.
" *2* " " 3 (3 times listed), 6, 8, 10 (6 times), 18, 7, and 5 (7 and 5 twice listed).
" *3* " " 7 (4 times), 13, 28 (3 times), 8 (5 times), and 6.
" *4* " " 5 and 3.
" *5* " " Nothing.
" *6* " " 8.
" *7* " " 8 and 13.
" *8* " " Nothing.
" *10* " " 11, 13, 12 (4 times), 19 (3 times), 8 (twice), 25, 7 (3 times), and 3.
" *11* " " 13.

From Phase	*12*	are derived	Phases	(Iron ores, by replacement).
"	*13*	"	"	Nothing.
"	*14*	"	"	17 (twice), 10 (3 times), 19 (4 times), 2, 21, 17 (twice), 12, 8, and 13.
"	*15*	"	"	16 (3 times), 17, 18, 12 (twice), and 10.
"	*16*	"	"	14, 10 (3 times), 22 (twice), 12 (4 times), 24, 6, 2, 1 (twice), 3, 27 (4 times), 25, 19 (twice), and 18.
"	*17*	"	"	12 and 18.
"	*18*	"	"	20.
"	*19*	"	"	18 (twice), 12, 13, 25 (7 times), and 7.
"	*20*	"	"	6.
"	*21*	"	"	7.
"	*22*	"	"	25.
"	*23*	"	"	12, 3, 14, and 19.
"	*24*	"	"	22.
"	*25*	"	"	12 (twice), 5, and 7.
"	*26*	"	"	4, 3, 7, and 27.
"	*27*	"	"	10 (twice), 12, and 23.
"	*28*	"	"	8.
"	*29*	"	"	3 (twice), 27, 7, 12, 30, 2, and 4.
"	*30*	"	"	4.
"	*31*	"	"	1 and 3.
"	*32*	"	"	3.

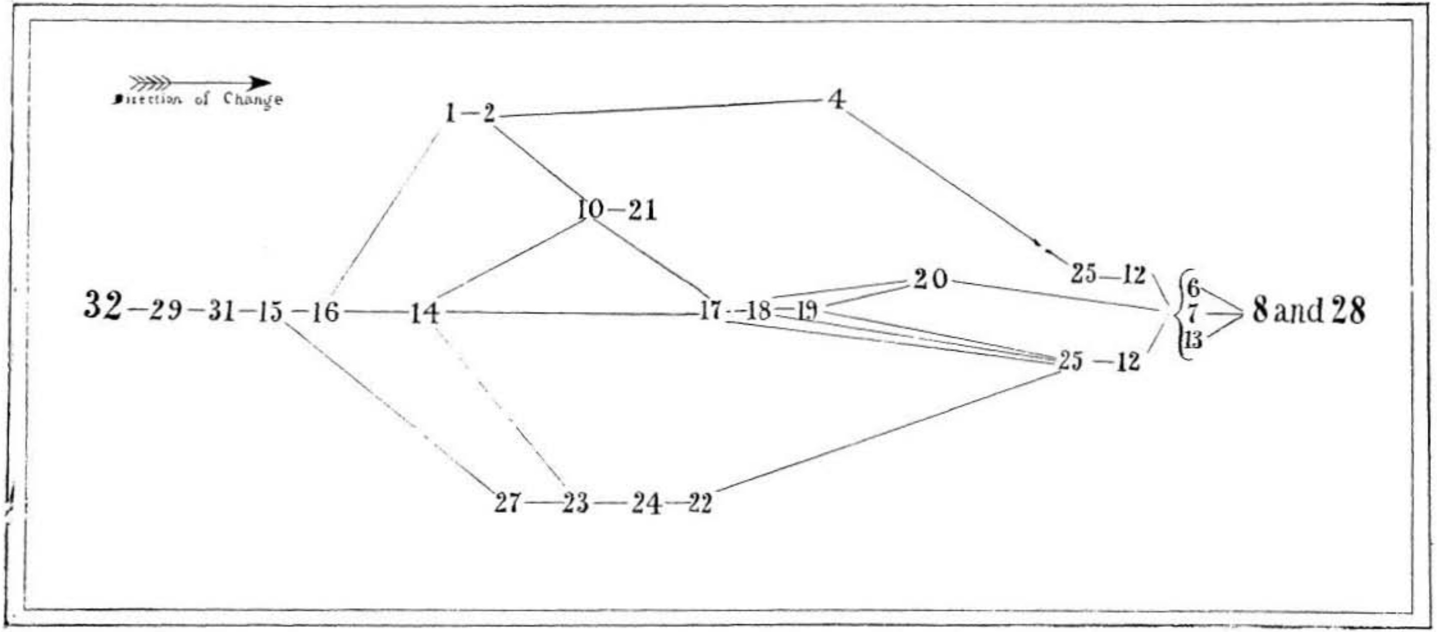
By inspection of these transitions it becomes at once apparent that there is a definite order which runs through them. This is shown by the recurrence, repeated many times, of the same change, showing that the change always takes place in a constant direction, is never reversed, and is apparently inevitable under normal conditions. At the same time each of the phases is seen to pass into so many others, and so many others are derived from it, that it is evident the process is a varied one, and protracted into a large number of stages; and again it is found that each of the phases derived in one case from a single primary rock may in other cases be derived from other primary rocks. Then if in any one of the transitions observed the derivation of one of the primary rocks from another may be established, the relation, not only of these phases, but of the phases that are derived from them, becomes at once apparent. A continuation of this process gives the relationship of all the phases to one another.

It is seen at a glance that those types from which few or no derivatives are recorded, stand near the end of the series, and, on the other hand, that types from which many others, representing as a whole a large part of the series, are repeatedly seen to be derived, stand among the results of the first stages in the process of change. This rule must be applied with caution in the first instance; for it may happen that few changes are recorded of a rock simply because it happens to be a rare type, and so the changes which actually take place in it have not been observed in the two hundred and thirty specimens studied. Still, the rule in general holds good; and the study of a larger number of specimens would entirely remove this difficulty. So phases like 5, 6, 7, 8, 11, 12, 13, 20, 25, 28, etc., probably represent the closing stages in the change; and phases like 30, 31 and 32, although few derivatives are shown for them, may yet be finally put in their rightful place near the beginning of the series by their resemblance to others which have already been put there. On the other hand, rocks like 10, 14, 16, 17 and 29 at once suggest themselves as representing those which must be placed among the first, and in this case there is no possibility of error in the classification.

By these methods the different phases are found to be related substantially as represented in the accompanying diagram. This diagram agrees almost exactly with nearly every one of the observed changes, an agreement rather remarkable, considering the possibilities for error in classifying by the physical peculiarities of the hand-specimen alone. (See Plate III.)

The process of change worked out by the method above indicated may be briefly described as follows:

A massive, granular, green rock, represented by the number 32, with often a peculiar mottled structure, as represented by 29 and 31, forms the first of the series. By a slow and gradual process of change, which is seen from the descriptions and from the specimens to be substantially a process of weathering, this rock goes through the series indicated by 27, 23, 24 and 22. In this process it becomes soft, loses its firmness and passes through various stages of color in the process of bleaching. This profoundly weathered rock which still, however, retains the mottled structure, then passes by further disintegration to a phase like 25, where the mottled structure is obliterated, and the consolidation of the resulting mass has produced a certain slaty nature. This rock may be very light in color, or it may be stained various hues by iron and other coloring agents. Further decomposition gives a scarcely coherent clay or powder, which is typically white, though, like 25, it may be stained. This is the condition of phase 12. This is the end of the decomposition process, but the powder may become strongly impregnated with iron, forming the various iron ores 7, 8, 28, 13, etc.



DIAGRAM, SHOWING THE RELATION OF THE VARIOUS PHASES OF THE IRON-BEARING ROCKS LISTED FOR THE WESTERN MESABA.

The figures refer to phases described on page 27.

The same mottled green rock gives rise to the series represented by 1, 2 and 4. Here the change is manifestly also one of decomposition, but it is much more rapid, and the leaching goes on faster than the comminution of material. The resulting rock, 4, bears a general resemblance to 25, the rock resulting from the slower and more protracted weathering, in that it is of low specific gravity, typically of light color, and is porous and friable. It differs chiefly in that the individual grains are much larger, so that the texture is granular instead of pulverulent. This coarser variety may undergo a further decomposition to a phase like 12, which is also the decomposition product of 25, or it may be directly impregnated with iron to form the iron ores. Phases 1 and 2 preserve the mottled structure, and the whole series bears a strong resemblance to the series of 27-22 inclusive, the differences appearing to consist in the different degree of access of the forces which produce weathering, in the different localities from which the specimens were taken. Phases 1, 2 and 4 are all found in one locality, where the phases of the other series do not occur; and phases 27-22 inclusive are profuse in a region which affords few representatives of the first series.

As a second chief division in the evolution of phases are the cherts, without mottled structure, and the slaty rocks. The cherts are usually slaty or banded, and pass by easy transitions into the more markedly slaty rocks. Sometimes the cherts contain scattered crystals of siderite, sometimes none. The more slaty rocks are usually characterized by a greenish color, fine texture and weathered appearance in some layers, and by the presence of a greater or less amount of iron oxide in others. These banded cherts and slates may spring from the green and massive rock, at the same point as the series before described; but they may also be derived from any point of the first series, in its less altered stages. Thus 14, which represents the pure cherts, is found to be derived from 16 in one case, and from 23 in another; 14 passes into the slaty rocks, represented by 17, 18, 19 and 20. Of these rocks those most deeply impregnated with iron pass directly into the iron ores, while the lighter, greenish varieties weather and are bleached till they pass into the type 25, and thence to 12. This last condition, represented by 25 and 12, will be seen to be identical with the last stages of decomposition of the series first described. As in the first case, of course, 12 may become impregnated with iron oxide and thus pass into the iron ores.

The hydrated oxides seem to represent the most stable form of iron under copious atmospheric agencies, and so these may properly be put at the end of our typical scheme.

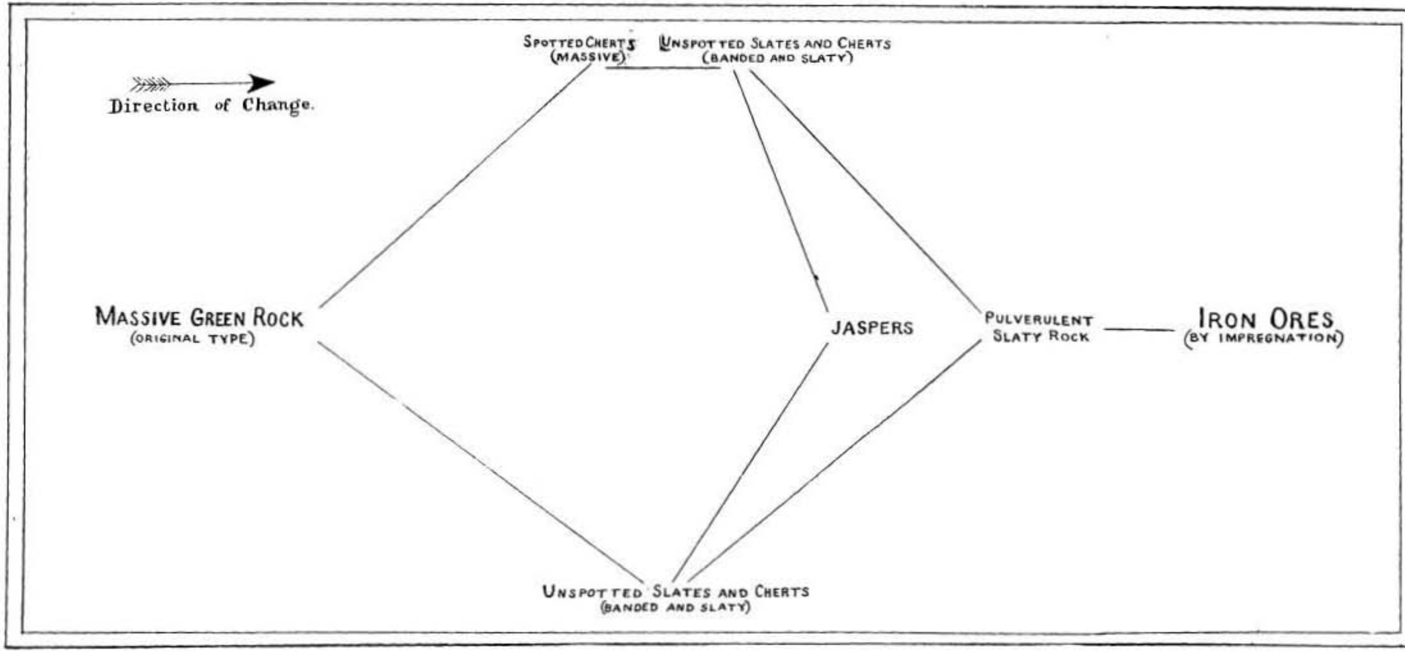
So far we have two main series, derived from a single initial type. The first series comprises the various stages of change under atmospheric influences, leading to the entire decomposition and the reduction to a clay-like rock. The second comprises the analogous processes of change as exhibited in a set of rocks which have lost the original massive and mottled structure, and have acquired a slaty or banded habit; these are derived either from the primitive type, or more often from some point in the first series. These processes lead finally to a clay-like rock which is identical with the rock resulting from the changes in the first series. In this first series the only apparent agency is one of weathering; in the second the change from the massive mottled to the slaty rock is not fully explained by the hand-specimen, but the subsequent changes which lead to the phases 25 and 12 are seen to represent weathering, as before.

The chief addition to these two divisions is the class of jasper-like rocks, represented in the scheme by 10 and 21. These are derived from certain very siliceous phases in each of the two main series: thus in the first series, they are seen to be derived from 2, and, in the second, from 14. Phase 21 is the end of this minor series. It is a crystalline "jasper," and is not known to pass into any other type. The process of development of this rock seems to be one of crystallization from the siliceous types whence it is immediately derived; and this process is sharply contrasted with the degenerative actions which operate in the formation of most of the members of the other series.

From this examination of the results of our tabulation and plotting, we may construct a simpler scheme of development, comprising only the grand divisions among the rocks. (Plate IV.)

ARRANGEMENT OF THE DIFFERENT GROUPS IN THE FIELD.

It is evident, from the fact that a single hand specimen often contains representatives of several widely differing phases, representing perhaps most of the larger groups, and that this occurs so frequently that a tabulation of the changes may be made from these specimens, that the different groups do not occupy any fixed horizon in the iron-bearing member. It is found in the field that any one of the groups may occur at any



DIAGRAM, SHOWING THE RELATIONS TO ONE ANOTHER OF THE PRINCIPAL CLASSES OF THE IRON-BEARING ROCK point in the iron belt; and when this group gives place to another, the transition may take place vertically, so that one division overlies another, or laterally. In either case the boundary between the two is generally indistinct, and very irregular. Therefore it cannot be said that any one phase or division of phases is referable to any distinct horizon. The cherty and slaty rocks, however, seem to occur in large bodies chiefly in the upper horizons of the member; and the clayey and pulverulent slaty rocks are found at the surface, at any horizon, and lying above the less altered rocks which are akin to them. Indeed, it is ordinarily the case that, in a given vertical section where varied phases are encountered, those which are put near the end of the scheme, and so represent the effect of the greatest activity of decomposing atmospheric agencies, are found near the surface; and the fresher and firmer rocks, which are placed near the beginning of the diagram, at greater depths. These distinctions however, so far as we have seen, are incident to the alterations which have come about in the weathering and other changes in situ, and so probably have little stratigraphical importance, in that they do not necessarily represent divisions in the rock as originally formed.

CHAPTER IV.

MICROSCOPIC STUDY OF CERTAIN GROUPS OF THE ROCKS OF THE IRON-BEARING MEMBER.

In order to study more accurately the relation of the different phases to one another, and the processes which took place in the multitudinous changes there shown, together with the motive for these processes, thin sections were cut from the specimens described, embracing all the more important varieties. The study of these sections has confirmed the conclusions that were arrived at by a study of the hand specimens alone; and a clearer view of the gradual changes and their causes was also obtained. The evidence which proves the derivation of one type from another, and finally the ultimate derivation of all the types from a single uniform primary rock, will be treated independently of the evidence obtained from the hand specimens alone, as that evidence was deduced independently of it.

The method which has been adopted in tracing under the microscope the evolution of the rocks is somewhat different from that employed in the study of the hand specimens. In the macroscopic study the method was to classify all the types, occurring in specimens the locality of which was not brought into question, but representing the length and breadth of the iron-bearing region of the Western Mesabi; to show that they were referable to about thirty closely allied phases; to show that in the specimens certain phases were associated with certain others in a way that could be explained only by the derivation of one from another since the formation of the iron-bearing member; by classifying all these derivative phases in the different specimens, to show for a certain phase what phases were invariably below it in the process of change—i.e., were derived from it, either directly or indirectly—and what phases were invariably above it, i.e., gave rise to it, either directly or indirectly; and thus to work out the general scheme of evolution. In microscopic study the multiplication of the number of stages that may be observed, and the certainty and ease with which one may be traced into another, permit a more accurate and satisfactory variation of this method. Certain localities have first been selected from which many different phases have been collected, within a small area. Generally this area is represented by a single test-pit. These test-pits have a diameter only large enough to permit two men to work in the bottom; and they are usually sunk in the solid rock to a depth of less than ten feet. When different phases are found in the rock thus thrown out, they are confusedly intermingled, without definite order, one occurring as residuary cores or as decomposition borders to another. The phases that are thus found, occurring in this known proximity and relation to one another, are grouped for special comparative study. By this study it is invariably found that there is a definite scheme of development of one type from another, and this scheme and the causes which have led to the changes, are carefully noted. So varied are the phases, even within small areas like this, that in some of the groups the principal stages of nearly the whole process of change which characterizes the iron-bearing member are present. Sometimes the groups are taken from a still smaller space, a single specimen often furnishing opportunity to study a number of important changes. In some places again, where test-pits are set closely together, and the intimate connection of the rocks in them is obvious, specimens are selected from any of them to form the group for study. When these different chief groups have been studied, it is generally found that a certain type in one group is identical with a certain type in another, and thus two groups may be connected to extend the completeness of the general typical scheme of development. If in one group the type which stands near the head of the series as observed for this particular case is identified with a type which stands near the end of the series in another group, then the scope of the scheme is greatly extended; and if the groups turn out to be roughly parallel, the interpolation among the phases of the one of the phases which are closely related but not identical, belonging to the other, brings about an elaboration of the scheme. When the larger groups have been thus connected, the outlines of the main part of the general plan are found to be complete; and those phases which have been taken singly from different localities may be found by comparative study to be identical with some of the phases in the scheme as already established, or to bear such evident relation to certain of these that their proper place is quite evident.

GROUP FROM SECTION 18, T. 58–19.

In accordance with this plan, the first group described is represented chiefly by sections 128, 129, 130 and 131. These are from the specimens of the same number, and are all from a single pit in the southeast corner of section 18, T. 58–19.

SPECIMEN 128.—Hand specimen shows a light greenish siliceous rock, grading into gray sideritic chert, dark chert, and bands of iron oxide. Three sections are cut from this, 128-A, 128-B and 128-C.

128-A.—In hand specimen a sideritic chert, dark-gray, with cloudy white crystals of siderite scattered through it, or angular cavities left by the dissolution of these crystals. Fracture conchoidal.

Under the microscope, there is a ground-mass of very finely divided silica. This silica does not show the fibrous structure of true chalcedony, nor the clearly-marked extinction and polarization colors of crystalline quartz. It consists of many very small grains closely packed together, which extinguish on revolution of the stage of the microscope; but without any marked polarization color other than a dull gray. The true nature of this variety of silica does not seem to be fully established, although it is the form which occurs frequently in many cherts and kindred rocks. Irving and Van Hise thus describe it in the cherts of the Penokee iron-bearing series:*

"It is that variety of silica or quartz which has in the polarized light a minute spotty appearance, due to exceedingly small individuals of quartz, mingled with more or less of silica, which is apparently amorphous. Hornstone, or flint, gives in thin section the same appearance, and the chert of the iron carbonates and hornstone have a very close macroscopic resemblance. That a portion of the silica is really amorphous, as indicated by the appearance of the section under the microscope, is further shown by its ready solubility in caustic alkalies."

*Tenth Annual Report of the United States Geological Survey. The Penokee Iron-Bearing Series of Michigan and Wisconsin, p. 384.

In his work on the Novaculites of Arkansas, Mr. L. S. Griswold describes the silica of a rock which bears a very close resemblance to the one under consideration, as follows:*

"Under the microscope the ground-mass is seen to be composed of crypto-crystalline silica, extremely fine quartz grains, extinguishing in polarized light, but too small to give any polarization colors or other optical characters. The separate grains average less than .01 of a millimeter in diameter, there being from 6 to 10 grains in a linear distance of .05 mm. The extreme variation is about .01 to .001 mm. in diameter."

Rosenbusch treats this form of silica very briefly, as follows:†

"The so-called quartz of the siliceous slates and of related rocks requires more exact investigation, and probably does not belong to quartz, but to chalcedony."

This particular variety of silica is the most common in all the rocks of the iron-bearing member, as well as in the particular section under consideration. In a future brief consideration of its associations and characteristics as shown in its occurrences in these rocks, it will be found to resemble rather the less highly organized forms of silica, such as chalcedony and amorphous silica, than the truly crystalline quartz. In the descriptions of slides it may be conveniently referred to as cryptocrystalline silica, to distinguish it from the amorphous silica, the typical chalcedonic silica, having a fibrous arrangement, and the true quartz. All these forms occur in various proportions in different parts of the rocks described.

To return to our description of section 128-A, we find in the ground-mass of cryptocrystalline silica crystals of siderite, averaging about one-tenth of an inch in diameter. These crystals may have perfectly regular outline, either of single individuals or twins, or they may lack any portion of this outline. In the latter case the lines of growth terminate in such a manner as to show that the crystal was disrupted after its formation, and the space filled by the silica. These lines of growth are regularly placed, one within the other, and are rhombic, conforming to the outlines of the perfect crystals. They may be traced in some cases quite to the center of the crystal. The outer parts are freshest, and the siderite becomes clouded from decomposition, progressively towards the center, which is semi-opaque. These features show that the siderite is wholly of

*Annual Report of the Arkansas Geological Survey for 1890. Vol. III. Whetstones and the Novaculites of Arkansas, p. 123.

†Microscopical Physiography of the Rock-Making Minerals, by H. Rosenbusch. Translated by Joseph P. Iddings. Second Edition. P. 172.

concretionary crystalline growth, and the arrangement of the silica in its present form has gone on at the same time. This seems to be a continuation of the process described in its beginning under section 78. (See Plate VII, Fig. 1). The rock has been strained since the crystallization of the siderite, with the result that the crystals have been broken into small grains, which under crossed nicols extinguish at slightly different angles, according to the degree of straining. While this strain has thus wrenched the crystal, it cannot account for the many incomplete crystals, in which the portion broken off is wanting, and cannot be found anywhere in the rock. Often, after the crystal has had part of itself thus torn away, it has continued growing, the new lines of growth following the outline of the broken form, instead of the perfect crystal outline, as before. This shows that the crystals were not of their present size at the time of the breaking, but were only partly grown, and that since then the enlargement has proceeded.

SECTION 128-C. This slide contains three distinct bands of the hand specimen: 1, the sideritic chert; 2, a light green cherty band; and 3, a dark red iron-stained band which grades into nearly pure iron oxide.

In that part of 1 most remote from 2, the rock is exactly like 128-A. As it approaches 2, there is a distinct, increasing tendency to a linear arrangement of the impurities of the chert, an increase in their amount, and a disappearance of the siderite crystals. What siderite remains becomes somewhat more decomposed. This transition rim is distinctly seen in the hand-specimen, and grades into 2. The change between this band and 2 is marked, though there is a somewhat gentle gradation from one to the other. In 1, a siderite crystal has sometimes entirely disappeared, leaving a skeleton of hematite or limonite which fills one half or less of the cavity, the remainder being filled with cryptocrystalline silica. But perfect crystals occur on the very border of 1 and 2, lying partly in one and partly in the other.

2 represents in the hand-specimen a light-green, cherty band, from $\frac{1}{4}$ to $\frac{1}{3}$ inch thick. Consists of finely crystalline silica in interlocking grains of much larger dimensions and different characters than the silica of 1. This mass is colored green by a uniformly distributed, hardly individualized dust, which appears to be a decomposition product, and in which a carbonate may be recognized, in excessively small grains. There are no crystals of any kind. These greenish decomposi-

tion products are seen by a low power to be somewhat aggregated into little spherules. There is a distinct linear structure, and a certain differentiation into lighter and darker masses, around which the lines run.

3, in the hand specimen is more or less impregnated with iron oxide. In the slide it is seen to consist of hematite and limonite, with many small interstices occupied by grains of silica. The iron is densest on the line which marks the contact between 2 and 3.

Conclusion: 3 represents a line of mechanical weakness, along which iron-bearing waters have entered, impregnating this band, and to some extent replacing the silica.

SECTION 128-B. Contains varieties 2 and 3, substantially as described above, and variety 4.

4 is of the same color as 2, but is somewhat granular in texture. It constitutes a band about two inches wide, interrupted by a narrow (¼-inch) band of iron. It frequently contains very small rounded grains of a substance with a black color, vitreous luster and conchoidal fracture. In places the rock has become porous through weathering.

Under the microscope is seen the peculiar spotted structure which has already been mentioned in the study of the hand specimens of the different rocks. This structure is usually characteristic of the rock macroscopically, but in this case only microscopically. It is marked by the presence of a profusion of small rounded bodies, averaging perhaps one-tenth of an inch in diameter, thickly scattered through the ground mass.

These bodies may be of any color and have their outlines preserved with any degree of distinctness. Sometimes, when rounded, they suggest concretions and resemble the oolitic structure of limestones; and again when subangular, they suggest detrital grains. In still other cases they are sharply angular, and grade upwards in size to angular fragments of a diameter as great as two inches. In this latter case they are are evidently fragments of a breccia. The nature and various causes of this structure will be discussed later. For these rounded bodies the term *granules* will be employed. This will cover not only those bodies which are of truly fragmental origin, whether original in the rock or secondary, but also others which resemble these closely, and make up perhaps 10 per cent of the whole number of granules. These latter will be seen to be partly of concretionary growth, and partly the results of peculiar phases of impregnation of weak spots in the rock by iron oxide. The structure of which these bodies form the chief characteristic will be spoken of in general as a *spotted-granular* structure. When the granules are somewhat separated the siliceous filling between them will be referred to as the *ground mass*, but when, as often happens, they are closely packed together, the intervening matter will be spoken of as the *interstitial substance*, and as filling the *interstices*. The term *intergranular substance* will be used with the same signification.

In 128-B, variety 4, the granules are made up of particles of quartz, somewhat larger than those of 2, together with an evenly divided clayey and a green chloritic substance.* A large ragged fragment of the same nature remains at one side, and in this and the smaller granules there is a certain splitting and division going on. The change consists in a gradual rending apart of the mass, a slight darkening of the chloritic substance, and the filling of the interstices with crystalline or cryptocrystalline silica, varying from coarser to finer, but in general somewhat finer than that of the granules. Around the granules are often darker rims of the chloritic substance. The outlines of the granules are rarely rounded; they are usually angular, often not entirely separated from one another, and sometimes with the parting only begun. The interstitial silica may be xenogenous,† but it is probably derived from the silica already in the rock. This may take place in the following way: 1. The formation of silica by disintegration of the chloritic substance. This is accompanied by changes of volume which produce cracks. 2. Segregation of pure silica along these cracks, and the growth of these veins, splitting the rock. 3. A separation of iron oxide, attending the disintegration of the chloritic substance, producing the darkening of the residuary chloritic matter in the granules, especially around their edges.

Conclusion: Variety 4 is the original rock of the series exhibited in this specimen. In certain parts of the rock there

*The nature of this mineral is not here definitely stated, but as the description of sections goes on, it will be seen to have been of the highest importance in the history of the rock. Its exact nature and origin was not determined until after these descriptions were written, and as a knowledge of this is not essential to the understanding of the various changes, as it was not essential to their working out, the discussion will be reserved till later. In the descriptions it will be referred to as here, by the indefinite term "chloritic substance."

†In the use of this term and other convenient words of the same kind, the work of F. Posepny in his essay, entitled, "The Genesis of Ore Deposits," (Trans. Am. Inst. Min. Eng. Chicago meeting, 1893,) is followed.

has been a mechanical movement, doubtless resulting from the release of strains accumulated during the metasomatic changes. Along the cracks formed by this movement the rocks have been impregnated with xenogenous iron brought by percolating waters, and thus the bands of solid iron oxide were formed. In the rock immediately adjoining these actual cracks the slight schistose structure induced has given rise to selvage bands where the spotted-granular structure has been mainly replaced by a faint linear structure. Adjoining these bands the general straining of the rock, without any development of schistosity sufficient to permit the impregnation by iron, has operated to greatly accelerate the processes of metasomatosis. This results in the almost total effacement of the spotted-granular structure, the simultaneous change of position of the silica and siderite, the concentration of the siderite, and the formation of the sideritic chert. Some of this siderite is to be found in the other forms of the rock; the rest represents the alteration product of the iron oxide under meagre access of oxidizing agencies.

SECTION 129. In the hand specimen greenish and flinty, standing about half-way between varieties 1 and 2 of section 128-A. It contains a residuary fragment one inch in diameter, which resembles variety 2 of 128-A.

Under the microscope there is a faintly-marked spotted-granular structure, much like that of variety 4 of 128-B. The granules are marked usually only by the chloritic substance, which is thinly sown, either in rims or in the center of the granule, or in little spherules; sometimes they are also marked by a finer grain of silica. The increase of silica, in proportion to the diminishing amount of the chloritic substance, forms the important distinction from variety 4, 128-B. Imperfect crystals of siderite are scattered through the rock: one of them, which is quite large, preserves one of its sides unbroken. This side passes through three of the granules and the intervening interstices, without any break, thus showing that the crystal was formed since the development of the spotted-granular structure.

Conclusion: This rock is derived from variety 4, 128-B, by the partial disintegration of the chloritic matter, the attendant separation of fresh silica, and the partial concentration of the siderite into crystals. A slight continuation of this process would give 128-A, and 128-C, variety 1.

An estimate of the proportion of the various constituents of this rock is: Silica, 90 per cent.; carbonates, 5 per cent.; chloritic and ferruginous matter, 5 per cent.

SECTION 130. The hand specimen is like 128-B, variety 4, but rather coarser in texture. Under the microscope it seems to be an intermediate stage between 128-B, variety 4, and 129. The granules are marked in the same way, but the chloritic substance shows a somewhat darker tinge, and they have been apparently traversed by fissures and redivided since the stage represented by 129. These fissures and interstices are filled by comparatively coarsely crystalline silica. In places the crystallization of the siderite seems to have just begun. There is some disseminated iron oxide. See Plate V, Fig. 2.

SECTION 131. The rock is nearly identical in outward appearance with specimen 14, described later, except that it contains reddish, crystalline patches that are nearly pure siderite. (These patches are what was classified as type 31 in the examination of the hand specimens, and will be seen to be merely a purer variation of the green rock). The rest of the rock is green, and granular in texture, with irregular fracture, and no sign of cleavage or schistosity. Under the microscope it is found to be made up chiefly of siderite. The red areas are comparatively pure, consisting of interlocking grains of considerable size. The green parts of the rock are made up of a ground-mass of smaller grains of siderite, in which is found a confused mass of minute brownish silicates with perhaps earthy hematite intermingled. Around the borders of these semi-opaque masses there are thickly interlocking radiating needles of actinolite. A very little silica occurs. This rock differs from 14 chiefly in the disappearance of the crystalline magnetite, and the great increase of the carbonate. There are seen in this slide two varieties of the granules. The first variety is identical with that of 14, except for the absence of the magnetite. The granules are marked by the presence of the semi-opaque brownish mass of silicates and actinolite, with a ground-mass of siderite and silica in small grains. The interstices are marked by more coarsely granular silica, and by larger crystals of actinolite, which radiate from the walls. The granules are hardly so distinct as those of 14, showing a change which may have resulted from the carbonatization of the magnetite. The second form of granules is best shown in the red, nearly pure siderite. Around the coarser grains here earthy iron oxide has formed, from oxidation of the siderite.

Sometimes this forms a network which surrounds each of the grains; sometimes it takes a broader circuit and forms an irregular ring, enclosing many grains, which are in every way similar to those without. Along this line whole grains of the carbonate have thus been changed to the oxide.

Conclusion: This rock occurs in the same pit with specimens 128, 129, and 130, which show a complete series of gradations in themselves. That 131 is connected with these in origin is evident. Either 131 is derived from the last stage (128-A) of the series, or the first stage (the fragment in 128-B, variety 4) is derived from it. The first supposition would involve the replacement of silica by siderite, which would be hardly probable, from a chemical standpoint, together with the effacement of the siderite crystals, and the introduction of an abundant chloritic and actinolitic ingredient. The second supposition is doubtless the correct one. It simply supposes the replacement of the carbonate of 131 by silica, and the reduction of the amount of the chloritic matter, which may be due either to silicification or to leaching. In other specimens the actual process is seen by which a rock like 128-A may be derived from a rock like 131. The change consists in the infiltration of silica, which took place early, the contemporaneous replacement of the larger part of the siderite by the silica, and the segregation of the remaining siderite into crystal form. It is also possible that the larger amount of silica in 14 may be due to some slight original difference in the two rocks.

FIRST GROUP FROM SEC. 33, T. 58 17.

The specimens constituting this group are all from the same pit,—27, 28, 29, 157, 158, 159, 160 and 161. The slides are cut from 27, 29, 160 and 161. In this group the derivation of one phase from another is sufficiently distinct in the hand-specimen, by the same evidence as has been already described, and which will not be repeated here.

SECTION 27-A. This is a rock containing four distinct phases. In the hand-specimen the boundary between neighboring phases is quite distinct.

Variety 1. Under the microscope this is seen to be the original rock, so far as this specimen goes. It is made up of silica, siderite, magnetite and hematite. The magnetite occurs in small irregular masses, never with crystal form. It generally forms a residual core in the middle of a mass of siderite, or, more rarely, of hematite. In the latter case both magnetite and hematite are sometimes imbedded in a mass of the carbonate, so that it seems that the change to a carbonate took place at one time, and that at a later time the changing conditions favored oxidation to a hematite. In the larger siderite masses there is generally a kernel of magnetite in the middle, and in addition, grains scattered irregularly. There is never any magnetite at the periphery of the siderite.

Hematite, red and earthy, occurs only as a decomposition product, almost always of magnetite. It forms irregular masses or streaks. In this way it surrounds the magnetite from which it is derived, and has also made its way into cracks in the silica. Siderite appears to be in all cases a decomposition product of magnetite. The larger masses, which almost always contain the residuary kernels of magnetite, have irregular shapes. As they grow smaller the decomposition has been more complete, and the kernels of magnetite are smaller and fewer. The smallest ones do not have these kernels at all, and these have often obtained a perfect rhombic form. These crystals, however, form but a small part of the whole mass of siderite. Rarely, a perfect crystal of siderite may be found in the midst of a mass of decomposing magnetite.

There are still indications of the existence of the granules so common in other sections. Frequently a narrow rim of magnetite or hematite, or both, gives the familiar outline of one of these forms. The interior is generally filled with silica like the ground-mass. From a study of other sections, it seems probable that the history of these forms is as follows: A granule made up mainly of siderite was oxidized along the edges into hematite. At this stage the remaining siderite was replaced by silica. Subsequently the hematite was changed into magnetite.

The ground-mass is composed of cryptocrystalline silica, clouded with some slight amount of clayey matter.

An analysis of this rock was made by C. F. Sidener, with the following results:

ANALYSIS OF SPECIMEN 27-A, VARIETY 1.

Silica	SiO	86.35	per cent.
Alumina	Al_2O_3	.78	"
Sesquioxide of iron	Fe_2O_3	7.41	"
Protoxide of iron	FeO	3.46	"
Lime	CaO	.01	"
Magnesia	MgO	.05	"
Potash	K_2O	.01	"
Soda	Na_2O	.12	"
Water	H_2O	.01	"
Carbon dioxide	CO_2	1.22	"
Total		99.42	

Variety 2. The granules which are largely filled by hematite or magnetite become more plentiful at one side of the space occupied by variety 1, and finally form a distinct band. This is variety 2. In the hand specimen it is strongly marked, and has the appearance of red jasper. Under the microscope the difference of structure is seen to be trifling. Most of the siderite of variety 1 disappears, and is oxidized to red hematite, which penetrates and stains and probably to some extent replaces the silica of the granules. All stages of the process may be seen in different parts of the band, which is about ¼ inch thick. The magnetite also decreases in quantity, but less rapidly than the siderite.

Variety 3 is characterized in the hand specimen by its black color and flinty fracture. It constitutes a band of about the same width as that of variety 2, of which it contains fragments. Under the microscope it is characterized by a fine irregular striping, parallel to the banding of the hand specimen. The ground-mass is of very fine cryptocrystalline silica, and is clouded with grains of sub-microscopic size, apparently of iron oxide and greenish decomposition products. It is sprinkled with small crystals and irregular grains of siderite, grains of magnetite, and blotches of hematite. These bodies have been frequently drawn out in a line parallel to the striping, and the lines of this structure are marked by the accumulation of iron oxide along them. While the transition from variety 1 to variety 2 is gradual, and is marked by a chemical, but no structural change, that from 2 to 3 is rather sudden, and follows a more or less well-defined line. The lines of striping of 3 sometimes run around large fragments of 2, and again they cut directly across, even breaking through the red granules. This indicates a mechanical shearing.

Variety 4 appears as a greenish slate in the hand specimen, with somewhat well-developed cleavage. Under the microscope, the line between it and 3 is well defined. It is straight in its general course, but exceedingly irregular in its details. There occur in 4 rhombic crystals which seem to be of decomposed siderite. When these project beyond the line into variety 3, they have often had one end broken off and carried a little way, in a direction parallel to the schistosity and the elongation of the particles of 3. A confused mass of decomposition products forms the main body of variety 4, and gives it its green color. These seem to be chiefly made up of the iron oxides, epidote (?), calcite, and chlorite, with the latter predominating. The schistosity is well marked by thickening of these materials along the lines of parting. A fragment remains which still has the structural features of variety 1.

Conclusion: Varieties 2, 3 and 4, were formed from variety 1, simultaneously, following a local schistosity, which was probably induced by a slipping or fault in the rock. The smooth outer surface of variety 4 in the hand-specimen may be the line of fracture. The schistosity realized its maximum effect in variety 4, and produced a chloritic slate; in variety 3 the lines of cleavage are microscopic, but the motion served to destroy the structural features of 1; in variety 2 there was no rearrangement of structural features, but this band was affected by the oxidizing agencies which penetrated through 2 and 3, and the oxidation of siderite and magnetite to hematite followed, producing the red color of the rock.

SECTION 27-B.—This is the same as 27-A, type 1. Some fine examples of the decomposition of magnetite to siderite may be noted.

SECTION 29.—Hand-specimen banded, with slaty cleavage; in parts heavily iron-bearing. That this is derived from 27 is shown in the changes noted in the specimens at the pit. Under the microscope, a very perfect schistose structure. It resembles 27-A, variety 4, with which it is really very closely related. The chief constituents are magnetite, hematite, silica and chlorite. The darker bands are made up almost entirely of magnetite and hematite (proportion about, magnetite 60 per cent., hematite 40 per cent.); the light green bands mainly of chlorite and silica, and between the two there are transition stages. There is also some calcite, some epidote and a very little pyrite. None of the principal minerals have crystal form, but are in irregular bodies, roughly elongated and parallel. The association of the chlorite suggests its formation from the magnetite or hematite by uniting with the silica, for the chlorite is in places in borders along the edge of the magnetite, or lines the interstices. The silica is finely crystalline. This change in the nature of the silica may be due to an infiltration from without, but more probably to a recrystallization of the cryptocrystalline silica. Many instances of this latter change have been noted.

SECTION 160-A. Hand specimen shows a perfect slaty cleavage; is banded with light green and dark red. The bands appear to differ in color rather than in texture; they have been brecciated and faulted, the fragments being sometimes as much as two inches in their greatest length, and oriented in all positions to the banding. Under the microscope, the light bands are composed of a mass of finely-divided chlorite and iron oxides, small grains and crystals of magnetite and hematite, with calcite and some siderite. These lighter bands are almost identical with variety 4, 27-A; and the darker ones find their counterpart in 29. A set of roughly parallel fine partings, marked chiefly by iron oxide, run through the mass. The darker bands, which have been deeply impregnated with iron oxide, probably represent a plane of greater shearing than the light ones. Subsequent to this shearing and the ensuing changes there has been another pressure, resulting, in certain zones, in the brecciation and intermingling of the bands. This is well shown on one side of the section. Angular fragments of all sizes, still retaining their original structure and schistose lines, are confusedly intermingled. In some of these displaced blocks the lines of schistosity run at right angles to the general schistosity of the rock. The planes of greatest brecciation seem to lie parallel to that of the banding.

SECTION 160-B is cut from the same specimen. It has the same characters, but is somewhat more brecciated, and contains a normal fault of about one-half inch throw (vertical). There is a marked fault-breccia developed, and a twisting of the layers on either side of the fault, indicating the direction of movement. The course of the fault is irregular.

SECTION 161-A. Compare 27-A, variety 2. The hand-specimen shows a dark-red rock, somewhat mottled with very fine darker spots, and faintly banded. Fracture conchoidal; no cleavage. This weathers on both sides to a light gray rock, more porous and friable, with granular texture, and a faint cleavage. 161-A is cut from the red rock. It resembles 27-A, but is somewhat more stretched, producing elongated forms of the granules. These granules are closely pressed together. They are made up mainly of silica, stained with a sufficient quantity of iron oxide to render them opaque. When the silica is not thus stained, it is seen to be variable from cryptocrystalline to finely phenocrystalline. Siderite is present, occasionally in small crystals, usually in broken and irregular fragments, which may be separate from the granules or may be associated with them. The evident derivation of this rock from 27-A, variety 1, explains this. In parts of the section there is a distinct wavy linear or fibrous structure. In these parts the granules are often cracked, often broken apart, sometimes shred and mingled indiscriminately. The interstices of silica have also been led by the stretching process to assume elongated and rounded outlines. The silica consists almost invariably of a nearly amorphous mass, which shows under the highest power, with crossed nicols, only a few scattering grains where extinction can be detected, the rest remaining uniformly dark. These scattering grains are cryptocrystalline. A comparison of this silica with that of 27-A, variety 1, shows by how small changes the fine cryptocrystalline silica reaches such a state of minute division that the individual grains cannot be detected under the highest magnifying power, and so must be classed as amorphous. It seems eminently probable, however, that this silica is really individualized, in grains of sub-microscopic size, and that its true nature is as far from colloid silica as it is from quartz.

SECTION 161-B, is cut from the weathered gray rock. The shearing seems to have been little greater than in 161-A, but the change is chiefly one of disintegration. In parts the fibrous structure is seen, but generally it is not distinct. The spotted-granular structure has become faint, and were it not for the association of this rock with 160-A, could not be identified with certainty. The disseminated iron oxide is collected in irregular bunches, or is scattered as dust-like limonite, in which form it stains slightly the whole section. The larger bunches of this iron have been dissolved out, leaving pores that riddle the rock, and attendant upon these changes has been the infiltration of calcite, which forms clusters of small grains. The silica is mainly apparently amorphous, as in 160-A.

SECOND GROUP FROM SECTION 33, T. 58-17.

The two specimens of this group, 164 and 166, are from the same pit, which is situated about half a mile southwest of the pit whence the group just described was taken.

SECTION 164. In hand specimen, a jasper, consisting mainly of dark gray silica, faintly marked with somewhat brecciated bands of red and light gray. Conformable with the banding there are thin seams of crystalline quartz, and also a vein of the same material which is about ¾ inch wide. A prismatic jointing is present. Compare with the "jasper" from Iron Cliff, (spec. 40, see p. 61.) Under the microscope the silica is seen to be mainly truly chalcedonic, with radiating fibrous structure. On the one hand, this grades into a variety where the individuals are so small as to be hardly or not at all discernible, and so may be called amorphous, and on the other into fine grains of quartz. The traces of the spotted-granular structure are distinctly discernible in this rock: (1), by the presence of clustering patches of iron oxide, which appears to be mainly crystalline hematite, and occasional associated sheaves of actinolite; (2), by the difference of the silica of the granules from that of the interstices. Interstices may be found which are marked by crystalline quartz grains, around the edges of which come the coarser chalcedonic, then the finely chalcedonic to amorphous silica, and finally the iron oxides. Conclusion: This rock has been altered by metasomatosis rather than by dynamometamorphism. The spotted-granular structure has not been sheared out of existence, but has been nearly effaced by changes of a chemical nature.

SECTION 166. In the hand specimen there are two parts. One is a red, mottled band about 1¼ inches thick. The color is given by thickly crowded red granules which occur with small bunches of magnetite, in a dark gray ground-mass. This band is somewhat brecciated, containing angular fragments of darker rock (which are stained red around the edges), as much as half an inch in their greatest length. The rock seems identical with 27-A, variety 2. The darker material forms the rest of the specimen, and from it the slide is cut. From this the red part has been formed by a weakening under stress, slight brecciation, and subsequent oxidation. Under the microscope, it has the spotted-granular structure, considerably altered, though not nearly so much so as in 164, which is derived from it. Resembles 27-A, variety 1, but differs from it in the disappearance of nearly all of the siderite. In 27-A, this is an important constituent, but here it occurs only as scattered films. The granules are strongly marked, and are made up of magnetite, with some earthy hematite and cryptocrystalline silica. Sometimes the granule is chiefly of hematite, but usually it is of clouded silica, with magnetite cores, rims, or straggling internal skeletons. The silica of the interstices is usually finely phenocrystalline, and at the contact between this and the cryptocrystalline silica of the granules there is a curious ragged band, which suggests that the finer is passing into the coarser by crystallization. This is supported by the fact that the coarser variety is also found in crevices in the middle of the granule, which are without apparent communication with the interstices. The comparison with 27-A, variety 1, suggests the same thing.

Summary: We may believe that 27-A, variety 1, and 166 were probably originally almost identical. Waters dissolved part of the iron of 166 and deposited it further on in the rock as carbonate, giving rise to 27-A, variety 1, (27-B). The loss of volume caused a contraction of 166, which resulted in the development of the prismatic jointing; and of the horizontal parting, which is marked by the white quartz seams of 164. Then the processes of metasomatosis—the governing motive being the striving towards greatest stability—went on, and, with the aid of crystallization, brought about the rock at Iron Cliff (section 40, see p. 61), where the silica is all crystalline quartz, and the spotted-granular structure has entirely disappeared. The carbonate deposited in 27-A, variety 1, together with the carbonatization of some of the original oxide of the rock, caused an expansion which resulted in certain movements and the production of certain zones of slight shearing. The result was: (1), the intimate mingling of the materials which had been so long segregating under metasomatic forces, and so in some wise a regenerative effect; and (2) the exposure of these materials to xenogenous infiltrated matter. This led to the formation of minerals which somewhat resemble the original ones, such as chlorite. From the comparative study of all the specimens it will be seen that a green chloritic mineral was very important in the least altered forms of the rock, and seems to have been there as early as we have any record. But in these sheared rocks the chlorite is disseminated irregularly in minute particles, while in the least altered rocks it is in firm, distinct masses; the iron is in a finely divided condition, instead of being crystalline; and a fine slaty cleavage replaces the massive structure. In an intermediate rock, originally identical with 166 and 27-A, variety 1, but lying between them, the result would be a complete carbonatization of the iron; the attendant removal of most of it so gradually as to prevent the accumulation of strains; and the concentration of the rest, to produce a sideritic chert like 128. Specimen 27-A, variety 1, would also, by a continuation of the already far advanced process, become a typical sideritic chert like 128, if it met with no further mechanical accidents.

THE IRON CLIFF GROUP.

The two specimens of this group, 40 and 41, are from the same pit in the hill known as Iron Cliff, in sec. 36, T. 59-17. As a whole, this hill is a peculiar phase in the iron-bearing rocks, for it is in large part made up of banded crystalline iron, often magnetic, and crystalline silica, or "jasper." There are few of the friable phases and sudden alterations that are seen in other parts of the field. The rocks much resemble the typical banded "jasper and ore" of the Vermilion range. They are marked by a prismatic jointing.

SECTION 40. In the hand specimen there are rather pronounced bands of "red jasper," "black jasper," and nearly black crystalline hematite, with magnetite. That this banding is secondary and has no relation to the original structure (indicating neither planes of detrital or chemical deposition, nor of the flow of an igneous mass), is shown by the course of the bands, which, instead of remaining parallel, often unite, and again fork and run at different angles. Besides the banding there is a fine lamination of differently colored silica. Both macroscopically and microscopically the rock shows a close resemblance to 35 (described later, see p. 64), from which phase it is derived by a very slight change.

Under the microscope it is seen to consist of silica, magnetite and hematite in about the following proportion: Silica, 90 per cent.; magnetite, 8 per cent.; hematite, 2 per cent. The silica is in the form of crystalline quartz, in small grains of somewhat uniform size, with irregular outlines. The magnetite is in clustering masses, with distinct though somewhat rounded crystal outlines, which are about the same size as the grains of quartz. In some parts of the silica bands they are somewhat more thickly strewn than in others, constituting under the microscope irregular and indistinct bands, and in the hand specimen a fine lamination of light and dark silica. This dark silica, when occurring in a broad band, constitutes the "black jasper." In bands the magnetite has been somewhat oxidized to hematite, mainly in the form of martite, thus forming the "red jasper" of the hand specimen. In another band the magnetite has collected into a dense mass. This is about $\frac{1}{3}$ inch wide. It is densest in the middle, but even here there occur interstices filled with quartz. Toward the periphery it becomes more scattered, thin bands of it alternating with layers of silica, till it grades off into the black jasper. Along this outer margin there is considerable decomposition to hematite. There is in this rock no trace of the spotted-granular structure. The silica grains are of about the same size as the predominating larger ones of section 35. (See p. 64.) This shows the change from the smaller cryptocrystalline variety to the coarser—an operation contemporaneous with the comminution, distribution, concentration, and recrystallization into bands of the iron, and the obliteration of the spotted-granular structure.

SPECIMEN 41. Color, dark red. The granules of the spotted-granular structure are distinctly visible to the naked eye. There are scattered through the mass large grains of crystalline quartz, which have the shape, size and appearance of sand-grains. These are not arranged in any definite layers, except that they become more abundant in the part of the specimen represented by 41-B. This part grades directly into 41-A, described above. It is darker, and in place of the spotted-granular structure has developed a slight cleavage. This may be due to shearing and subsequent decomposition, or to decomposition alone. 41-A has a conchoidal fracture, and neither jointing nor cleavage.

SECTION 41-A. In the slide there are two varieties, differing from one another slightly and grading together. *Variety 1*, in the centre of the slide, has the normal spotted-granular structure. The granules are rounded or sub-angular, are closely packed, and are made up of silica, hematite and chloritic and clayey matter, in the order of abundance named. The silica is finely cryptocrystalline and is clouded with iron oxide. Magnetite occurs in irregular fragments, either intimately mixed with the hematite or as cores in the hematite masses. There is a slight tendency for the granules to lie with their longer axes roughly parallel. This is due to a stretching under mechanical pressure, as will be shown further on. The most striking feature in the rock is the presence of the large angular grains of crystalline quartz, which were mentioned in the description of the hand-specimen. This quartz is entirely different from the rest of the silica in this slide, and from the usual silica of any other of the slides of the iron-bearing member examined. They appear to be sand-grains. They are perhaps fifty times as large as the largest grains of the other silica; they are traversed by cracks which indicate great straining which the rest of the rock appears not to have shared; and there is a variety of shading in them, due to the relative abundance of foreign inclusions. The silica in which they are embedded varies from cryptocrystalline to chalcedonic, the latter showing radial fibrous structure. These grains must be considered fragmental. Variety 1 is surrounded by and grades into variety 2.

Variety 2 is marked by a distinct parallel schistose structure, the lines of which curve around the fragment of variety 1. Here the granules are pulled out into long masses parallel to the lines of the schistose structure, or assume torn and irregular outlines in place of the rounded ones. The coarser and the finer intergranular chalcedonic silica are confusedly intermingled, or drawn out in the same way as the granules. There is here a decided predominance of the chloritic ingredients over the iron oxides, while in variety 1 the reverse is decidedly true. The grains of apparently fragmental quartz have also undergone the same force as the other ingredients. They have sometimes been broken, and the pieces separated from one another by small distances, in the direction of the lines of the schistose structure.

Conclusion: This rock has undergone a slight mechanical shearing, as is shown by the torn and irregular outlines of the granules, and their stretching in a common direction, by the breaking and separation of the fragmental quartz, and the development of chloritic and clayey matter in place of the iron oxides. This motion must explain the motive for segregation in bands of the materials of section 40. It is probable that these bands follow planes of slight weakness, which originated at the same time as the shearing in 41.

SECTION 41-B. From the lamination of the hand specimen, this seems to be a more complete shear-zone. Under the microscope, the rock is seen to have altered to a black, opaque mass, which by incident light is seen to consist mainly of the iron oxides. The traces of granules are very faintly shown. This mass is liberally sprinkled with the fragmental quartz grains. They have undergone no change, save for a slight corrosion of their margins. There is a single residuary area of chalcedonic silica. The change in this rock has probably been due to the straining, which produced a comminution of the fragments of the rock; followed by the action of percolating waters, which dissolved the cryptocrystalline and chalcedonic silica, and replaced it by iron. The fact that the quartz grains were not attacked is another proof of their independent origin. This specimen is only about twenty feet from the quartzyte below it, on which the iron bearing member is here seen to rest. These fragmental quartz grains are of the same nature as those of the quartzyte.

GROUP FROM THE CHICAGO PROPERTY, SEC. 4, T. 58–16.

The sections in this group are from specimens taken from adjoining pits on the Chicago property. The pits farthest from each other are about 150 yards apart. In general the material at the different pits is very much alike, but certain phases differ from others in the same pit. The sections are from specimens 35, 36, 37, 39, and 53.

SECTION 35. In the hand specimen, it seems to consist mainly of silica, stained light red and having a jaspery appearance, and magnetite. While these two ingredients are irregularly distributed, yet there is a tendency to a concentration into indistinct, non-persistent, roughly parallel bands. In the darker bands magnetite prevails, in the lighter ones the silica. Along the darker bands pitted decomposition has set in. Under the microscope the granules and interstices of the spotted-granular structure are often distinctly seen, but are often faint, and sometimes nearly obliterated. The magnetite is in irregular masses, often showing a clustering motive, with distinct outlines, yet with no strict crystal boundaries. In one place it is clustered into an irregular darker band without definite boundaries. This band, save for the slightly increased proportion of magnetite, is identical with the rest. As is usual, the rock on one side of the band is much poorer in iron than that on the other, showing that most of the iron was derived from one direction, and pointing to waters acting under the influence of gravity as the chief cause. The silica varies from cryptocrystalline to finely phenocrystalline, the latter somewhat predominating. The two are sometimes mingled confusedly; but where the spotted-granular structure is best preserved the granules usually consist of the finer silica, and are surrounded by the coarser grains of the interstices. The position of the magnetite in the section has no relation to the traces of the granules; hence the silica, even in this finely divided form, is stabler. Scattered crystals of siderite occur, generally more or less oxidized.

SECTION 36. From the same pit as 35. In the hand-specimen is light-gray and siliceous, with small grains of magnetite visible to the naked eye. There is no banding, but the rock is riddled with pits, which are lined with a crumbling powder that appears to be partly limonitic. Under the microscope, the estimated proportion of different constituents is: Silica, 92 per cent., Magnetite, 4 per cent., Limonite, 2 per cent., Siderite, 2 per cent. The powder of this rock gave reluctant effervescence with cold dilute hydrochloric acid, but effervesced freely on warming. In general structure the rock is like 35. The outlines of the granules can everywhere be distinctly traced, though in most cases they are marked only by a slight difference in the size of the silica grains, and by a cloudy yellowish color. The magnetite bodies have the same general habit as in 35, but are fewer, and have occasionally distinct crystal boundaries. Micaceous hematite occurs in small blood-red specks, associated with the magnetite. Siderite appears scattered through the section in very small, vaguely outlined forms. It often surrounds magnetite, in which case the magnetite loses its crystal outline. When present in any considerable body it is usually rusty with oxide. It thus appears to be entirely of secondary origin. Two or three of the "pits" described in the hand-specimen are shown in the section. The original distinction between them and the smaller decomposition spots which can be seen only under the microscope seems to have been a clustering of magnetite. At present they are characterized by this, by a lack of regular outline and by the decomposed condition of the adjoining rock. In this decomposition border siderite is found in numerous small irregular clustering grains, which surround the magnetite, when the latter is present. Conclusions: In the process of change magnetite has become segregated into certain spots more thickly than in others. On the freer access of oxidizing agencies, the decomposition has begun at first around these groups, since the iron is more easily attacked than the silica. The change of the iron is first of all to a carbonate, after which it is taken into solution and carried away, to be deposited further on, leaving an empty pit, lined with products not yet far enough advanced in decay to be taken into solution. The extension of these rust-spots in time decomposed the whole rock. The hand-specimen in places is already more than half decomposed. (See Plate IX, Fig. 1).

SECTION 37-A. From a pit about eighty yards from the first. Resembles 36, both in the hand-specimen and under the microscope. The chief difference is the presence of calcite in spots, these spots corresponding, in size and distribution, to the rust-pits of 36. The granules can be distinctly observed everywhere, chiefly by the difference in grain and coloring of the silica, as explained for 36. The magnetite has lost all connection in position with the granules, is sometimes with crystal outline, and has a tendency to congregate in clusters. These spots are also characterized by the presence of siderite and calcite (or magnesite) in larger quantities than in the rest of the section. The calcite is usually in large, clear grains, showing cleavage; the siderite is in small irregular patches, as in 36. The history of this structure is as follows:—1. The concentration of the magnetite into clusters. 2. The beginning of oxidation at these points, (into siderite or hematite). 3. The infiltration of calcite from extraneous sources into the spaces opened by decomposition. 4. The action of the calcite on the undecomposed magnetite to produce siderite. 5. In the next stage the solution of these carbonates would give the peculiar rust-pits of 36. There is a very small amount of actinolite in the rock.

SECTION 37-B.—From the same specimen as 37-A, into which it grades on some sides, and from which it is separated on others, by a rather distinct mechanical crack. It is apparently a residuary fragment, although on the side where the crack intervenes between it and 37–A it has the semblance of a pebble. It is fine-grained, and green in color. There are in 37 A much larger quantities of calcite than in 37-B, and the crack between the two seem to have been the passage-way for the waters that brought the mineral. A fine vein of calcite (magnesite?) traverses 37-B. The crack that has been thus filled is much wider than that between 37-A and 37-B. The result was that the waters found sufficient passage-way, and instead of forcing their way into the rock and impregnating it with calcite, as in 37-A, they carried off some of the country rock in solution, in the near vicinity of the walls of the fissure, and brought about a general decomposition; thus giving rise to a distinct broad dark selvage strip on both sides of the vein. Across this strip and the vein the section was cut.

Under the microscope, the vein, which is at its broadest point about 1-16 inch in diameter, is seen to be mainly filled with well-crystallized calcite, showing cleavage, and often the successive stages of growth, in perfect crystals. Iron in the form of earthy hematite and siderite is scattered between the crystals and along the walls, in such manner as to show that it is secondary to the original material of the vein. In the selvage strip of the country-rock the traces of the spotted-granular structure are almost entirely obliterated, being only faintly shown in places under crossed nicols. The predominating feature is the ground-mass of very finely cryptocrystalline silica, more uniform and finer than that of 37-A. Iron is almost lacking, save for its occurence in earthy, semi-opaque masses of decomposition-products. In these masses actinolite, chlorite, calcite, and siderite, probably occur. The change of the silica under freely oxidizing forces is very important. When these agencies do not have access, the reverse or crystallizing process takes place, as is seen in 40 and many other sections.

SECTION 39. From same pit as 37, and closely associated with it. Is distinct in appearance from 37, owing to the mottling which the distinctly marked granules produce. In color light-green; fracture conchoidal; no cleavage or jointing. Under the microscope the rock is seen to be much less altered than 37. The primary granules which correspond to the granules of 53-1 make up about 60 per cent. of the entire mass. Surrounding these is a secondary border which makes about 25 per cent. of the mass. This leaves only about 15 per cent. of the interstitial pure silica. The general structure resembles very much 14 and 17, which will be described later. The primary granules are composed of a compact green chloritic substance, in firm masses traversed by roughly parallel partings; it is slightly pleochroic. Others are darker and opaque from decomposition products, such as earthy iron oxide. Some of them have internal magnetite fragments. Sometimes carbonate, either fragmental or crystalline, but generally much decomposed, is found. These granules rarely have well-rounded outlines; they are usually ragged and angular. Small fragments are scattered everywhere. Surrounding these granules as a decomposition rim is a body of pale-green, finely matted actinolite, in clusters and sheaf-like forms, with which are intimately mingled limonite, cryptocrystalline silica, and carbonates. Last of all, the small angular interstitial cavities are filled with grains of finely phenocrystalline quartz.

SPECIMEN 53 is from a pit which is about 100 yards southwest of the last. This pit passed through ten or twelve feet of soft black slates, and then through two or three feet of the hard gray siliceous rock belonging to the iron-bearing member, substantially as described for the other specimens in this group. The contact between the slates and the iron-bearing rock is well-marked, and there is no sign of transition between the two. The slates in nowise resemble the iron-bearing rock. They dip gently to the south. South of this pit all explorations have revealed the presence of the upper slate member. Specimen 53 is taken from the contact of the two formations. Section 53-1 is cut from that part of it which belongs to the iron-bearing member, and 53-2 from the soft black shale.

SECTION 53-I. The hand-specimen is a dark greenish-gray; fracture in general irregular, but has a tendency to a rough horizontal parting and also to a vertical jointing; structure, spotted-granular; contains a rounded fragment resembling a pebble, which may be a pebble or a residuary fragment.

Under the microscope the ground-mass is a finely phenocrystalline silica, the grains of which interlock in such a manner as to put their formation in place beyond a doubt. Through this are scattered rounded, angular or broken fragments, the largest of which perhaps average 1-16 inch in diameter. Prominent among these are rounded grains of crystalline carbonate (probably calcite or magnesite), which from their appearance were almost certainly originally detrital. The cleavage is very well shown, and they are tinged a dirty brown by impurities which have found their way into the cleavage crevices. Their appearance is strangely contrasted with the calcite (magnesite?) which has entered since the formation of the rock. This is very abundant, occurring as an aggregate of very small grains, in color pure white. In this manner it forms borders around the granules, or small bunches in the interstitial silica. It never shows cleavage or crystal form. (See Plate V, Fig. 1; also Plate VIII, Fig. 1).

Besides the carbonate, there are rounded, angular, irregular, or shattered masses of the green chloritic substance, which also in many cases may be detrital, though often they have been disrupted by the movements in the rocks subsequent to consolidation.

In the majority of the greenish bodies, however, the green mineral has been decomposed, depositing silica in very small cryptocrystalline grains, as a result.

In the majority of the granules it is evident that the silicification has gone on in place, for it has been to some extent accompanied by slight movements, which seem to have produced the torn and irregular forms.

Conclusion: In this section, fragmental and non-fragmental material is mingled. This is the extreme upper contact of the iron bearing member. Compare, on the extreme lower contact, sections 41-A and 41 B. (See pages 62,63.) The rock has evidently already gone through a great deal of metasomatic change, as is evidenced by the interstitial secondary silica, the secondary silica of the greenish granules and the borders of secondary carbonate. In this case it seems clear that replacement has had nothing to do with the development of engranular silica, for the granules of carbonate have not been attacked, but remain quite unaltered. The conclusion is inevitable that the green material is extremely unstable under circumstances where the carbonate is not affected.

SECTION 53-2.—In hand-specimen black and soft, with perfect slaty cleavage. The line of contact with 53-1 is even and distinct. Under the microscope, about 60 per cent. of the mass is seen to be made up of a carbonate which resembles calcite. It does not effervesce with cold dilute hydrochloric acid, however, but only on warming, and analysis shows it to be entirely magnesite. The rest of the section is occupied by fine clouded greenish material. The structure of 53-2 has not the slightest resemblance to that of 53-1, no more than has the mineral composition. The structure of 53-2 is the familiar one characteristic of a fragmental rock, and especially of a limestone. The grains of magnesite are scattered uniformly through the section; intermingled with them are irregular and ill-defined flakes of the greenish materials, which are apparently of later origin than the magnesite. The rock bears no resemblance to any of the specimens from the iron-bearing member that have been examined, not even the sheared and sometimes calcified cherts and slates, for these have a linear or fibrous structure indicative of their origin; 53-2 has no trace of this, nor yet any of the spotted-granular structure; nor does it show any tendency to concentration and crystallization. Taken into account with its field relations as described, and its resemblance tc rocks like 76 and 112, which will be described later, we must consider it as the bottommost layer of the slaty series which immediately overlies the iron-bearing member, and that the line of demarkation between 53-1 and 53-2 is the line of contact between these two grand members of the Animikie series.

An analysis of this rock gave the following results:

ANALYSIS OF 53-1 (CHEMICAL SERIES NO. 236).
BY C. F. SIDENER.

		Per Cent.
Silica	SiO_2	41.73
Alumina	Al_2O_3	4.07
Sesquioxide of Iron	Fe_2O_3	14.43
Protoxide of Iron	FeO	19.85
Lime	CaO	.02
Magnesia	MgO	4.41
Potash	K_2O	.02
Soda	Na_2O	.18
Carbon Dioxide	CO_2	5.76
Water	H_2O	5.65
Organic Matter		3.50
Graphite	C	trace
Manganese	Mn	trace
Total		99.62

The part of the specimen from which this analysis was made was evidently more altered than that from which the section was made, as is shown by the great decrease in the amount of magnesite, and the corresponding increase of the iron oxides and the iron-bearing silicates. As an explanation of this it may be said that while the fragment from which the section was cut was within ¼ inch of the contact, that from which the analysis was made was a layer, one side of which formed the contact itself; and the change must be attributed to the intimate proximity of 53-I, the siliceous and ferruginous representative of the iron-bearing member.

Conclusions: In 53-I, 39, 37-B, 37-A, 36 and 35, we have a fine series illustrating the processes of change, and reaching almost from one end of the typical scheme of development to the other. The chief motive has been the process of decomposition and concentration under the influence of a moderate amount of atmospheric agencies, the goal being the greatest possible stability under these conditions. Attendant on this there has been the introduction of a more unusual factor, due to the proximity of the rock to the overlying calcareous beds,— the infiltration of xenogenous carbonates. This attendant circumstance has modified the action of the governing motive somewhat, but the two remain sufficiently distinct for their results to be separately noted.

Section 53-1 shows many angular fragments, hardly yet broken apart, of the firm mass of chloritic matter, with finely disseminated iron oxides and other ferruginous materials. This chloritic matter must for the present be regarded as the primary rock of the series. That the brecciation has occurred without any considerable carriage of the fragments from their original positions is shown by the fact that the fragments fit closely together, are yet connected in many cases, and are never rounded. Around the edges of the granules, the combination of this silica with the original substance produced a broad border of secondary minerals.

39 appears to be directly derived from 53-1, by a process of oxidation. The original fragments of the chloritic substance have become nearly opaque from the formation of hydrated iron oxide. The small decomposition bodies of 53-1 have been extended, till they often fill up the whole of the intergranular space. These decomposition areas, instead of being pure white calcite as in 53-1, are light green, mottled with brown, and are made up of an intimate mixture of the carbonates, limonite, actinolite and silica. The rounded grains of carbonate have also been decomposed, till only a small portion of the original grain remains in the middle. When this process goes on a little further the original grains will be quite obliterated, and a somewhat homogeneous mass of decomposition products will remain.

In 37 we find that the decomposition has gone on till the chloritic substance has almost entirely disappeared, and is replaced by iron oxides and silica, which still mark the outlines of the granules. Usually the iron oxide has been leached out and scattered through the section, or concentrated in places, leaving the granules marked by the finer and clouded silica alone. The iron when concentrated has sometimes become crystalline, and has passed from the earthy form to the magnetic state. In 36, the process has still further proceeded. The outlines of the granules have become indistinct. This has resulted from the concentration of the little remaining iron oxide in them, and also from the partial crystallization of the fine cryptocrystalline silica, which has passed in some cases into the phenocrystalline condition, and so cannot be distinguished from the silica of the interstitial spaces. In 35 we have a still more advanced stage. The granules are with difficulty made out, even in the most favorable places; the silica has become predominantly phenocrystalline; the iron has been further concentrated, and has begun to arrange itself into rude bands along the lines of greatest weakness in the rock; and the rock resembles more the typical "jasper" of the iron region than anything else.

The infiltration of xenogenous carbonates has had a peculiar but independent effect. They have scarcely penetrated 39, and so there are no results here. In 53–1 they have probably supplied the carbonate rim around the granules. In 37 they have produced the differentiation between 37-A and 37-B, and have collected in the more open parts of 37-A. The effects of this impregnation are more clearly seen in 35 and 36, when oxidizing agencies have attacked these carbonates, and from them formed centres of disintegration scattered everywhere through the rock, which, ever growing larger, soon give it a curious pitted and honeycombed appearance, and when carried to the extreme produce the decomposition of the entire body.

GROUP FROM SECTION 10, T. 58-19.

The principal specimens in this group—149, 150 and 151,—are from the same pit.

SECTION 149. In hand-specimen yellow; varies from a flinty texture to soft and crumbling. The harder spots of grayer material are residuary fragments. Fracture somewhat conchoidal; a distinct faint banding. Under the microscope there is a lighter residuary fragment, and a darker portion. *Variety 1*, the residuary fragment, has a somewhat distinct convex boundary. It consists of a fine background of cryptocrystalline silica, through which are disseminated clusters or individual crystals of actinolite, and some iron oxide dust. *Variety 2*, which surrounds variety 1, differs chiefly in the presence of a larger amount of actinolite and iron oxide, the latter becoming especially important. The result is that the section is in places quite opaque. There is a tendency to a linear arrangement of the materials. Both varieties, but especially 2, are traversed by numerous cracks. *Conclusion:* 2 differs from 1 by virtue of having been more cracked and strained mechanically, and so acquiring a more distinct set of sometimes parallel lines of weakness, which allowed freer access of percolating waters, and have brought about a more complete impregnation with iron oxide. Both 1 and 2 are in an advanced stage of metasomatic change, and the process may well have been hastened by the movements in the rock.

SECTION 150. In the hand-specimen roughly banded. In the middle is a residuary, white, granular, somewhat porous rock, of irregular fracture. This passes on both sides to a fine, brown, flinty rock, like 149, and this rock in turn is weathered on one side to the depth of a quarter of an inch to a blood-red pulverulent rock, partly of earthy hematite.

SECTION 150-A is cut from the light, granular rock, which may be called variety 1, and is just beginning to grade to the brown, flinty rock, or variety 2, on the edges.

Variety 1 consists of a background of cryptocrystalline silica, in which the traces of the spotted-granular structure can be distinctly made out. The granules are distinguished chiefly by the finer grain of the silica, as compared with that of the interstices; and also by scattered patches or solid cores of earthy hematite, and very minute fragments of actinolite (?) and chlorite (?). The interstices between the granules have been to some extent impregnated with impurities. The patches of earthy iron oxide which occur in the granules have often been in part or wholly washed out, leaving the rounded pores characteristic of certain parts of the hand-specimen. There is evidence of a stretching parallel to the general banding of the rock. This is shown by the tendency for the granules to arrange themselves with their longer axes parallel, as if pulled out of shape by a common force; and also by a breaking apart of some of the iron oxide patches, forming fissures which are perpendicular to the general direction of the tension.

Variety 2 is marked by a linear structure. That these lines represent planes of special weakness is shown by the impregnation of the rock near them by earthy iron oxide. When there is no such impregnation, the spotted-granular structure is found to be more nearly effaced along these lines than anywhere else in the rock. The impregnation gives the rock its brown color, and of course hides the spotted-granular structure. A considerable quantity of cloudy, decomposing siderite in scattering and very small masses is present. It seems to be a late decomposition product, for it is nowhere concentrated and occupies no definite place. It is often associated with, but not confined to the granules, in the main body of the rock; and in the impregnation bands it is closely associated with the hematite or limonite. Its presence seems to indicate the process of impregnation as follows: In a part of the rock more or less removed from this specimen, the iron was taken into solution by slowly filtrating aquæous agencies as a carbonate. Part was deposited through the rock as carbonate, but most found its way to the weaker lines, and there, under stronger oxidizing influences, was precipitated as the sesquioxide, usually hydrated.

SECTION 150-B. Contains variety 1 and variety 2. Variety 1 is more changed than in 150-A. The spotted-granular structure is fainter, and the materials are more or less arranged in lines. In separated irregular lines iron has been concentrated, and is now chiefly in the form of martite, in which the cores of the original magnetite still frequently remain. Variety 2 is quite opaque at its contact with 1,—a proof that the difference between the two originally arose from a curving crack, from which the mineralizing solutions leaked down into the rocks below, forming 2, while it left the rock above, or variety 1, little altered. As the distance from this original fissure increases, the quantity of iron oxide steadily diminishes, and it soon becomes quite translucent. The fact that the iron is an impregnation is then plainly seen. In parts a fine network of earthy oxide can be seen surrounding the grains of silica.

Conclusion: The band of martite in 1 is an impregnation from a fissure. That at the contact of 1 and 2 was the same. From this latter the iron penetrated downward, forming variety 2. The process is evidently a replacement of cryptocrystalline silica by iron.

SECTION 151. Like variety 1 of 150-A and 150-B, but less altered than either,—the least altered rock of the series. Structure spotted-granular. The granules are distinct, and show little alteration by stretching. Their outlines are usually subangular. Most of the iron oxide that formerly occupied them has been dissolved away, except perhaps in rims around the edges, thus giving rise to the porous, honey-combed structure which is a peculiar feature of the hand-specimen. Some few of these granules which are made up chiefly of earthy iron oxide still remain intact; others have had the iron half-dissolved out; and from this to the empty pore there are all stages. Most of the granules which remain unaltered, however, are those which contain a predominance of silica instead of iron. This silica is somewhat coarsely cryptocrystalline, and is usually sparsely impregnated with hematite, limonite and siderite. On both sides of variety 1 are bands of variety 2. These bands curve so as to nearly meet, and are seen to follow fractures. The process is seen to be simply impregnation, as above described, without any discernible mechanical straining other than as shown in the fractures themselves, These bands represent the field in which filtrating chalybeate waters met the oxidizing agents, which penetrated inward from the fractures, and where the iron was thus precipitated in the rock.

Conclusion: A spotted-granular rock, advanced in change, consisting chiefly of iron in the granules and cryptocrystalline silica in the interstices, has been subjected to slight mechanical pressure, resulting in parallel strains of varying intensity. In some cases the effect was sufficient to produce the obliteration of the spotted-granular structure, the development in its place of a slightly schistose arrangement of the minerals, and the crystallization of a small amount of actinolite. Section 149, variety 1, shows this. Usually there was no such effect, and the strain produced only an irregular cracking. In other cases still, the only result was a general weakening. Subsequently waters, coming into the rock, rendered accessible by these accidents, removed the iron from some places and concentrated it along the lines of weakness in bands and along the weaker zones as impregnations.

GROUP FROM SECTION 2, T. 58-18.

The members of this group, numbers 72, 74, 78, 79 and 80, are all from a single shallow pit in the northwest of the southwest of section 2, T. 58-18.

SECTION 72. In the hand-specimen, this is seen to be coarsely brecciated, the fragments being of black or red chert, and the matrix a spotted-granular rock. The section is so cut as to include a portion of the matrix, and of two of the large fragments. The larger of these fragments is composed partly of dark gray, and partly of reddish chert, and the smaller is entirely of the reddish variety.

The matrix, which may be called *variety 1*, resembles 65 and 74. The rock is composed of silica, magnetite and hematite, their relative abundance being in the order named. The granules are rounded or subangular, and are closely crowded together. In them the magnetite sometimes has crystal boundaries; but generally it has none. The hematite is earthy. Around certain bodies of magnetite there are concentric rings of magnetite and silica, which may be truly concretionary, but from their irregular, often non-persistent course, they are more probably phenomena attendant upon the oxidation and consequent contraction of an original siderite, the stages of which process have been more fully worked out in other sections, and will be described later. Briefly, an original mass of siderite oxidizes on the periphery to hematite. The loss of volume entailed in this change results in the contraction and the development of a more or less perfect fissure between the outer rim of hematite and the main body of siderite. This crack is then filled with silica in solution from the surrounding rock. This takes place repeatedly, the fissures becoming less and less pronounced as the volume of the contracting carbonate becomes smaller, till finally there is no parting produced. A subsequent deoxidation of the hematite to magnetite gives the exact structure that we now find in the rock. The siderite still remains in this section in considerable quantities, and the process described can to some extent, be seen to be still going on. This carbonate is in the form of irregular cloudy masses and grains in the interior of the granules. In some it constitutes the main part of the granule; usually it is somewhat replaced by silica, and appears only as irregular residuary grains; sometimes it has entirely disappeared. These bodies have generally magnetite and hematite rims. Blood-red earthy hematite occurs constantly as a decomposition product, in some cases of the magnetite, in others of the siderite. Thus it may form the rim of a body in which siderite, with silica, occupies the centre; or it may constitute part of the centre of a granule of which magnetite forms the rim. By oxidation of both magnetite and siderite, and staining of the silica, it comes to be uniformly distributed throughout the whole body, and these blood-red granules are the most common variety in certain parts of the section.

Variety 2. The larger fragment. The line of separation between this and the matrix is quite distinct, yet in most of its area it retains traces of a spotted-granular structure which clearly resembles that of the surrounding mass. The boundaries of the granules are not so well marked, and they have been distorted so that the longer axes are apt to lie in a common direction, and parallel to numerous wavy and shadowy lines which mark the change that has taken place in the rock. The darker part is made up of finely comminuted and indiscriminately mingled cryptocrystalline silica and dust-like iron oxide. In the red part, which shades off gradually from the darker part, the iron oxide has concentrated itself to some extent between the grains of silica, thus forming a rude network. The silica grains are also slightly enlarged. The massing of the iron oxide gives bodies of it large enough to reflect the light, and this gives this part of the rock its red color. Both the black and the red parts of 2 are traversed by veins of cryptocrystalline silica, which do not extend into the matrix, and are nearly at right angles with the general parallel structure.

Variety 3. The smaller fragment. The outline of this is rounded. It has the spotted-granular structure much better preserved than has 2. The outline of each of the granules is very clear, but on the whole is much fainter than the corresponding lines of the matrix. The silica is more finely divided, and the iron oxide is scattered as dust through the section, or concentrated into bunches large enough to give a reddish color to the rock. There are no lines of shearing observable.

Conclusions: A spotted-granular rock is seen to have undergone metasomatic changes, by which the granules were altered by change of siderite to hematite, and this to magnetite, with some attendant introduction of silica. In the course of these processes a strain developed in the rock which culminated in a shearing motion of the weakest zone, which produced bands of more or less schistose and altered rock. A continuation of this motion produced a slow breaking up of the bands and a slight separation of the fragments. (The fragments are still arranged in irregular bands.) After this accident, metasomatic changes continued, giving to the fragments their red color, and in the matrix continuing the processes already begun. Compare specimen 27, whose history is very much the same, except that this has escaped the actual fracturing of the bands. In specimen 73, which is from the same place as 72, and is similar in every respect, a sideritic chert is seen to constitute the core of one of the larger fragments, the outside of the fragment being a reddish chert as in 72, and the matrix being as described above. This is evidently a further continuation of the process of concentration subsequent to the complete intermingling of the materials by shearing, which in 72 is most developed in some parts of variety 1.

The powdered rock 72 gave little reaction with cold dilute hydrochloric acid, but on warming afforded an abundant effervescence of carbon dioxide.

SECTION 74.—Like 65, both in hand-specimen and slide. The decomposition proceeds from certain centres in the rock, thus giving a pitted appearance. Under the microscope, as well as in the hand-specimen, it is seen to have a distinct spotted-granular structure, and generally is coarsely brecciated as well. The silica is very finely divided and might be classed as cryptocrystalline to apparently amorphous. Its appearance throughout the whole section suggests incipient disintegration. The decomposition-pits have irregular boundaries, and a border which is quite dark under crossed nicols. This border is a finely mixed aggregate of the ferrous and siliceous ingredients of the rock, in minutely small particles. The leaching out of the iron leaves the white powder which is seen to line these pits in the hand-specimen. The process of disintegration of cryptocrystalline silica to an extremely fine powder, under atmospheric agencies, is finely shown in this specimen. The general structure of the rock, where not decomposed, is like that of the matrix of 72.

SECTION 78.—In the hand-specimen a dark-gray ground-mass, mottled with red granules; fracture conchoidal; prismatic jointing; no cleavage. Under the microscope, the granules are strongly marked, but are in an advanced stage of metasomatic change. They are composed of iron-oxide in the form of earthy hematite or limonite, either in masses or distributed through the silica; their outlines are rounded; they are separated one from the other by some distance; and occasionally they become confused with the ground-mass. In these cases the finer grain of the silica, as seen under crossed nicols, usually distinguishes them. Magnetite occurs sparingly, either as residuary cores in the granules, which occasionally make up the most of their bulk, or as small crystals in the ground-mass of silica. Hematite is found only in the granules, in which it occupies a part or the whole of the space, and occurs with or without the residuary cores of the magnetite from which it is evidently a decomposition product. In its later stages of change, it is dissolved and replaced by silica, and this process goes on till only a staining remains to show the presence of the iron, the rest being entirely of silica. Finally even this disappears, and the granule at times becomes confounded with the intergranular material. Siderite is an important mineral in this rock: it is distributed in such a way as to make the rock a transition stage between the common massive spotted-granular rock and a sideritic chert. It is found on the edges of the granules, in irregular masses, evidently a decomposition product of the hematite, which generally forms a residual core. Often the core is of both magnetite and hematite. In this case the magnetite may form the residuary core for the hematite, showing that at first the conditions of oxidation were freer, permitting the change from the magnetitic to the hematitic state, and that subsequently a partial withdrawal of the supply favored the change of both magnetite and hematite to the sideritic state. Siderite also occurs in small crystals in the ground-mass. Here it often encloses some of the larger silica grains around which it has formed, and the successive crystal outlines which mark the stages of growth are plainly seen. Thus this siderite, like the magnetite of the groundmass, is of a segregationary origin. It is evident that, as this process goes on, with the change of the remaining magnetite and hematite into siderite, the concentration of this siderite to make larger these tiny crystals, and the rearrangement of the silica in consequence, that the spotted-granular structure will be obliterated, and a chert, containing large crystals of siderite, will result. (See Plate VII, Fig. 1.)

SECTION 79. The specimen from which this is taken is an extremely brecciated mass. The section is cut from one of the larger fragments of the rock. It is of chert, which in its hard parts is banded with alternating fine gray and white lines, and in other places is decomposing to a white powder. Many of the smaller crevices between fragments of this nature are filled with translucent crystalline quartz. of the variety that is commonest in quartz veins. This shows that when the brecciation took place the rock was in a dry, hard condition, and, as a consequence, gaping crevices were left between the crushed and broken fragments. These crevices were subsequently filled by quartz from freely percolating waters, in the same way that ordinary veins are formed.

Under the microscope, section 79 is composed of finely comminuted silica and iron oxide dust. The iron is to some extent concentrated into bands, some shadowy and microscopic, others coarser. The coarser ones follow fractures which traverse the rock. The oxide is chiefly magnetite mixed with some hematite and limonite, and this gives the black color to the bands.

Conclusion: This rock has the same origin as the larger fragment of section 79, except that the shearing has been more violent, producing certain lines of weakness along which the iron afterwards was concentrated, instead of uniformly through the rock. In the hand-specimen some of the other fragments are seen to still preserve a distinct spotted-granular structure, but to be otherwise quite like the fragment that has been described.

SECTION 80. In the hand-specimen, a breccia like 79. Under the microscope it is a much-broken mass, the fragments of which are made up of silica, calcite and other carbonates, and the iron oxides, in various proportions. The mass appears to have been originally composed mainly of silica and the iron oxides, but at the time of its brecciation it has been thoroughly wrenched and cracked. There followed the infiltration of calcite, forming veins and impregnations, and combining with the elements already present to form a large number of confused secondary products. In some spots the rock is almost pure calcite.

GROUP FROM SECTION 6, T. 58-17.

In this group are included sections 82 and 83, with hand-specimen 70. They are all from the same pit in the southeast of the northeast quarter of section 6, T. 58-17. This pit was explored with the diamond drill, and so to a much greater depth than those which have been described formerly. Below the glacial drift the first thing encountered was a thin conglomerate, composed almost exclusively of fragments from the iron-bearing member, and greatly decomposed. This was supposed to be of Cretaceous age. The base of this was a lignitic swamp deposit, connected with and apparently of the same age as the conglomerate. This rests upon a porous, friable, finely pulverulent deposit, strongly resembling a consolidated kaolin. Typically it is a pure white, but when stained with iron oxide it becomes banded with red, yellow and brown. This deposit is eighty feet thick, and at the bottom it passes gradually into a harder and firmer, although somewhat decomposed rock. This rock was passed through to the depth of over two hundred feet and the drilling was stopped while yet in it. Specimens 82 and 83 are from the hard rock, very near one another, at a depth of about 180 feet from the surface; specimen 70 is from the soft white pulverulent deposit.

SECTION 82. Hand specimen of a dark gray color spotted with red and white; fracture conchoidal. Under the microscope it has a spotted-granular structure, but is advanced in metasomatosis. The granules are distinguishable by rims or internal fragments of magnetite, earthy and micaceous hematite, and limonite, and by the very fine cryptocrystalline nature of the silica. The interstices between the granules are of fibrous chalcedonic silica, with sometimes the exception of a small space in the very center, where there are grains of phenocrystalline quartz. The fibrous chalcedony shows in places a disintegration into a very finely divided granular state, much resembling the silica of the interior of the granules. It is evidently this that gives the powdery white appearance to certain parts of the rock, and with the completion of the process and the leaching out of the iron, finally results in the transformation of the entire rock to the consolidated white powder.

SECTION 83. In hand-specimen, this is, in general appearance, like 82. The color differs, however, in that the groundmass is light green instead of dark gray, and that the granules mainly appear black instead of red. Under the microscope the iron is seen to be less in amount than in 82, and occurs as crystalline masses of magnetite. The granules and the interstices, to a less degree, contain a light green finely disseminated chloritic substance. The silica is about the same in general, but in places more coarsely crystalline grains are observed. Both 82 and 83 crumble easily under the hammer to a fine gray or white powder.

SPECIMEN 70 is a consolidated fine white powder, with a greasy feel. It can be easily cut with a knife into any desired shape. It is mainly white, with frequent bands of brown or light red. That these bands are later in origin than the reduction of the rock to its present condition, and result from the precipitation of iron oxide from infiltrating waters, along the weakest zones, is quite certainly shown by a study of this and other specimens from the same place. For while the bands are in general beautifully distinct and parallel, yet they take advantage of any weaker line which offers, whatever the direc tion, and offshoots from the main band may be found, striking off at any angle, and generally terminating blindly. This material was at first supposed to be a kaolin, and later, from its evident origin and by analogy with other powders of like nature, but developed on a smaller scale, it was suspected to be a silica powder. An analysis was made of the white portion of the rock with the following result:

ANALYSIS OF NO. 70 (CHEMICAL SERIES NO. 238) BY C. F. SIDENER.

Silica	SiO_2	77.89 per cent.
Alumina	Al_2O_3	13.55 " "
Sesquioxide of iron	Fe_2O_3	1.83 " "
Lime	CaO	trace.
Magnesia	MgO	.36 per cent.
Potash	K_2O	.84 " "
Soda	Na_2O	.58 " "
Water	H_2O	4.45 " "
Total		99.50

This analysis shows the rock to be mainly a pure silica powder, with a large amount of the hydrous silicate of alumina, or kaolin; a very small residual portion of the decomposed and leached iron oxides, here evidently in the form of the hydrous sesquioxide; and small amounts of the calcium, magnesium, potassium, and sodium which entered into the composition of the rock from which this was derived.

Conclusion: In this group 83 is evidently the primary rock. It also stands in the first part of the typical series of change. In it the granules are closely packed together, and are made up in large part of the green chloritic substance. The silicification of the chloritic substance may be seen to be going on, as described and observed more fully in specimen 217, (p. 84). In section 82, the granules are smaller and more rounded, and the chloritic substance has disappeared, attended by a proportionate increase in the silica. The silica is somewhat finer than in 83, showing the effects of disintegration, and this process is plainly still going on. In 70, the rock is entirely decomposed to a fine white powder, which consists of free silica and silicate of alumina, with trifling amounts of the other elements. These ingredients result from the decomposition of the greenish silicate of 83, which has produced the separation of silica and the leaving of a residual clay. The more soluble decomposition products, including the iron, have been leached out from this residual clay, leaving mainly kaolin.

82 may be compared with 125 and 39, and 83 is nearly identical with 166.

GROUP FROM SECTION 22, T. 58-20.

The members of this group are sections 213, 215, 217, 219, and 220. Of these 213 and 215 are from one pit, and 217, 219, and 220 are from another about twenty yards distant from the first. These pits are in the northwest quarter of the northwest quarter of section 22, T. 58-20.

SECTION 213. In hand-specimen, mainly a dark brown rock, heavy with iron, and with somewhat of a metallic lustre. There are also scattered residuary blotches, streaks, and patches, of a pinkish-white rock, mottled with red. These patches exhibit faintly the spotted-granular structure. On one side of the specimen is a body of white, finely crystalline silica, about 2½ inches in length and ¾ inch wide, which appears to be the filling of a cavity that resulted from some movement in the rock, or possibly from decomposition. In places, oxidation has changed the brown rock to some depth, producing a deeply pitted surface, coated with brown and yellow powder. This seems to follow a rough parting plane in the rock. In other places the decomposition has been more slight and serves to bring into prominence the spotted-granular structure of the rock, by dissolving out the interstices. This leaves the harder granules, with empty spaces between, like an aggregate of sand grains. This, it will be observed, is the reverse of the usual effect of decomposition, for in general the granules are the first to yield, and the result is that the rock becomes filled with rounded pores. The constantly changing character of this rock, both mineralogically and structurally, sufficiently accounts for this. There is a distinct jointing on two sides of the specimen, marked by smooth surfaces, in addition to the rough horizontal parting described above. These joint-planes if produced, would intersect each other at an angle of about 60 degrees. Under the microscope, 213 has in its least altered portions, which represent the lighter residuary patches of the hand-specimen, a spotted-granular structure. The granules contain various scattered and fragmental forms of iron—magnetite, earthy and micaceous hematite, and siderite. The darker portions of the rock differ in composition only in the relative proportion of the different minerals. There is a marked increase in the amount of iron minerals, which varies from about 10 per cent. in the lightest parts to perhaps 60 per cent. in the heaviest bands. Magnetite and hematite (both earthy and micaceous) are present in nearly equal amounts. The magnetite is in small masses with ragged boundaries, surrounded by the other forms. The hematite is mainly associated with the magnetite in such a way as to show its derivation from it. Siderite is another plentiful ingredient, and also an apparent decomposition product of the magnetite. In one place a complete pseudomorph of siderite after a cluster of magnetite crystals is seen. The distribution of the three forms of iron is such as to indicate the following order: 1. A change of the original magnetite to siderite. 2. The oxidation of both magnetite and siderite to hematite. The silica of the groundmass varies from finely to coarsely cryptocrystalline.

In structure the darker portions differ from the lighter in the obliteration of all traces of the spotted-granular structure, and in the development of certain roughly parallel planes of mechanical disturbance.

Conclusion: A spotted-granular rock has been subjected to some strain, which probably arose from contraction of volume in the processes of change. This contraction has produced without doubt the smooth vertical jointing, and probably also the rough horizontal parting. Microscopically, it has resulted in the roughly parallel cracks, and the lines of special weakness, which run around the unchanged lighter parts. There is no microscopic or macroscopic schistosity, to indicate any lateral slipping. Following the weakening of the rock there has followed the oxidation of the magnetite to siderite and hematite, its concentration in the zones of greatest weakness, and the consequent obscuring or obliteration of the original structure. It is to be noted that the siderite in this and in many other sections surrounds the magnetite as a decomposition product, and is cloudy and without crystal form. It thus comes under the group of decomposition products from magnetite called *leucoxen.* Rosenbusch describes it as an alteration product of ilmenite, titaniferous magnetite, and rutile. Concerning its nature he says:* "Its chemical composition is not the same in all cases where it has been investigated, and has been considered the equivalent of a variety of minerals (titanite, anatase, and siderite) by different observers." In every case where this mineral is present in these rocks, chemical tests show it to be siderite, and no signs of titanium can be found either in it or in the magnetite whence it is derived. The existence of this leucoxenic decomposition product surrounding magnetite has sometimes been held as sufficient evidence that the magnetite was titaniferous, but it is clear that it is not necessarily the case.

SECTION 215. In general appearance like 213, from which it differs in that some of the lighter spots are pure white, and the darker parts are more fine-grained. Under the microscope the rock is like 213, also, but there is no trace of the spotted-granular structure. The mineral constituents are scattered irregularly around. Conclusion: This is nearly identical with 213, but shows a slightly further advanced stage of change, resulting in the effacement of the granules, the scattering of the minerals, and a greater development of secondary products.

SECTION 217. This is nearly identical, both macroscopically and microscopically, with 125. In the hand-specimen it is dark green, very faintly spotted and contains small blotches, bands, and spots of magnetite. There is an irregular jointing, but no cleavage; the fracture is conchoidal; the specific gravity rather high. Under the microscope, the spotted-granular structure is well shown. The granules are rounded, subangular, or irregu-

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*Microscopical Physiography of the Rock-Making Minerals. By H. Rosenbusch Translated by Joseph P. Iddings. Second, revised edition, p. 165.

lar, and are closely crowded together. They consist mainly of the compact green chloritic substance described in 39, 125, and other slides, together with actinolite, magnetite, hematite, and siderite. Magnetite, in very small crystalline grains, and with associated hematite, is usually scattered sparingly through the granules, but is in places concentrated as described in the hand-specimen. The process of granular-brecciation is seen to be going on in some parts of the section, where the large, angular granules are sometimes cracked and seamed by fissures of varying width; sometimes separated into distinct smaller granules by an enlargement and continuation of these fissures; and again further separated and rounded, but their general outlines continuing such that they nearly match one another.

The green chloritic mineral has never any crystal outlines, but it encloses crystals of magnetite, and in places, under high power, it is seen to contain many very minute clusters of pale-green, pleochroic actinolite. It is slightly pleochroic, varying from lighter to darker green, and often shows an irregular cracking. In places this mineral occupies the whole of the granules; in others it becomes filled with silica in spots and fissures; then it is reduced to form a kind of network around the silica; and finally the granule is composed almost entirely of silica, with only a few dust-like grains, giving a cloudy greenish appearance, to mark the existence of the chloritic substance. From the chloritic granules to the siliceous granules there is every conceivable gradation, and one runs into the other so that it may be seen to be a process of metasomatic change. In the freshest phases the chloritic substance is marked only by a slight mottling of lighter and darker green. Soon, however, there appear scattered through it curious small dark rings. By nice adjustment under a high power the real material of the ring is seen to be a very narrow band of transparent silica. It is extremely fine, and varies from an apparently amorphous to a finely cryptocrystalline or chalcedonic nature. The number of these rings rapidly increases in the next stage, till the whole surface is covered with them. They grow larger, too, in both directions, so that on the outside they meet and unite, forming compound rings, and rosette-like forms, and, on the other side, the material inside the ring becomes smaller. It also becomes darker in color than at first, apparently from a growing excess of iron, in some cases becoming quite opaque. In the next stage the change has gone on till the silica has usurped most of the space in the granules. The chloritic substance, grown darker and nearly opaque, forms a compact network around the silica. The chloritic centre of the rings has in most cases disappeared, in others is represented by a very small patch of ferruginous clayey material. By this time the silica has often assumed a distinctly chalcedonic nature. It is usually made up of fibres that radiate from the inner core of the ring, or if this has disappeared, from the centre of the circle, and terminating at the circumference. In proportion as the circle grows larger and tends to unite with others this fibrous structure becomes obscure and passes into a semi-crystalline condition, in grains that have an undulatory extinction and low polarization colors. In the last stage the chloritic substance has disappeared, and the silica occupies the whole granule, except for the cloudy residuum which gives it a color sufficiently distinct to contrast strongly with the colorless silica of the interstices. The silica at this time is semi-crystalline, semi-chalcedonic. Only occasionally are the traces of the fibrous arrangement met with, and yet there is no firm crystalline structure. There seems to be a tendency, however, for each of the original rings to form, when crystallized, a distinct grain. There may be found single granules which represent each a stage of the process of change described, but usually all the stages are seen going on in the same granule, passing from the nearly pure chloritic substance to nearly pure silica. Actinolite forms a small part of the section, perhaps 5 per cent. It seems to be invariably of secondary origin, since it is found chiefly around the edges of the granules, from which the crystals radiate into the intergranular spaces. (See Plate VI, Figs. 1 and 2).

Although the chief method of silicification of the granules is by the process described, there is an important auxiliary. In many cases silica which is probably foreign to a granule penetrates along cracks which have been produced by some movement in the rock, and enlarges them by wedging and by replacement of the wall-material; and in this way continually divides the granule into fragments. Cracks which traverse the whole rock, on the other hand, usually give rise to impregnation veins, along which chiefly magnetite, with some hematite and calcite, is concentrated.

That the silica which takes the place of the chloritic substance is formed from its decomposition, and not from replacement, is shown by the method of distribution of the change, in that it does not begin at the periphery or in mechanically weak places, but appears simultaneously in all parts of it; so that portions remote from other silica and outside influences are quite as much affected as any. Moreover, the separation of earthy iron oxide, coloring the remaining chloritic substance a dark brown, is proof that a decomposition has actually taken place.

Conclusion: This rock is near the beginning of the typical series of change. As in other similar sections, the original rock seems to have consisted chiefly of a chloritic substance. In the decomposition of this substance there has resulted the separation of free silica together with iron and the more soluble salts. These soluble materials were almost totally leached out; the iron, less soluble, was taken into solution and mainly deposited near by, and is represented by bands and blotches of considerable size and frequency. What few carbonates are scattered along the microscopic impregnation veins are probably also derived, through this change, from the original green chloritic substance. They are chiefly calcite, probably magnesian. The processes observed in this rock, it will be seen, have gone on under conditions of comparative freedom from modifying highly oxidizing forces. Had the supply of these been somewhat greater, and yet not great enough for complete oxidation, the iron would have separated as carbonate, and in this form would have occupied more of the bulk of the rock. This carbonate would probably be afterwards *replaced* by silica, by reason of its greater solubility. In the rock under consideration waters bearing carbonic acid had slight access, and so separated silica is the most noticeable result of this change. It is this silica, taken into solution and carried down into the rock below, that would in turn replace the carbonates formed under our suppositious conditions.

An analysis of this rock gave the following results:

ANALYSIS OF 217 (CHEMICAL SERIES NO. 241).
BY ALONZO D. MEEDS.

		Per Cent.
Silica	SiO_2	56.28
Sesquioxide of iron	Fe_2O_3	15.25
Protoxide of iron	FeO	18.28
Alumina	Al_2O_3	3.29
Lime	CaO	.93
Magnesia	MgO	.72
Soda	Na_2O	.25
Loss on Ignition		4.75
Total		99.75

It must be remembered that this analysis is independent of the iron which has been concentrated into spots and bands.

Its place has been filled with silica. Nearly all of the iron which has become separated by decomposition of the silicates has been removed in this way. In any attempt to estimate the exact composition of the original rock this must be reckoned, and the corresponding amount of silica deducted.

SECTION 219. In the hand-specimen, this closely resembles 217. There are scattered all through it, however, small grains which show pearly crystal faces, and give abundant effervescence of carbon dioxide with cold dilute hydrochloric acid. There is also some pyrite in disseminated crystals. Under the microscope, the chloritic substance, inclosing magnetite, is substantially as described for 217. The peculiar features attending the separation of silica are not quite so well shown, however. The magnetite sometimes is almost entirely changed to earthy hematite; the interstitial silica is coarsely chalcedonic. Around the margins of the granules a fibrous fringe of silica is arranged, and when the intergranular space is narrow, these fringes meet in the middle. Where it is larger, as where three meet, there is a space in the middle where the grains are coarser, and approach a crystalline phase, though they rarely give any polarization colors. Fully 30 per cent. of the section is composed of large crystalline grains of calcite, which shows perfect cleavage, but has allotriomorphous outlines. This has penetrated the rock and crystallized both in the granules and in the interstices; when it penetrates both, it obscures to some extent the spotted-granular structure.

Conclusion: The habit of this calcite makes it clear that it is not a secondary product, but is xenogenous. Its source was probably from the altered limestone beds which overlie the rocks of the iron-bearing member. The occurrence of pyrite shows the presence of sulphuric acid, as well as lime, in the waters. The existence of this acid in a rock which shows such profound decomposition of its silicates has some additional significance, as we shall see later.

SECTION 220 is nearly identical, both in the hand-specimen and in the slide, with 213 and 215. Faint traces of the spotted-granular structure may be observed, but could not with certainty be identified by this slide alone. The silica is very finely cryptocrystalline. The iron and dark ferruginous secondary products form a network of irregular shape and distribution. Some of this is magnetite, in small grains, but the most is a micaceous hematite, with limonite; and some actinolite, which is stained dark red by impurities.

Conclusion: In this series 217 is evidently the least altered phase. 219 is essentially the same thing, but is altered by impregnation of calcite and pyrite. From this 213, 215, and 220 are derived by exposure to oxidizing forces. There is no evidence of any auxiliary dynamic action, even of that common kind provoked by the metasomatic changes themselves. The result is a rock without definite structure, composed of cryptocrystalline silica and scattered iron oxides and secondary products. In other words, nearly the whole length of the typical process of change separates two specimens within a few feet of each other, which we must believe to have originally been identical; and the only agent in this change which we can discern is the common atmosphere.

GROUP FROM THE MOUNTAIN IRON MINE.

The members of this group are sections 97 and 232, and specimen 204. The ore body of the Mountain Iron mine lies in a depression from which the land rises to the north, east and west, while on the south it passes by a gentle slope into the lower country. On the north, there rises almost directly from the low-lying ore-body a steep bluff, on the face of which are outcroppings of hard siliceous rock, banded with hard ore. These outcrops are of especial interest, since they were among the first traces of the iron-bearing rock known on the Mesabi, and although they were repeatedly examined and adversely reported upon, yet doubtless they gave the motive to the search which finally resulted in such signal success. Specimen 97 is taken from this outcrop. Specimen 204 is taken from a mass of hard ore which was found surrounded by soft hematite, in the process of mining. That this is a residuary fragment, representing the former state of much of the rock which has since been changed to form the soft ore, cannot be doubted. In shape it is irregular, with ragged outlines made by the decomposed and crumbling surface. It is probably about four feet square by two feet thick; in its inner parts it is a hard, gray, porous rock, apparently of hard hematite, but probably siliceous; but it grows softer towards its periphery, till it passes into beautiful purple, yellow, brown and red soft ore. Specimen 232 is from a pit near the mine, which encountered no ore.

SECTION 97. In the hand-specimen, this is red and crystalline, and is coated with a thick layer of botryoidal limonite. Under the microscope, it is seen to be mostly composed of crystalline quartz, in large and small angular fragments. This rock presents evidence of having been broken, strained, and shivered in a most remarkable manner. The resulting cracks have served for the introduction of crystalline limonite, which has here segregated in minute veins and has to some extent impregnated the quartz. This gives the light red color to the rock. *A certain constant direction of the fissures, indicating a single strong fracturing force, moving only in one direction, is seen throughout the rock.* The importance of this will be seen later, in the discussion of the origin of the ore-deposits This rock presents none of the commoner features of the iron-bearing rocks. It is simply a crushed and fractured mass of crystalline quartz, in which no individuals are distinguishable, no granular structure or crystalline outlines; and this quartz is stained with limonite. From the general appearance of the rock, and the plentiful incrustations of limonite in fissures and on the outer surfaces, it is quite safe to conclude that the iron is idiogenous, and is but a remnant of the amount that was originally in the rock. The rest has been entirely removed through the channels for percolating waters opened up by the profound fracturing.

SECTION 232. The hand-specimen shows three distinct varieties, one derived from another. The first is nearly white, shaded to gray. It is apparently homogeneous, of granular texture, and irregular fracture. It appears to be identical with the lighter residuary portions of 213, 215 and 220. This is stained brown by iron oxide to form the second variety, which surrounds the first, leaving it as irregular residuary fragments of all sizes. The introduction of the iron seems to be the chief change. This second variety is identical with 149 and 214, and is closely related to 224. The third variety is a crystalline hematite which is formed from the second by a complete ferration. The boundary line is irregular and vague, and the residuary patches of the second variety are quite as common, if not as conspicuous, in the hematite as those of the first are in the second.

The section contains varieties 1 and 2. The first variety shows clearly the spotted-granular structure, and indicates no mechanical disturbance. The granules are large, subangular, and are closely fitted together. They contain so little besides silica, however, that in the hand-specimen they are not distinguishable from the interstitial spaces. They are clouded by a thinly scattered dust. The silica is very finely cryptocrystalline, while that of the interstices is coarser, varying from cryptocrystalline to finely phenocrystalline. The change from 1 to 2 is marked by an impregnation of limonite, which replaces the silica. First the fine silica of the granules is replaced, and until this is entirely accomplished the interstices are not usually attacked, so that the granules become pellets of iron oxide with the crevices filled in by silica. Gradually, however, these bodies broaden, and eventually the interstices become much reduced in size, and sometimes disappear. It is evident that a complete replacement of the silica gives, if all the iron be in the yellow hydrated state, a soft ore like the yellow bands in the Mountain Iron mine. If the granules remain, as they are apt to do, in the hematitic state, while the interstices are replaced by hydrated peroxide, a somewhat granular brown ore will result. Crystallization in small finely disseminated masses through the rock as hematite, without attendant consolidation, gives the "blue" granular hematite. These different processes will take place in different zones of the rock, according to its porosity and mechanical weakness, these qualities determining the amount of oxidization which may take place within a given time. The third variety of the hand-specimen is not represented in the slide. It differs by a nearly complete replacement of the silica, and the crystallization of the earthy limonite into hard ore.

SPECIMEN 204. The structure of this piece of hard ore reminds one of that of the more highly ferrated parts of 232, just described. Evidently the same process has operated here and the results are the same. The rounded granules are yet distinguishable, by reason of the removal of the interstitial matter, leaving cavities which produce the porous structure of the rock. According to the degree to which enlargement of the original granules, as described for 232, has gone on, their outlines become less perfect; and frequently there has resulted a considerable diminution in the size of the intergranular space. The granules are of hard hematite, but the abundance of the empty interstitial spaces expose them to easy hydration. All through the rock the effects of this are seen in the scattered yellow powder, and, as stated, upon its periphery it passes gradually into the soft ore of which it is a residuary fragment.

Conclusion: A violent mechanical fracturing of the original rock at Mountain Iron has laid a considerable strip open to freely oxidizing forces. The evidence of this motion is clearly preserved in 97, which is so situated, at an eminence above the general plane of action of surface waters, that it has not been greatly altered. The fracturing, however, had for a result on this rock the removal of most of its iron in solution. At the same time, the silica which remained became crystalline. The iron derived from this rock, together with the iron from all parts of the iron-bearing rock which came under the action of the surface waters, found its way into the lower parts of the fractured area, and was there deposited, being able, under these conditions, to replace the easily soluble cryptocrystalline silica. All the stages of this replacement are seen in 232. The final result was a hard, porous, somewhat hydrated sesquioxide. It is interesting to remember, however, that the white and almost totally non-ferruginous nature of the primary variety of 232 shows that at a period prior to its impregnation by iron, it had been leached and its iron carried away to form the first layers of the ore-deposit. The subsequent replacement of this leached rock by iron indicates a filling up of the basin by the growing thickness of the ore. The ore seems to have been hard and porous at first, judging from the hematite portion of 232 and from the residuary fragment 204, but freer oxidation soon operated to reduce it to a state of more or less complete hydration. The extreme of this process is in the yellow göthite, but nearly all of the soft ore contains more or less of combined water. Opposed to this further oxidation and hydration, was the change in certain regions by partial crystallization to a granular and friable ore, such as the "blue" hematite.

GROUP FROM THE VIRGINIA BASIN.

The members of this group are 10, 11, 12, and 13. They are selected from different places, to show the general nature of change in the rocks as the proximity to the great Virginia ore-basin increases. Specimens 10 and 11 are from the same pit, about 400 paces south of the northeast corner of section 4, T. 58-17, and so about a mile north of the great ore-bodies. Specimen 12 is from a pit on the Wyoming property, which is situated about half way between the locality before described, and the ore-bodies; and specimen 13 is from a hard portion of the ore at the Rouchleau mine, where there is a large and valuable deposit, and which is surrounded by many others of the valuable mines of the Virginia basin. Thus a series, beginning with the rock at some distance away, and ending with that directly associated with the ore, is obtained.

SECTION 10. Made up of silica and magnetite, which occupy more than 99 per cent. of the section. The magnetite is evenly distributed through the field, in the form of irregular, compact masses, large enough to be visible to the naked eye, which usually have distinct crystalline boundaries. There may be, instead of the bunches of intergrown crystals, an attenuated string, which may be reduced at times to single individuals. Bands of magnetite with less definite crystal form, or lacking it entirely, are contained in the granules, and serve to emphasize the existence of the fast-disappearing spotted-granular structure. Sometimes these bodies form an internal network in the granule; sometimes they are external, and outline its rounded form. Besides this compact magnetite, the same mineral in the form of dust is distributed throughout the section. It is usually more closely massed in the granules, where it fills out the form suggested by the firmer skeleton. In other parts of the section this definite arrangement becomes lost, and the dust-like magnetite is scattered irregularly. The silica is of two distinct varieties. The first is that which has been denominated finely cryptocrystalline, and occupies the granules; the second is finely phenocrystalline, and is found in the interstices. Between the two there is every stage of gradation, and yet they are quite distinct, both in their position and their nature. It is a constantly observed phenomenon that when a mass of magnetite is bounded on one side by the cryptocrystalline silica, and on the other by the phenocrystalline, the first side is apt to have a rounded or irregular outline, while the second will be usually perfectly crystalline. This constant association suggests that the two kinds of silica may have the same relation as the two kinds of magnetite, that the finely divided sort passes into the coarser by a simple process of crystallization. Indeed, in many of the granules this change seems to be even now taking place, for not only does the coarser silica surround them and occupy the crevices in them, but along these fissures and sometimes far into the granule, the crystallizing motive appears to be at work. This process appears to be contemporaneous with the concentration of the magnetite dust into crystalline form.

The coarser silica is usually marked by a mechanical crack which runs through the middle of the area. There are often ramifying cracks extending from the main one, and these are sometimes extended so as to form a rude network. The main crack generally runs around the edge of the quartz grains, but sometimes cuts through them. These are not found in the finer silica; and they were probably formed *after* the crystallization took place. If any strain were brought to bear on this rock (such any change of chemical relations or even of temperature, bringing about expansion or contraction), it might be relieved in the finely divided silica by the slipping of particle on particle, but in the more brittle and tenacious fragments of the coarser crystalline silica could only result in fracturing. These cracks are often seen to cut across a grain, forming two portions that extinguish nearly enough together to show that they were originally one, and yet at a slightly different angle. Cases of this can be observed where the angle increases, owing to more complete separation of the parts, till finally the original unity of the fragments can not be established. This suggests that the grains of the coarser silica may have been originally much larger than at present, and that the present individualized condition may have resulted in part from fracturing and re-arrangement. But the perfect transitions from the coarser to the finer sort show that while this process has undoubtedly had some effect, yet the crystallizing motive has been far more active. (See Plate VIII, Fig. 2.)

SECTION 11, from the same pit as section 10, in a general way resembles it. The chief constituents are again silica and magnetite; but while in section 10 magnetite formed from 25 per cent. to 30 per cent. of the field, in section 11 it forms only from 5 per cent. to 10 per cent. The remaining space, which in 10 is filled with magnetite, is in 11 occupied by open pores, which in general correspond to the shape of the magnetite masses, and from which it is evident that the iron has been dissolved. All stages of this dissolution can be seen, from the magnetite mass with an irregular gap on one side, to the cavity with fragments of magnetite still clinging to the sides, and finally to that with the quite clean siliceous walls. The line between the magnetite and the cavity is sharp, and there is no evidence of any alteration into other forms of iron previous to being taken into solution. The silica is exactly as described for 10, and the different varieties chiefly distinguish the granules, whose existence is still clearly seen. The magnetite dust which is associated with the cryptocrystalline silica does not seem to have dissolved out, but it has undergone a concentration into bunches. That only the crystalline magnetite has been attacked was probably due to the fact that it was more easily accessible to atmospheric influences, as indicated by its association and the probable manner of its formation. The repository of a part of this dissolved iron is seen in the section to be two small veins, which are remote from one another, but if produced would intersect at an angle of about 120 degrees. At right angles to one of these veins there is a third and smaller one. They consist of persistent, but irregular bands of crystalline magnetite, which appear to follow mechanical fractures in the rock. In places the magnetite of these veins is riddled by irregular cavities, and along these and along the edges there is an evident decomposition to earthy hematite and limonite, so that often a mass of the yellow and red ores are seen surrounding a small residual core of magnetite. Often the whole of the magnetite band is cut by ramifying lines of hematite, which in places grow broader till they nearly coalesce. In the hand-specimen broader bands of magnetite are seen, but marked by the same features as these little veins: the sum of all of these veins contains enough iron to account for all the grains dissolved from the body of the rock.

SECTION 12. Composed of about 90 per cent. silica, about 10 per cent. of blood-red earthy hematite. About 80 per cent. of silica is phenocrystalline, showing brilliant polarization colors. The grains are of about the same size as the largest central ones of section 11. But the cracks which were noted as partly separating the grains, have here become larger, and contain earthy red hematite, deposited from iron-bearing waters which have forced their way in. The widening of these cracks and the consequent loosening of the mass has then been accomplished in two ways—first, by the partial solution and replacement of the silica by iron, and second, by the mechanical pressure exerted by the growing vein. The result is that the rock is extremely friable, and crumbles easily. The grains, however, still retain their interlocking forms, which show their crystallization in place. Considerable areas of these fragments extinguish nearly simultaneously or with a slightly undulating extinction. These areas seem to have been at first united, and to have been subsequently fractured. The cryptocrystalline silica occurs but in one place, where it forms a residual (?) fragment of considerable size.

The iron which in 10 and 11 accompanied this variety of silica is present also in this slide, but here it is entirely earthy hematite instead of magnetite, and is either scattered through the mass or arranged in more or less rudely parallel fibrous bodies. The iron leached from the rock since it was in the condition of section 11 is seen in the hand-specimen to have been concentrated into a broad band, which consists partly of iron, in a highly oxidized and hydrated state, and partly of the silica which has not yet been replaced. It will be remembered that a part of it is also found in the crevices between the silica grains.

In outward appearance, and even at the first glance under the microscope, this rock resembles a loose, friable detrital sandstone. Both its structure, as explained, and its evident derivation and method of formation, show that this is not the case, but that it is one of the multitudinous peculiar phases of the iron-bearing rock. There is no trace of any original detrital grains, nor is the appearance of the silica like that of the clastic rocks.

SECTION 13. Dense opaque brown hematite. The ore is porous, being filled with irregular cavities, which occupy about 10 per cent. of the section. The walls of these cavities are lined with minute clusters of radiating dark red crystals, which, when detached, form asterisk-like bodies. Occasionally, in the ore, there is a little micaceous hematite. The resemblance of this rock, a residuary fragment of hard hematite in the soft ore of the Rouchleau mine, to specimen 204, the residuary fragment in the Mountain Iron mine, is significant. They are nearly identical, both in their composition and their porous structure.

Conclusion: There is a progressive change in the nature of the rock as one goes from the rim of the Virginia basin towards the centre. The first rock described is one which we know from our comparative study to be a phase already far advanced in the processes of metasomatosis. The spotted-granular structure is still well preserved and the granules are marked by the characteristic finer silica, and by the presence of a part of the iron in the rock. Most of the iron, however, has been dissolved out of the granules and has crystallized either in the granules or the interstices, or partly in both, as it happens. Together with this re-crystallization of the iron, there is a corresponding process going on in the silica, by which the fine cryptocrystalline sort is seen to be passing slowly into the coarser phenocrystalline variety.

In the next stage, the iron which has been concentrated into disseminated crystals has been again dissolved and redeposited in impregnation bands along fractures in the rock. These fractures may run in any direction, but there is a general parallelism between the most conspicuous of them.

In the next stage we do not find these hard concentrated bands; for, with the increasing decomposition, they have apparently been again dissolved and carried still further on, till in the end they go to swell the ore deposits at the bottom of the basin. But the pulverulent oxide, which in the former stage had not been attacked, has in this been dissolved and concentrated into a band whose highly oxidized and hydrated character affords sufficient evidence of the conditions under which it has been formed. Here, again, the crystallization of the silica, noted as beginning in the first stages, has gone on till nearly all the rock is of crystalline quartz, in grains of somewhat uniform size. In the crevices between these grains iron oxide has entered, and has operated to separate the grains of silica, so that the rock is loose and friable.

In the last stage, a porous hard hematite is encountered, whose origin is evidently the same as the hard concentration bands in the other stages; and whose porous nature is probably connected with the spotted-granular structure of the original rock, as explained for the similar sort of ore at Mountain Iron. This hard ore is found as a residuary fragment in the midst of the soft ore, and doubtless the latter has been derived from it by the easy oxidation and hydration which the porous structure offers.