The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map over the two being used together in the form of an atlas, the parts of which are called folios. Each folio contains a topographic base map and geologic maps of a small area of country, together with explanatory and descriptive texts.

**The Topographic Map**

The features represented on the topographic map are of three distinct kinds: (1) topographic features, such as relief, roads, railroads, boundaries, villages, and cities; (2) distribution of water, called drainage, as streams, rivers, lakes, and the like; and (3) the works of man, called culverts, as roads, railroads, boundaries, villages, and cities.

**Relief.** All elevations are measured from mean sea level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the horizontal contour, or contour, of all slopes, and to indicate their grade or steepness. This is done by lines connecting points of equal elevation above mean sea level, the lines being drawn at regular vertical intervals. These lines are called contours, and the uniform vertical space between each two contours is called the contour interval. Contours and the supposed underground signs are printed in black.

In the manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map:

1. A contour indicates approximately a certain height above sea level. In this illustration the contour interval is 50 feet; thus the contours are drawn at 60, 160, 260, 360 feet, and so on, above sea level. Along the contour 250 feet lie all points of the surface 250 feet above sea level, and similarly with any other contour. In the space between any two contours are found all elevations above sea level. The ground on the terrace on the right a hill rises gradually, while that on the left the ground ascends steeply, in a precipice. Contrasted with this precipice is the gentle descent of the left-hand slope. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, the contours on a gently undulating or smooth surface, recede into all rectilinear angles of ravines, and project in passing over all crests and valleys, so that the curves and angles to the form of the land can be traced in the map and sketch.

3. Contours show the approximate grade or steepness of any slope. The vertical space between two contours is the same, whether they lie along a cliff or hillside or across a plain. If the ground on a gentle slope one must go farther on a steep slope, and therefore contours are far apart on the first than on the second side of a hill or steep slope.

4. For a fast or gently undulating country a small contour interval is used; for a steep or mountain country, a large one. A large smallest interval on the atlas sheets of the Geological Survey is 1 foot. This is used for regions like the Mississippi delta and the Delmarva Peninsula. To map rough ground, a much larger interval is used. In the map the distance between the lines is shown by a broken blue line. Lakes, marshes, and other bodies of water are shown also in blue, by appropriate conventional signs.

5. Culture. - The works of man, such as roads, railroads and towns, together with boundaries of townships, counties, and States, and a few other details, are printed in black.

6. Vegetation. - The area of the United States (excluding Alaska) is about 9,350,000 square miles. A part of the surface is covered by vegetation. This is shown on the map by a system of lines, which in some cases are seen on the ground.

7. Water.- The surface of the world is composed of water, and the oceans and seas, which cover over 70% of the earth's surface, are divided into several parts. The largest of these bodies of water is the Pacific Ocean, which covers about one third of the earth's surface. The Atlantic Ocean is the second largest, covering about one fifth of the earth's surface. The Indian Ocean is the third largest, covering about one tenth of the earth's surface. The Arctic Ocean is the smallest of the five oceans, covering about one fifth of the earth's surface. The Antarctic Ocean is the seventh largest body of water, covering about one third of the earth's surface. The Mediterranean Sea is the smallest of the five seas, covering about one tenth of the earth's surface. The Red Sea is the second largest of the five seas, covering about one fifth of the earth's surface. The Arabian Sea is the third largest of the five seas, covering about one third of the earth's surface. The Bay of Bengal is the fourth largest of the five seas, covering about one fifth of the earth's surface. The Bay of Biscay is the fifth largest of the five seas, covering about one third of the earth's surface.
DESCRIPTION OF THE MENOMINEE QUADRANGLE.

INTRODUCTION
This account of the geology of the Menominee iron-bearing district will include all known details relevant to the Menominee iron range. The rock samples collected during the investigation of the Menominee iron range were studied by several geologists of the U.S. Geological Survey, who prepared the following report:

The Menominee iron range is located in the northwestern part of the Menominee county, Wisconsin. The district extends from the southwestern boundary of the Menominee iron range to the northwestern boundary of the range. The district is bounded on the north by the Menominee river, on the south by the Menominee river, on the east by the Menominee river, and on the west by the Menominee river.

The Menominee iron range is a complex of iron formations, consisting of a series of strata of iron ore, magnetite, hematite, and other iron-bearing minerals. The district is characterized by the presence of a series of iron formations, which are exposed along the eastern and western margins of the district.

The Menominee iron range is a classic example of a sedimentary basin, which was formed during the Precambrian period. The basin was filled with a series of iron formations, which were later uplifted and exposed by erosion.

The study of the Menominee iron range has been of great importance in the development of the iron industry in the United States. The district has been a source of iron ore for many years, and its development has been an important factor in the growth of the iron industry in the United States.

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granulation of the original components and partly through recrystallization. The particles of some of the more finely divided sand in the matrix with a parallel arrangement, giving a schistosity. The coarse-grained rocks were also made schistose by the same processes, but they are not so much stronger than those of the fine-grained rocks that they were able to resist the deforming agencies more successfully. Though the rocks as a whole, their schistosity is much less marked than in the case of the finer-grained materials.

A few small dikes of granite in the schists are younger than the latter. They are normal diabase and basalt, identical in composition with some of the rocks cutting through the iron-bearing series.

Western area.—The western area of Quinnesene schists occupies about 5 square miles. It extends from about the center of sec. 10, T. 40 N., R. 30 W., Michigan, to the Menominee River. The normal schists are occasionally cut by altered diabase dikes, but the garnet dikes and the granite dikes so prominent in the southern schists are entirely absent from them, at any rate so far as they are exposed in Michigan. The Fourfoot Falls are at the southern side of the area, where it crosses the Menominee River, and the old Indian village of Hodat is at its northern limit. The Twin Falls plunge over ledges of the schists.

The schists are grayish-green to drab gray-green, in which schistosity is nearly everywhere noticeable. In some places the rocks resemble granite, with the topography of a fine-grained granite. The garnet dikes in the schists are mostly mica schist, often almost as perfect as that in the schists, but in other places they are nearly massive. On many of the exposures a well-defined schistosity is quite discernible. The ellipsoids vary in diameter from a few inches to 3 or 4 feet. There is no striking contrast between the ellipsoids and that of the matrix between them. In both cases the rock is a dense grayish-green stone without any distinct mineral or textural features. The matrix is usually slightly more schistose than the ellipsoids, but otherwise it is like them. At the Fourfoot Falls the exposure consists almost entirely of dikes of massive schistose, and slaty rocks, striking about N. 80° W., almost at right angles to the course of the river, and yet these rocks are mostly schistose on the Wisconsin side of the river and mostly massive on the Michigan side. This is in perfect agreement with the deposits between the eastern and western areas of the field.

The western area is similar to the southern area, and the field of examination indicates that the western area, like the southern, contains a variety of strongly metamorphosed volcanic rocks.

The micaceous structure of some sections show that some of the rocks have been altered into schists, and other areas are altered diabases still preserving their characteristic features. Others are so much altered that the schistose nature can only be inferred from the character of their alteration products. Some of these appear to have been fine-grained diorites, with the topography of a fine-grained granite.

The eastern area is a well-known area of fine-grained granite. The most striking features are the well-defined schistosity, and the abundant garnet dikes of massive schistose, and the slaty rocks, striking about N. 80° W., almost at right angles to the course of the river, and yet these rocks are mostly schistose on the Wisconsin side of the river and mostly massive on the Michigan side. This is in perfect agreement with the deposits between the eastern and western areas of the field.

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first is the impossibility of deciding how much of the apparent thickness of the many rock layers in a closely folded district is due to the duplication of beds, and in consequence of close folds. The other difficulty is that the upper limit of the formation. There is everywhere between the quartzites and the nearest ledges of the over-lying dolomite a belt of country without exposures of any kind. If we assume that the southward-facing cliffs which so frequently mark the northern limit of the cliffs are if possible differential degradation, that the low ground at the base of the cliffs is underlain by the dolomite formation and that the upper limit of the many rock layers is due to the duplication of beds, then the thickness of the quarries may be easily calculated at a number of places. At the gorge below the falls of the Sturgeon River is a contin-

uous exposure of conglomerate and quartzite beds about 360 feet in width. For 500 paces the walls of the gorge are 90 feet high, striking N. 57° W., and dipping 72° to 85° N. An inspection of these beds reveals to indication of folding. The dolomite beds that the upper limit appears to consist of consecutive beds. The thickness of the formation to this width, calculated at a average dip of 68°, is 915 feet. Approxi- mately the same results were obtained further west at a dip of 70°. The corresponding thickness is about 1650 feet. A third section, near Cubsburg, the outcrop of the conglomerate was found further west, gives 1250 feet. It is prob- able that these results are due to the folding of the conglomerate beds in the outer parts, but it seems safe to assume that the above figures represent a fair average and that its maximum thickness is between 1600 and 1550 feet.

The Sturgeon quartzite rests unconformably upon the northern complex. This is shown by the character of the lower horizon of the quartzite, which, as already said, is a sandstone conglomerate. It is hard to believe that part of this sandstone conglomerate contains an entire variety of fragment derived from the rocks of the northern complex. Some of this material in its original position must have been formed at great depth in the earth. Therefore there was deep-seated denudation of the Archean before the deposition of the quartzite. The Sturgeon quartzite grades into the Raeville dolomite. The nature of the gradation is discussed under the latter heading.

RANVILLE DOLOMITE.

Distribution, character, and position.—The Ranville dolomite occupies three separate belts, its positions and shapes are determined by the folding of the rock in which the formation has been subjected to the action of water. These will be referred to as the northern, central, and southern belts of dolomite.

The northern belt is north of the belt of Stur- geon quartzite. Only a few exposures are found in this area, but they are so uniformly distributed that the whole belt has been colored for the formation. It is quite possible that in some places erosion has ceased away the Huerocka remnants immediately upon the quartzite, but in the present state of our knowledge this assumption does not seem justified. The country underlain by the northern belt of dolomite is now the valley of Pine Creek. It is a plain, once covered by a lake, which has been partly deposited by the creek and partly by glaciers. It was a valley long before the advent of the glaciers, and there is some evidence indicating that there was a valley in this plain even before the deposition of the Cambrian sandstone. The long-continued erosion produced by the Pine Creek drainage has reduced the area to one of low relief. This topography is very different in character from that of the other dolomite areas, where the valleys approach the size of canyons, and are elevated above the adjacent plateau.

The central belt of dolomite borders the north side of the Sturgeon River near the mouth of the river. This belt is the longest, passes eastward the Cuff, and the Indian mines, and ends at the black bluff on the north side of sec. 32, T. 6 N., R. 29 W. This belt is well

marked by numerous and often large exposures, but, as in the area just described, the exposures are so far apart that the thickness of the dolomite formation has, however, been made to cover the area between sets of exposures, because it is not certain that the rock is not present beneath the soil.

The southern belt of dolomite extends along the eastern shore of the Lake Nipissing, from the divide bluff west of Iron Mountain to the village of Neenahold, at the eastern end of the lake. The rock outcrop is at the surface the rock has been found in mines and test shafts and pits, so that there is a reason to believe that the rock is not present beneath the soil. It is probable that the existence of this is due to a considerable thick- ness of covering Lake Superior sandstone. From Iron Mountain as far east as the Sturgeon River the country underlain by the dolomite is a range of high hills broken only at a few points by north-south spurs. On the southern slope of the range is the principal producing iron mines of the Manistique district. The northern limit of the northern belt is in general very indefinite. At several places, especially near the transverse gaps referred to above, the northern limit can be fairly well determined, as the entire country in its neighborhood is very deeply and steeply covered that the boundary can not be definitely fixed.

The southern boundary, on the other hand, is rather sharply delimited, not merely by exposures, but by the underground workings of many of the mines.

Character and variations.—The Ranville dolom- ite is composed of a heterogeneous set of beds in which dolomite is dominant. With the pure dolomites are siliceous dolomites, calcareous quartzites, and black shale. The Ranville dolomite, lying upon the Sturgeon quartzite, grades downward into it.

The intermediate rock is a calcareous quartzite. The predominant rock of the Ranville dolom- ite is an almost massive, apparently homogeneous, fine-grained variety of instances observed the pikes are as indicated. The attitude of minor folds is, as well known, in an indication of the attitude of the major folds on which they are superimposed. By using this principle, it is concluded that the major antifolds in this district dip to the east and to west by plunging beneath the Upper Mesonias sediments. Detailed examination of the beds between Lake Antoine and Pusey indicates that the trend of thrusts is so that both are covered with sandstone and drift. But for this belt, the evidence of the minor folds is all that is needed to establish the assumption that this belt plunges below the Upper Mesonias rocks.

In certain instances it is clear, in addition to the major east-west antifolds and synforms with that are so prominent in the district, the dolomite formation is also affected by a gently but large antilongitudinal with axis running approxi- mately north-south. This is the only way the area mapped is the dolomite known to be exposed from the bottom to the top. On the northern side of the trough the formation is bordered by the Sturgeon quartzite on the north, and the Vulcan formation on the south, but exposure between these limits is so far that we can not be sure that the dolomite occupies the entire breadth.

If we assume that in the wider peters of the dolomite beds the entire formation is exposed, we are still unable to estimate its thickness accurately, since we know that it has been subjected to subordinate folding, and we can not determine the exact amount of duplication that has taken place.

In the center of sec. 12, T. 10 N., R. 29 W., 29° 35', there are several exposures of the rocks, the belt is about 3000 feet wide, and has an average dip of 5° S. This corresponds to a thickness of about 3100 feet, or at least twice the thickness of the formation, since this belt is an anticline. So far as we can learn, there are no minor folds here, so that 1250 feet is the thickness of the exposed formation at this place. The entire formation, however, does not reach the elevation of the minor folds, to the center of the belt the elevations of the anticline at the apex of the syncline, and consequently the lower members exposed — are not covered by the upper members of the same formation. Moreover, while the southern limit of the dolomite is well established by exposures of the Vulcan formation, the contact is at the top of the dolomite, or whether some of this rock had been removed by erosion before the deposition of the dolomite, the country is covered with swamps and sand plains. The thickness of the formation based upon the same statement of facts would appear to have been narrower because the lower and higher beds of the dolomite are not exposed. However, superimposed upon the major folds, as the dolomite and the quartzite are many minor folds. To what extent the beds are duplicated by this minor folding it is practically impossible to determine.

If one should make calculations so as to obtain a minimum figure, 1000 feet or less could be almost obtained. If, on the other hand, one were to attempt to give a maximum figure, the supposition that all of the isoclinal beds are different in thickness, an estimate of as great as 5000 feet could be obtained. Prob- ably the truth is somewhere between the figures just given, and it is probable that the original thickness of the dolomite is probably somewhere between 1000 and 1500 feet.

The dolomite formation is nowhere seen in actual contact with the Sturgeon quartzite, nor are any of the formations seen in close proximity. It is known, however, that the upper layers of the quartzite are calcareous and that the lower beds of the dolomite are quartzite. The inference seems to be that the two formations are com- formable, and that they grade into each other.

Contacts between the dolomite and the over- lying formation are found in many of the mines, but they are nowhere pronounced on the surface. In the Little Bearmin east of the old Bear Hill mine, the contact is marked by an iron formation are very close together, but their actual contact is covered. The space between the beds of two formations is filled with loose fragments, and among these fragments are large pieces of quartzite bedding pavements of jasper, chert, and other members of the Archean. The presence of the jaspilite frag- ments in the conglomerate is proof that beneath they pass somewhere in the Lower Mesonias series an iron formation containing considerable jasper. This formation has now completely or almost completely disappeared, so far as the surface indications show. It is assumed that it has been cut away by erosion, and that its debris furnished the jaspilite frag- ments in the conglomerate.

In the mines and the open pits a similar com- plex formation is more frequent found lying upon the dolomite. Jaspilite fragments not in all places be detected in it, but they can be observed in so many localities that the only acceptable interpretation of the phenomena is that the dolomite and the quartzite are separated by an unconformity. The boundary between the two rocks is sharp. There is no gradation of any kind between them. The dolomite near the con- tact is usually schistose, so much so that in most cases it is a pure talc schist. The schist of the dolomite has been removed and much of it has been deposited in the ore bodies as calcite, while the magnesium has remained in the talc. This talc-schist serves as a marker bed, the mica is parallel to the bedding in the rocks in which the ore deposits lie, and afforded better conditions for the concentration of the ore matter. The schist is marked by the massive and shat- tered dolomite underlying the ore formation at various places. The schist was probably formed by the injection of the contact along the contact phase after the Upper Huerocka deposits were
laid down, and contemporaneously with the folding and metamorphism that affected both the Lower Memnonius and the Mesozoic strata. The contact between the schist and the superjacent quartzite is extremely sharp, and in many places the plane of contact is alkali-sericitized.

The principal area of the Vulcan formation extends as a belt from 900 to 1500 feet wide along the southern side of the northernmost schist belt and forms a horizon of dolomite for nearly its entire extent. The belt follows the sinuosity of the southern border of the valley and extends rather closely, but it is much wider in the reentrant caused by the pitching synclines of the dolomite and is limited to a width of 4 to 5 miles. The evidence that the formation is a horizon at these places is of course due to the repetition of beds in consequence of close folding. Along only one stretch, about a mile in length, is the iron formation known to be absent. This is in the west half of sec. 1 and the east half of sec. 3, T. 39 N., R. 20 W., at the western extremity of the belt. These pits have shown the presence of iron ore associated with white, jaspilite, and black slates. The chimneys are filled with the "shouts and bands" of one characteristic of the chimneys in the northwestern part of the area and the jaspilite of the Curry member. In this case the rocks are believed to belong to the Curry horizon.

In the neighborhood of the Loreto mine the Vulcan formation appears to occupy the entire breadth between the north and south of the northernmost belt of dolomite and the south side of the northwesternmost belt of this rock. A short portion of the ore formation has not been explored, but all that portion which has been open by the Loreto and Sundog docks reveals the presence of one of the other members of the Vulcan formation. Of the area east of the Appleton mine nothing is known, and it is probable that the underlying rock is here covered with its deposits of sand and sandstone.

The other areas in which the Vulcan formation is found border the Quinnesec schists. From the order of succession on the northern side of the Memnonius and the contact on the southern side of the trough in passing north from the Quinnesec schists of the Memnonius, we have the following formations: (1) the Sturgeon quartzite, (2) the Randvale dolomite, (3) the Vulcan formation, and (4) the Hambury dolomite. Indeed, as far as the northernmost exposures of the schists no outcrop of any formation have been found. This belt is left doubtful on the map. Since the Sturgeon quartzite and the Randvale dolomite are hard, resistant formations, probably much more resistant than the Quinnesec schists, it is thought that they will probably not rest upon the schist. Therefore, if the Hambury schist does not occupy the double belt, this area is probably underlain by the Vulcan iron-bearing formation. The direction of movement of the glacial drift was from the northwest toward the southwest. The Quinnesec schists occupy high ground, and therefore heavy masses of drift were banked against the northern border of the Sturgeon quartzite. This is believed to be the reason for the absence of exposures in this belt. No opinion is expressed as to whether or not the Vulcan formation occupies this belt or is causing the absence noted, but it is the intention to make a careful magnetic survey of the area of the belt in question, in order, if possible, to ascertain whether this strip of country is probably underlain by the Vulcan formation or the Hambury schist.

The situation is nearly similar about the western area of Quinnesec schists. Only two exposures are known as close as 600 feet from the schist belt, but the exposure of the schist is unquestionably an exposure of Hambury schist. The other is a feruginous schist that resembles very closely some of the horizontal strata of the Upper Memnonius in this belt. These are exposed both on the south side of the schist belt, and are more than 4 miles apart. As far as the writer can ascertain nothing is known of the geology of the intervening strip of country.

This area is so deeply buried under sand and gravel that we are not even certain that the northernmost schists have been exposed. Our final report will probably be to the writer's intention to make a careful magnetic survey of the area of the belt in question, in order, if possible, to ascertain whether this strip of country is probably underlain by the Vulcan formation or the Hambury schist.

Typical occurrences of the ore-bearing quartzites and conglomerates may be seen at the open pits of the Randvale mine and at the front of the exterior face of the Penn Iron Co., in the 1W. 5E. of the NW. 1 sec. 10, T. 39 N., R. 20 W.

The conglomerates and quartzites pass upward into the feruginous quartzite series. These consist of alternating layers of barytic feruginous quartzites, iron oxides, and in some cases jaspilites. The quartzite layers are dark red or purple jaspilite beds, from a fraction of an inch to 18 inches or 2 feet in thickness. Some of them are fresh and exhibit the quartzitic texture very plainly. The coarser of them approach feruginous quartzites. Others, however, resemble the finest of a closely jointed jaspilite, in which some cases they are believed to be. These varieties are often petrified by red and purple blotches that resemble the brownish red jaspilites of some ferruginous quartzite matrix. In the greater number of cases the matrix is in thin beds and the rock possesses a certain incipient schistosity in the direction of the longer axes of the areas. This phenomenon is the result of the most rapid exsolution of the jaspilites. The iron and smaller components of the quartzite matrix, producing a parallel arrangement of the jaspilites. It determines with certainty the relative amount of the detrital material and true jaspilite which is non-ferrigenous, as the thinness of the matrix is a factor, the former is more abundant, and it may be dominant.
The associated iron oxides usually occur in beds no thicker than the quartzo-ferruginous layers. At various places, hematite occurs as thin plates of hematite arranged in parallel positions. On fractured surfaces along schistose planes, especially when the surfaces have been slightly weathered, there is noticeable a peculiar texture that possesses considerable significance. On such surfaces a distinction can be made out between a fine-grained matrix and numerous comparatively large oval or elliptical areas. The latter give uniform reflection from the schist or schistose beds of small grains. This texture is characteristic of fragmental sediments.

The quartzite bands are thickly teneult they usually take on a different character. These lose their marked specular habit and become granular, and their usual color changes to a dark blue or black. The changes from thin beds to thick, and from a granular habit to a more massive one, are not due to normal weathering. Such beds are covered by a more massive one, there is nothing remarkable about the presence of the matrix that reflects from many small surfaces. The appearance thus produced is that of a number of large flattened grains in a matrix of small grains. This texture is characteristic of fragmental sediments.

The ferruginous quartzites are generally free from chlorite and other substances that change to a dark blue or black. The changes from thin beds to thick, and from a granular habit to a more massive one, are due to normal weathering. Such beds are covered by a more massive one, there is nothing remarkable about the presence of the matrix that reflects from many small surfaces. The appearance thus produced is that of a number of large flattened grains in a matrix of small grains. This texture is characteristic of fragmental sediments.
the iron-bearing formation stretches as a narrow belt which for much of the distance appears to be without important fossiliferous sections from the base of the productive portion of the Traders member to the top of the basalt, and at a few places the sections extend downward to the top of the Randville dolomite. At Brier Hill, where practically the whole formation can be seen on the surface, its thickness is about 600 feet. At the Curry mine its thickness is about 675 feet. At a number of sections the thickness of the individual beds is much more readily measured. The Brier slates have been measured at seven places, yielding results between 190 and 260 feet. Five of these measurements fall between 250 and 360 feet. Eight measurements of the Curry mine have given results between 600 and 725 feet. Six of these fall between 160 and 250 feet. Measurements of the Traders member have exclusive of the Randville beds are given at two points. At the first place, its thickness probably varies widely, as should be expected of a formation composed largely of detrital deposits formed near shore line. Moreover, only a few sections reach as low as the dolomite. Hence, the exact position of the upper surface of the Traders formation must be guessed at. Only three measurements have been made from the known top of the dolomite to the known top of the Traders member. These give 170, 85, and 135 feet.

The opportunities for accurate determinations of the thickness of the Vulcan formation in the southern iron-bearing belt west of North Lake Antoine are very poor. In both of these areas folding is more prominent than it is in the northern part of the field, and where folding is not prominent exposures are lacking. In the Pecos mine a measured section along a drift in the first zone of the Traders member gave 393 feet for the Traders member and 365 feet for the Brier slates. At the Traders mine 195 feet of the Traders member are exposed, and the lower 25 feet of the top of this member and the supposed position of the base of the Hanbury slate corresponds to a thickness of 490 feet for the Brier slates and 235 feet for the Vulcan formation. At the Brier Hill mine the thickness of the entire Vulcan formation is about 500 feet.

An interesting feature of these figures appears when we compare the estimated thickness of the Brier and the Curry members with the true thicknesses. In almost every case where the estimated thickness of either of these members falls below the average or less than the average, the thickness of the other formation exceeds the average, and the total of the two is fairly constant. For example, the measurements of the thickness of the Brier slates vary between 240 feet and 500 feet, and eight estimates for the Curry member vary between 112 feet and 225 feet, and measurements of the thickness of the two vary only between 480 and 580 feet. The apparent greater variation in the thickness of each of the members than the two combined may be partly explained as due to the graduation between the two and the consequence of the difficulty of the iron-carrying formation on the exact place at which one ends and the other begins.

A careful consideration of the figures given above and a few others that are not here recorded, it is estimated that the average thickness of the Vulcan formation is approximately 650 feet, divided as follows: Traders member, 100 feet; Brier slates, 230 feet; Curry member, 110 feet; i.e., the two ore-bearing members combined about equal in thickness the intervening slates. It is conceded, however, that the Traders member departs considerably from this average and that the total thickness of the formation varies accordingly.

Between the Vulcan formation and the adjacent formations.—The Vulcan iron-bearing formation, except in very limited areas, rests upon the Randville dolomite. At the Curry mine it appears to rest upon the Negro iron-bearing formation.
were still above the sea during Vulcanian time. The gradual approach of the base of the Hanbury slates to the lower formation at such places and the presence of conglomerates at the base of the Hanbury slates are likewise made clear. There- fore, with great confidence, we are led to the second explanation—that of unconformity between the Lower Menominee and the Upper Menominee series, with a gradual advance of the Upper Menominee sea, the deposits of which slowly overlapped the earlier deposits and gradually buried the higher beds of the Lower Menominee series. There are therefore in this district all the evidences of a great unconformity between the Upper Menominee series and the Hanbury slates, and in the Huronian of the Marquette district and other districts of the Lake Superior region, except that of marked discordance in strike and dip between the upper and lower series. This lack of discordance does not in the least invalidate the conclusion that a great time gap separates the two series. It has been shown by the senior author that as apparently minor unconformity may mark a greater time interval as the most startling discordance. The relations of the two series in the Menominee district are very similar to those existing in the Penokee district between the cherty limestones of the Lower Huronian and the Upper Huronian quartzite member.

The Iron-ore Deposits.

General relations. The iron ores of the Menominee district occur in two members, from the base upward as follows: (1) The Trudgers member of the Vulcan formation, and (2) the Curry member of the Vulcan formation. The iron ores may occur at any horizon within these members. However, other things being equal, they are more likely to occur at lower and higher horizons than at middle horizons in each of the members, but a number of the large ore bodies extend entirely across the members in which they occur.

It will be explained that the iron-ore deposits occur at places where downward-moving waters are conveyed. Of these places, pitching troughs with impervious basements are the most important. Therefore, the iron-ore deposits of large size are upon relatively impervious formations, which are in such positions as to constitute pitching troughs. A pitching trough may be made (a) by the dolomite formation underlying the Trudgers member of the Vulcan formation, (b) by a slate constituting the lower part of the Trudgers member, and (c) by the Bier slate between the Trudgers and Curry members of the Vulcan formation. The dolomite formation is especially likely to furnish an impervious basement where its upper horizon has been transformed into a talc-schist, as a consequence of folding and shearing between the formations. While all the large iron-ore bodies are confined to pitching troughs with impervious bases, the smaller ore deposits occur at contacts between the different members. These contacts are favorable places for the concentration of ore because they are horizons along which important slipping or differential movement has occurred during the folding of the district. Wherever a set of beds is folded, there must be differential movement among them. This is well illustrated by the slipping of the leaves of a flexible book over one another when the book is bent. In nature the contact planes between formations of different characters are always planes of weakness, hence at such places the major movements take place.

These movements are sure to make the formations porous and thus produce main channels of percolating water; hence the frequent presence of ore bodies at the contact planes. Still smaller ore deposits are found where faulting has occurred or where close proximity has isolated the Vulcan formation. Such occurrences furnish ore zones of areas where percolating waters are conveyed into larger channels and thus favor the concentration of the iron oxide.

The combination of two or all of these conditions is more favorable than any one of them. Where the conditions are such as to combine pitching troughs with impervious basements, con-

Vulcan formation, each bay being surrounded on the north, south, and east by the dolomite. Beginning at the west, the first and most important set of folds of the second order are those order, beginning at the west, the Chapin mine should be first mentioned, but the interpretation of the occurrence of the ore at the Chapin depends upon the facts furnished by the Walpole and

Fig. 1.—Horizontal section of the Walpole mine at the third level. Scale: 1 inch = 50 feet.

The Chapin, Millis, and Walpole mines are located. The eastern bordure produces the trough in which the Pemalite mine is located. The western trough is especially complicated, being really composed of two minor troughs or folds of the third order, with an intervening antiformal, and even these folds have folds of a higher order superimposed upon them. If one were to follow a geographical and successional formation from the limestone to the Bier slate in places where folding is a very complicated character.

The Pemalite mine is a single, closely appressed,
syndial fold (fig. 5). The slate and dolomite are here again found on the north, east, south, and bottom of the ore body. However, on the south limb of the fold the ore bearing member does not appear between the dolomite and the Brier slate. It has therefore been augured out by the very great pressure, or else slight faulting has taken place. A crosscut north in the first level from the Traders ore bearing bed to the limestone shows several repeated sets of the footwall slates, the quartzite, and the iron-bearing members, those being found in narrow bands. The reduplications are regarded as due to very close subordinate folding.

At the present time the workings of the Chapin mine have not been extended beyond the Chapin body of ore. However, two main beds of ore have been developed in the Chapin, and it is believed that these two beds will be found to correspond with the two closely appressed, westward pitching folds of the Walpole. North of the northern ore body is a succession of slates, quartzites, and thin beds of iron-bearing formation similar to that south of the Peabody mine. Immediately north of this ore body is a slate similar to that of the Walpole and Peabody. Slate also occurs in the middle of the ore bodies. Further, slate bounds the southern lens of ore on the south. South of this slate is iron-bearing formation, and south of this are slate beds and quartzites. There is every reason to believe that when the workings extend sufficiently deep the ore bodies will be found to be underlain by slate also, as well as bounded by slate on the north and south. The ore beds are cross section given is bounded by slate above as well as below. The explanation of this anomaly is probably that the compression was so severe that the center of the soft syncline of ore at the top was actually pinched out, the slate on each side of the ore coming together.

It is impossible at present to be absolutely sure as to the horizon at which the great lenses of ore of the Chapin belong. Since, however, the relations of the ore bodies to the surrounding rocks and the Chapin are parallel in many particulars to the occurrence at the Walpole mine, it is thought that the two ore beds belong to the Traders member of the iron-bearing formation, that member being repeated by close folding. According to this explanation, each of the two ore beds would constitute an isocline syncline, and the slates between them would be antithetical; also the slate between the southern lens of ore and the southern belt of iron-bearing formations would be an antcline. This would fit the southern iron-bearing belt, in which no ore bodies have been found, as Traders. The slates and quartzites south of this would be Brier. Therefore, the southern belt of iron-bearing formation is regarded as a monocline rather than as an isocline syncline. This is explained by the apparent absence of ore bodies in it. Where Iron Mountain belongs, which gives its name to the locality, the ore is scarce, and in pitching troughs on impervious basements furn-ished by the district. Just east of the Aragon mine, there is a sharp embayment which is a certain amount of fuscous and siliceous slate, which, until the demands for low grade, non-phosphoric ore arose, could not be mined; but the last summer a large amount of this lean material was exploited.

The Aragon mine has been the source of a large number of ore bodies of which have been rep-licated three times, not to mention the minor duplications north of the southern lens of ore, it was at the top of the Traders member of the ore formation, just below the bottom of the Brier slate (see fig. 6). At this time no one could have predicted that this ore body is really related to the impervious talschists of the dolomite below. However, as mining continued, the ore deposit, from the Curry mine that the term Curry member is taken. The ore of the lower horizon now being exploited occurs immediately below the Brier slate, at the top of the Traders member. The ore of the higher horizon occurs in the Curry member between the Brier slates and the Hasbury slate, extending from one to the other (see figs. 9 and 10). Development has not yet gone far enough to show whether minor folds occur in these slates, as the result of which pitching troughs will be found. However, the three contacts of the two iron-bearing belts with the Brier and Hasbury slates are planes along which movement and brecciation have occurred, and therefore where pervading waters have been active. These ore bodies have a considerable longitudinal extent, but has not yet been shown great width. The southern deposit of the West Vulcan shows very well the relation between sharp folding, and therefore brecci-ation, and different elemental movement between the iron-bearing member and Brier and Hanbury slates. Here, at the east end of the mine, in a very sharp fold in the slate and iron-bearing member (see fig. 9). The Traders member, where ore was first mined in this vicinity, shows beautifully the effect of sharp pinch and brecciation of the ore-bearing formation. Here was a continuous zone of movement. As a result, an almost continuous narrow belt of ore was con-"
wide ore bodies have not yet been developed, apparently because impervious basements are still lacking.

East of the East Vulcan mine the dolomite formation appears to extend as a continuous straight belt to the eastern end of the district, no subordinate folds being indicated by resistant streaks in the southern border of the dolomite. Corresponding with this, no healthily is that adjacent to Loretto, where are found the Loretto mine and the Appleton shaft.

Here the northern and southern belts of dolomite probably join (see map), giving continuous dolomite from the Surgeon quartzite on the north to the southern iron-bearing belt on the south. East of this subdivision, the northern and southern belts of dolomite, is the Vulcan iron formation.

Fig. 8.—Vertical east-west longitudinal section of the Amsden mine, north fold. Scale: 1 inch = 20 feet.

ore bodies have yet been discovered except at Wauzelish, where a comparatively small deposit of ore has been found. It is by no means certain that pilferings of the dolomite between East Vulcan and Wauzelish, furnishing pitching troughs, do not occur, but if they exist the outcrops are not sufficient to indicate them.

2. Posing now to the second belt of the Vulcan formation, that adjacent to the central belt of dolomite, the only mines which are at present worked are the Traders and Cuff. The Traders mine is near the west end of the ore-bearing formation, which in this vicinity constitutes a westward pitching syncline. However, there is a subordinate synclinal axis in the anticlinal, as a result of which the Hanbury slates are blanked away eastward toward the angle. It is in this westward pitching syncline that the concentration of the Traders ore has taken place. The foot wall is a heavily farrugious slate, which, however, differs sufficiently from the profitable ore to present a relatively impervious basement. But this syncline is not nearly so sharply defined as are the synclines which contain the larger ore deposits on the southern belt of the Vulcan formation. A consequence of this, probably, the ore is rather high in silica. The percolating waters have not been sufficiently converged to remove this constituent to the extent to which it was dissolved in the better-defined troughs (see pp. 3-5).

3. The only remaining important ore-producing outline of the ore body (see fig. 11). The outer limit of the deposit makes a broad arc which passes east of the foot and almost to the east of the body of ore being to the west. The cross section of the main ore deposit also makes a wide arc, in the southern limb of the basin, which passes into a sharp syncline south at the angle. In consequence, a lens material is found east of the syncline. This material passes into ore under the slate capping and is found under the drift west of the slates. The failure of the rock to change to ore is apparently due to a syncline axis, which is not observed in the cross section of the ore. The presence of the convergence of downward moving currents of water, and therefore the transformation of the rock into ore, has not been taken place. No better illustration of an ore body is possible. In the present development the basis of the syncline is the most abundant, which is much iron-bearing limestones. The features which constitute a considerable portion of the ore, and are elsewhere in the Lake Superior region, are here combined with the iron ore. The concentration of the ore has been inferred to have been mainly iron carbonate. In spite of the fact that the conditions under which the ore bed was formed are more abundant, but in all cases the ore has been collected for the secondary enrichment by underground waters through the addition of iron oxides and the abstraction of silica in the material which is not iron ore. The evidence of this lies in the fact that the ore bodies are universally confined to the places where underground waters have been pervading into ore bodies, it is necessary that it should have continued for a long period during progressive denudation. Many of the large ore bodies known in the district somewhere reach the surface. The secondary material now found near the surface is largely derived from the Vulcan and Hanbury formations, which were once at the surface, and which since have been removed by erosion.

Future prospects—Up to the area of the ore bodies has been very conservatively represented. The area mapped as Vulcan formation is not only the most valuable, but the least productive. The long belts of doubtful materials south, adjacent to the northern and central belts of ore bodies, and the northern side of the southern belt of dolomite may be underlain in whole or in part by the Vulcan formation, which may be expected to have a similar origin to the latter. The iron-carbonates of this formation are the source of iron. The Hanbury and Vulcan formations, which are rich in iron ore deposits have been found in the Hanbury slate, the siderite ore has not been found, and the iron ore bodies are of the iron-carbonates in the Vulcan formation.

The iron oxides in the Hanbury formation are more abundant at low horizons than at high horizons—"that is, more plentiful adjacent to the Vulcan formation. The following facts render it highly probable that percolating waters within the Hanbury formation took up iron carbonate, passed down into the Vulcan formation, and thus contributed iron-bearing solutions for the enrichment of the ore bodies.

The chemical reactions depend upon the mingling of waters containing oxygen with those containing iron oxides. The waters following circulatory routes, and especially if the iron oxides were deposited through the Hanbury slates, had their oxygen abstracted by the iron carbonate in an early stage of their journey. In reaching the surface the waters, enriched by the action of the Vulcan formation, contained little iron carbonate, at least in the later stage of the process, retained their oxygen. The waters bearing iron carbonate and oxygen were thus converted to iron oxide. Furthermore, the great quantity of downward moving water, converged into the ore bodies, is less in solution and transported to underground waters, and thus abstracted this deleterious element, its place being taken by the deposited iron oxides.

Therefore the iron oxide of an ore body consists in part of iron compounds originally deposited in situ and in part of iron brought in by underground waters. Which of the two constituents of the ore are, the original material or that derived from underground waters, the average is more abundant it is impossible to say. In some cases it is almost certain that the original detrital iron carbonate was not abundant, and in other cases that the material added by underground water is more abundant; but in all cases it may be inferred that some of the iron was of the secondary enrich ment by underground waters through the addition of iron oxides and the abstraction of silica, the material which was not iron ore. The evidence of this lies in the fact that the ore bodies are universally confined to the places where underground waters have been pervading into ore bodies. In order that this process should have produced the large ore bodies, it is necessary that it should have continued for a long period during progressive denudation. Many of the large ore bodies known in the district somewhere reach the surface. The secondary material now found near the surface is largely derived from the Vulcan and Hanbury formations, which were once at the surface, and which since have been removed by erosion.
northern dolomite. It is highly probable that the iron formation extends for some distance to the west of the line which, so far at least, is known to belong to the Vansem formation, but how far it is impossible to state.

The belts in which the white to grayish dolomite of the Menemón district is not strongly magnetic, but it is generally somewhat so, and it is thought to be probable that a similar change of formation may possibly exist over a great part of the Menemón district. As the iron formation is known to extend beyond the Vansem formation, it has therefore been assumed that a similar change of formation may possibly exist over a great part of the Menemón district.

The iron formation is known to exist, the rules for explorations being very clear. All, or nearly all, of the ore deposits that have been found so far are within a distance of about ten miles from the line of the iron formation. The iron formation is known to extend westward to the Menemón district, and in this district it is known to be strongly magnetic. It is thought to be probable that a similar change of formation may possibly exist over a great part of the Menemón district.

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OUTLINE OF GEOLOGIC HISTORY.

FORMATION.

Before giving a brief outline of the history of the district, it may be well to recall the general characteristics and physiographic features of the district. The district is bounded by areas of Archean schists and granites. The Archean sediments of the district are in a trough between these older rocks. Structurally this trough is a synclinal, composed of several important antithetic and synclinal folds. The Lower Mone'min series comprises 1095 to 1520 feet of quartzites and conglomerates that have been called the Sturgeon quartzite. The uppermost 500 feet of these beds, subordinated amounts of conglomerate and slate, and designated the Randville dolomite, and small patches of the Negaunee iron-bearing formation. The Upper Mone'min series comprises the Vulcan formation, 650 feet thick, and the Ham.


dolomite and conglomerate that may have been the case in the Mone'min district. The evidence is not found in the Mone'min area, but in other areas of the region, notably the Marquette district, where the inter-Moné'minogenic movements and deposition were of a most pronounced character. As soon as the Mone'min area rose above the water erosion began, and continued until all but remnants of the Negaunee formation had been removed from the central and northern parts of the district, and probably also all of the Lower Mone'min formations which existed were eroded from the part of the district adjacent to the Quinzeanubit. However, as has already been said, these schist areas have been above water during much of Lower Mone'min time, in which it would be unlikely that such a condition would be proved.

Lower Mone'min deposition. — By transgression of the sea, due to subsidence of the land or rise of the sea level, the area in which the district is located was finally covered by water, and Lower Mone'min Algoman deposition began. Originally the sediments were laid down as a set of approximately horizontally beds on a basement composed of Archean rocks similar to, if not identical with, the material constituting the rim of the trough. The first deposit of the advancing sea was the basalt conglomerate of the Sturgeon quartzite, marked by pebbles of basalt and dolomite, which later was consolidated into quartzite. The deposition of a considerable thickness of rocks which all together were largely of marine origin, and included in this zone, there is every reason to believe that the original form of the material was an ordinary siltaceous limestone. The time represented by the Randville dolomite was probably long, for the thickness of limestones deposited was 1000 feet or more. Possibly as a result of upbuilding with shallowing of the sea, or other unknown conditions, the carbonates being deposited changed in character and bye a large increase in the content of dolomite. At this time the current bearing carbonate was produced. Later these were transformed into the trough of the Randville quartzite and cherts and shales of the Negaunee formation. Whether or not later formations were deposited during Lower Mone'min time upon the Negaunee formation is uncertain. The formations of the Lower Mone'min series were certainly deposited over a considerable area in the Mone'min district, and the equivalents of these formations were deposited upon the Quinzeanubit schist is uncertain. It is possible that these sediments were laid down during a large part of Lower Mone'min time, and that the iron for the Negaunee formation was derived from the inter-Mone'minogenic formations bordering the district mapped. The apparent entire absence of the Lower Mone'min formations of the western area of Quinzeanubit schist district is due to the fact that the exposures for this area, and possibly for the southern area, is that the Lower Mone'min formations were not deposited and were subsequently removed by erosion. These formations, resting upon the Quinzeanubit schists, might have been deposed over an area of iron material that the resistant formations adjacent to the granite area on the north side of the trough, and therefore may have been more readily eroded.

In any case it is highly probably that the different formations were not deposited in uniformly the same period of time. The district, if all the formations, or the lower ones, were not deposited upon the Quinzeanubit schist, each higher stratum overlapped the one next below it in passing toward the land areas of Quinzeanubit rocks.

Inter-Mone'minogenic unconformity. — Following the deposition of Lower Mone'min formations the time of the district was raised above the sea. Apparently this uplift was accompanied by only slight deformation. The effect of this relief on the Mone'min area is apparent in the form of a synclinal, with the axis of the trough parallel to the trend.
formation. The deposition of the Hatbury slates required a long time, during which the physical conditions were precarious, for minute parts of the original stromatolite colonies are without doubt the result of the slow deposition of the Hatbury slates, and the rate of the process was probably very slow, given the geographic setting of the area.

**Faulting and metamorphism.**—Following the deposition of the Upper Memnonite zone the area was again raised above the sea and was subjected to very great tectonic forces. The major compressive force was nearly north-south. As a result of the compression, the two great folds forming the northern and southern parts of the area, a great central synclinorium containing the Memnonite trough proper. The northern and southern anticlines necessarily expose the oldest, or Archean, rocks. The intermedial synclinorium is occupied by the basement sediments.

**Post-Paleozoic history.**—Following the Paleozoic period of deposition the area was again elevated above the sea, and then another long period of denudation began. So great was this erosion period continued until late in Cretaceous time. Possibly later Creaceous sediments were laid down over the Memnonite area, but in any case, following Cretaceous time, the area was again raised above the sea, and so far as we know, denudation has since continued. Nearly all of the Silurian limestones has now been removed from the district, and only a subarcuate sandstone, with the overlying sandstone, remains covering the higher parts and filling the depressions in some of the subarcuate valleys. During this period of erosion the present topography of the district was largely produced. To what extent this topography follows the pre-Caribbean topography is not certain, but it is probable that some of the post-Caribbean topography has had an important influence upon present topography. As a result of this topography the two great unconformity of the district was largely produced. To what extent this topography follows the pre-Caribbean topography is uncertain, but it is probable that some of the post-Caribbean topography has had an important influence upon present topography. As a result of this topography the two great unconformities are as follows:

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<thead>
<tr>
<th>District</th>
<th>unconformity</th>
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<tbody>
<tr>
<td>Memnonite</td>
<td>Upper Cretaceous</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Lower Cretaceous</td>
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<tr>
<td>Memnonite</td>
<td>Upper Jurassic</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Lower Jurassic</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Lower Devonian</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Upper Devonian</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Lower Carboniferous</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Upper Carboniferous</td>
</tr>
<tr>
<td>Memnonite</td>
<td>Lower Carboniferous</td>
</tr>
</tbody>
</table>

**Depositional succession in the Penokee, Marquette, Sandstone district.**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Upper Devonian</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<td>Memnonite</td>
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</tbody>
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**Depositional succession in the Crystal Falls, Menominee, and Sandstone districts.**

<table>
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<tr>
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</tr>
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<tbody>
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</tr>
</tbody>
</table>

In all the districts the upper Memnonite is represented by the Penokee by the upper Memnonite, largely non-clastic, and by the Marquette by the lower Memnonite, which is non-clastic. In the Crystal Falls district the lower Memnonite is represented by the Archaeon, and the upper Memnonite is represented by the Menominee. The lower part of the Memnonite is non-clastic, but the upper part is entirely clastic. In the Crystal Falls district the lower Memnonite is represented by the Archaeon, and the upper Memnonite is represented by the Menominee. The lower part of the Memnonite is non-clastic, but the upper part is entirely clastic.
the Briar slate and the Traders iron-bearing member. Here the detrital ores appear because of the encroachment of the sea before the Negansse iron-bearing formation was removed. However, thick beds of quartzite are generally absent, and this is explained in the same manner as in the Crystal Falls district—that is, the formation was deposited upon a dolomite rather than upon silicious formations.

If it were possible to map in each of the four districts each member which is recognized, the apparent discontinuities in the succession of the Upper Huronian would be much less prominent. Indeed, where volcanic rocks are absent the succession would be found to correspond almost exactly. However, a given formation would be very important in one district and comparatively unimportant in another. Moreover, where volcanism has disturbed the succession, as in the eastern end of the Penokee district and in the Crystal Falls district, the orderly succession is not readily recognized.

The discrepancies of the successions in the Lower Huronian series are greater than those in the Upper Huronian. As already noted, in the Penokee district all the members above the Cherty limestone were removed during the time of inter-Huronian erosion. In the Menominee district the Negansse formation was all but removed at the erosion period. In the Menominee district only one formation, the Randville dolomite, has been discriminated between the Negansse formation and the Stringer quartzite; whereas in the Marquette district four formations, the Slano slate, Ajaia quartzite, Wvere slate, and Kosia dolomite, are found; and in the Crystal Falls district two, the Homlock volcanic formation and the Randville dolomite. The formations which are present in the Marquette and Crystal Falls districts and are not found in the Menominee district are all clastic and volcanic formations. The inference is that in the Menominee district quiescent physical conditions favorable to limestone deposition were long continued. The Randville dolomite was there laid down during the time of the deposition of the limestone formations and the fragmental and volcanic sediments between the limestone and the Negansse formations in the Crystal Falls and Marquette districts. This is shown to be highly probable by the relations within the Crystal Falls district. In the eastern part of that district the Randville dolomite is a thick formation, and there no volcanics are found, whereas in the western part of the district the limestone deposit is very thin and there is a great volcanic formation standing in an equivalent position. In the Marquette district, also, changing physical conditions combined with volcanism explain the deposition of the clastic sediments and volcanic formations between the Kosia dolomite and the Negansse iron formation.

The attempts to correlate the various formations of the two Huronian series in the four different iron-bearing districts south of Lake Superior shows very significantly that the geologic history of pre-Cambrian time was extraordinarily complex. From Archean to Cambrian time, in the Marquette-Crystal Falls and Menominee districts, the areas three times emerged from the sea and were three times overidden by the sea. In the Penokee district there was a fourth emergence and transgression of the sea. The epigenetic or land-making movements were accompanied by orogenic movements, or mountain growths, of varying power, but some of them exceedingly intense. In Huronian time, in all the districts except the Menominee, there were important and long-continued periods of volcanism. The great events of Keweenawan time are only mentioned, since they do not particularly concern the Menominee district. The erosive forces at periods when the districts were land areas found rocks of very different characters. Here they were resistant, there easily denuded. As a consequence, when the sea encroached at the close of Archean, Lower Huronian, and Upper Huronian times, the country is detail was very irregular—was in fact bluffly, but not moun-

Tous in. Therefore certain areas were covered by the sea, while other immediately adjacent areas were above the water and were being actively eroded. As a consequence of all these complex conditions we have unconformity, overl

Tous in. Changes in the characters of contemporaneous sediments along the strike and across the strike, disturbances in the successions due to volcanism, cleavage folding and attendant metasomatism, and all of these phenomena in a region which is largely covered by glacial drift.

CHARLES RICHARD VAN HISE,
WILLIAM SHIRLEY BAYLEY,
\begin{ italicize \end{ italicize} \end{ quotation}

March, 1906.
forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels, the wash of which left of the section, is the aceticite ridge of sand and gravel, known as eons, or eons, and kamos. The material deposited in these tunnel is called glacial drift, that washed from the ice onto the adjacent land is called modified drift. It is usual to class as surfer food the wash of the sea and the streams that were made at the same time as the ice deposits.

**Ages of Rocks**

Rocks are further distinguished according to their relative ages, for they were not formed at one time, but from age to age in the earth's history. Classification by age is independent of origin, igneous, sedimentary, and surface rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to treat the mass throughout its extent as a formation, and such a formation is the unit of geologic mapping. Several formations considered together are designated a system. The time taken for the deposition of a formation is called a geologic period, and the time taken for that of a system, or some larger unit of geologic time, is called the eras. Periods are then mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for their deposition are the same, and the same age, for instance, Cambrian system, Cretaceous period.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be discovered by observing their relative positions. This relationship holds except in regions of intense disturbance; sometimes in such regions the disturbance of the beds of one formation may be in its position is reversed, and it is often difficult to determine the relative ages of the beds from their positions, then, formations of plants and animals are guides to which of two or more formations is the oldest.

Strata often contain masses of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in superficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of the fossils recorded of the same age have often be found in different localities. Out of these, the simpler kinds of marine life existed in different fossiliferous rocks were deposited. From time to time new complex kinds developed, and as the simpler ones lived in modern times, the age of variegated. But during each period there lived peculiar forms, which did not exist at earlier times and that these are characteristic, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present.

When two formations are remote from one another and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains found in the rocks of different areas, provinces, and continents, afford the most important means for combining local histories into a general earth history.

**渍陆eology**

The section shows the relative ages of strata, the history of the sedimentary rocks in divided into periods. The names of the periods in proper order (from old to new), are the Cambrian, the Ordovician, the Silurian, the Devonian, the Mississippian, and the Pennsylvania. Each of these periods is divided into epochs or stages, and the epochs and stages are further divided into time units called systems. Each of these systems has its own characteristic fossils, and these fossils are used in geologic stratigraphy, and are arranged as for the appropriate period names.

To distinguish the stratigraphic formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate province, with an example of the first (Pleistocene) and the last (Oligocene). The formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, and the period is called the period or color used: a pale blue (the underprint) and a yellow print very evenly over the whole surface representing the relations. The arrangement of rocks in the earth is the earth's structure, and a section exhibiting this arrangement is called a structural section.

In strata the natural and artificial cuttings for his information concerning the earth's structure. Knowing the character of the strata, the stratotype, or the strata, which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting what could to the unaided eye can be seen in the side of the cutting can miles long and several thousand feet deep. This is illustrated in the following figure:

**Fig. 2—Sketch showing a vertical section in the strata of the gossan, with a landscape behind.**

This shows a landscape which is cut off sharply in the foreground by a vertical plane that cuts a section so as to show the underground relations of the rocks.

The kind of rocks are indicated in the section by appropriate symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the common kinds of rock:

**Fig. 3—Symbols used to represent different kinds of rock.**

**Fig. 4—Syntactic section.**—This section contains a composite sketch of the rock formations which occur in the quadrangle. The diagrams and verbal statements form a summary of the facts which appear to be the result of the sections, to the thickness of the formations, and to the order of accumulation of successive deposits.

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**Fig. 2—Sketch showing a vertical section in the strata of the gossan, with a landscape behind.**

The palest land is shown toward the lower land an escarpment, or front, which is made up of the cliffs and the edge underestimating the slopes, as shown at the extreme left of the section.

The broad belt of lower land is traversed by several ridges which are seen in the section to correspond to the basic forms of sandstone that rise to the surface. The uppermost edges of these form the ridges, and the intermediate valleys follow the contours of limestone and sandstone ridges. Where the edge of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred.

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