GEOLOGICAL SURVEY OF MICHIGAN.

UPPER PENINSULA
1869-1873
ACCOMPANIED BY AN
ATLAS OF MAPS.

VOL. I.
PART I.
IRON-BEARING ROCKS (ECONOMIC).
[cont'd.]

BY
T. B. BROOKS.

MEMORANDUM.—It has been deemed advisable that the Appendices, referred to in this Part, should be issued separately as Vol. II.

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CHAPTER V.
MENOMINEE IRON REGION.*

THE centre of this region is about 40 miles west by north from Escanaba, 50 miles south-west from Marquette, and 5° miles north from Menominee, as the bird flies. (See Map, No. II.) The area known to bear iron is embraced within a square of 16 miles, being portions of Towns 39, 40, 41 and 42, Ranges 28, 29, 30 and 31. This does not include the iron deposits west of the Paint river, nor the Michigamme mountain, owned by the Republic Iron Co., in Sect. 4, T. 43, R. 31.† The iron ores in the Menominee region occur in two approximately parallel E. and W. *belts*, each probably composed of two distinct *ranges* or horizons of ore; these belts are separated by a broad granite area, in which a little unpromising Iron has been found on Sects. 10 and 15, T. 41, R. 29.

This granite area narrows towards the west, caused by the convergence of the iron belts, and has nearly the shape of a flat-iron. The region is drained by the Menominee river, which skirts its W. and S. sides, and by the Sturgeon, a branch of the Menominee, which winds through the eastern part of the iron-fields.

*The facts contained in this chapter, as well as on Map No. IV. of Atlas, are largely from the Surveys and Explorations of Prof. R. Pumpelly and his assistant, Dr. H. Credner, made for the Portage Lake and Lake Superior Ship Canal Co. Prof. Pumpelly placed his private notes and sketches at my disposal, and added most valuable explanations. A valuable paper on this region is "The pre-Silurian formation of the Upper Peninsula of Michigan, in North America, by Dr. Herman Credner, Leipsic, illustrated by maps, diagrams and geological sections found in Plates VIII. to XII. (from the Journal of the German Geological Society)." Prof. Pumpelly and Dr. Credner are not in any way responsible for the hypothesis of structure here employed, nor for the views expressed as to the quality of the ores.

†A large amount of silicious iron ore occurs at this locality on the S. W. side of a high hill. Marble is found south and west, but in greatest abundance to the north, between Deer and Fence rivers, and on the upper waters of those streams. This district possesses much geological interest, and quite possibly economic importance, but means were not available for its examination.

1. SOUTH IRON BELT.

The South and, geologically, uppermost iron range of this Belt is probably the most regular and one of the most extensive iron deposits on the Upper Peninsula. The most easterly exposure of ore in this range is at the Breen mine on N. ½ of N. W. ¼ of Sec. 22, T. 39, R. 28. This location is 34 miles from Escanaba, and 45 miles from Menominee, in a bee line. The air-line distance from the elbow of the C. & N. W. R. R., now in operation, is 12½ miles.

Travelling from the Breen mine on a course N. 74° W., which is parallel with the general course of the river, we find on S. ½ of Sects. 11 and 10, N. ½ of Sect. 9, and S. ½ of Sect. 6, T. 39, R. 29, large natural exposures of ore, which have been still farther developed by recent explorations.

In the N. ½, of Sect. 2, T. 39, R. 30, are boulders of iron-ore, and near the S. ½ post of Sec. 34, T. 40, R. 30, magnetic attractions, which indicate the presence of the iron range. Near the S. ½ post of Sec. 30, T. 40, R. 30, is a large exposure of ore; thence, following a line of magnetic attraction which leads about W. by N., we find in the centre of the S. E. ¼ of Sec. 25, T. 40, R. 31, another exposure of ore, and a continuation of the local magnetic variations, westerly towards the Menominee river, two miles distant. A range of iron ore, corresponding with this and probably its continuation, has been made out in Wisconsin, between the Brule and Pine Rivers. Here are no less than nine large exposures of ore, the extreme ones 16 miles apart, which lie in one straight, narrow belt.

Immediately N. of this iron range is a broad belt of impure marble, equally regular, of greater thickness, but which apparently widens towards the W.

North of this, in the vicinity of the Sturgeon River, on Secs. 7 and 8, T. 39, R. 28, and Sec. 12, T. 39, R. 29, are local magnetic attractions and iron boulders, which are believed to mark the position of another geologically lower iron range, although no outcrop has been seen in this vicinity; but near the centre of N. ½ of Sec. 20, T, 40, R. 30, just N. of Lake Antoine, is an outcrop of silicious ore.

Strong magnetic attractions can be observed near the S. W. cor. of Sec. 22, and iron boulders in Sec. 27, and also on north shore N. of Lake Fumeê, in T. 40, R. 30.

These indications make certain the presence of a second iron range, although it cannot be demonstrated that these several shows belong to one horizon.

These two ranges, separated by the marble, constitute the South iron belt. North of and underlying both, is an immense bed of quartzite, which is well exposed at the falls of the Sturgeon river, Sec. 8, T. 39, R. 28; also on Sec. 1, T. 39, R. 29, and Sec. 28, T. 40, R. 29, and at the southwest ¼ of Sec. 23, T. 40, R. 30, as will be seen by the map. This quartzite, although believed to be geologically conformable with the ore formations, is not parallel with them, running more northwesterly, and dividing in T. 40, R. 30, into two and perhaps three ranges.

North of this quartzite, and underlying the whole series already described, are the Laurentian, granites, gneisses and schists, which make up the *granite area*, already referred to as probably being barren in workable deposits of ore, and which, therefore, our investigations do not embrace.

South of the south iron range, already described, is a bed of chloritic schist, well exposed on the south shore of Lake Hanbury, Sec. 15, T. 39, R. 29, and on the Sturgeon river in Sec. 13. Immediately south is a second quartzite, which is quite different in its character from the bed already described.

Next south is a broad belt of argillaceous slate, running parallel with the iron range, and exposed at several points in T. 39, Ranges 28 and 29. (See map.) South of this, and embracing portions of the Menominee river, is a broad well-defined belt of chloritic, hornblendic and dioritic rocks, running parallel with the iron range, the harder members of which form the barrier rocks of all the falls in this part of the Menominee, and probably those of Pine river in Wisconsin. This series are perfectly exposed at Sturgeon Falls, Sec. 27, T. 39, R. 29, and at the great and little Bequensenec Falls, and Sand Portage, in T. 39, R. 30.

2. North Iron Belt.

The North iron belt or range has a course nearly due east and west, and is all embraced, so far as known, in the south tier of Sees, of T. 42, Ranges 28, 29, and 30. The most easterly discovered exposure of ore, known as the Felch mountain, is in the N. ½ of Secs. 32 and 33, T. 42, R. 28, and is sixteen miles north and three miles west from the Breen mine, the position of which has been defined. Travelling due west, fragments of iron ore are found in N. E. ¼ of Sec. 31, T. 42, R. 28; after which no absolute proof of the presence of iron is found (although it is probably continuous) until we reach Sec. 31, T. 42, R. 29, where, in the centre of the section, is an immense exposure of iron ore in an E. W. ridge, which can be traced westerly halfway across Sec. 36 of the next Township. The natural exposure of ore on Sec. 31 is larger than at any other point in the Menominee region, and the quality is as good, if not better, so far as can be judged by surface indications. Magnetic attractions and iron boulders, found farther west and southwest on this range, prove its extension in that direction. Whether the westerly course continues, or whether it curves to the southwest, as seems probable from the position of the lower quartzite and local magnetic attractions in the northwest part of T. 41, R. 30, has not been determined. The latter hypothesis is most in accordance with the known facts, although the southeast dip of the quartzite on Secs. 17 and 18, observed by Dr. Credner, is not explained. If this hypothesis is true, the iron range should cross the Menominee somewhere in Secs. 24 or 25, T. 41, R. 31, into Wisconsin. There can be little doubt but that the North and South belts belong to one geological horizon, hence somewhere come together.

The existence of two distinct iron ranges in the North belt, does not admit of so easy proof as in case of the South belt. The facts which point towards this are the following: About one-fourth of a mile north of the iron range, already described as existing on Sec. 36, T. 42, R. 30, is a bed of marble running east and west, parallel with the iron, on both sides of which are slight magnetic attractions. Prof. Pumpelly found, "about 80 paces south of this marble, an outcrop of strata made up of layers of quartz, magnetic iron and chlorite," probably of no economic value.

Again, in the E. ½ of Sec. 35, are two parallel lines of feeble magnetic attractions, several hundred feet apart, and to the north are some large, angular boulders of magnetic ore; similar smaller boulders are found between Secs. 33 and 28, still farther west.

South of the iron deposits on Secs. 31 and 36, is a bed of marble, somewhat similar to the one already described as underlying the south iron range of the South belt, and possibly the equivalent of it, as the two have the same relative geological position. Farther south, immediately adjacent to, and overlying the granitic rocks, is a heavy bed of quartzite, which is undoubtedly the equivalent of the lower quartzite, already described as forming the base of the South belt. This quartzite at the S. ¼ post of Sec. 31, T. 42, R. 29, is characterized by the presence of mica scales in the bedding planes, and might be denominated a micaceous quartz schist. It has considerable resemblance to the rock, associated with the Cannon ore in the Marquette region. This fact possesses considerable geological interest in connection with the relative age of the Felch mountain ore deposit,

which, I think, belongs in this lower quartzite. See Chap. III., Group H. mica schists, and below.

The Huronian rocks in the N. ½ of Sec. 31, are covered with horizontal layers of Silurian sandstone, hence cannot be seen. North of the iron on Sec. 36, is the marble already mentioned, which is peculiar in being filled in places with crystals of kyanite, giving the gray weathered surface of the rock a rough jagged character, like a coarse rasp.

Just N. of the N. ¼ post of Sec. 31, T. 42, R. 29, is an east and west range of gneiss rock, and still farther north a heavy bed of hornblendic schist. At numerous points east and west, through the centre of T. 42, Ranges 28, 29, and 30, are outcrops of similar hornblendic rocks, together with beds of mica schist and gneiss, traversed in places by dykes, and perhaps by beds of granite. This broad belt of hornblendic rocks is apparently represented in its westerly extension, where it crosses the Michigamme river, by the mica and chloritic schists and gneisses, so well exposed at the Falls of the Michigamme, Cedar Portage, Long Portage, Norway Portage and intermediate points in Towns. 41 and 42, R. 31. Similar rocks cross the Paint river, a few miles farther west. This series would correspond in their geological position, as they do partially in their lithological and topographical characteristics, to the hornblendic and chloritic series, already described as forming the southernmost formations of the South belt, and which there, as here, produce numerous waterfalls.

Near the centre of this hornblendic belt, in the north part of Secs. 21, 22, 23, and 24, T. 42, R. 29, is a line of comparatively feeble magnetic attractions, which seems to have no equivalent in the South belt, unless it be in Sec. 28, T. 39, N. R. 18, E. Wisconsin; or in one of the beds of hornblendic rock at Little Bequensenec Falls, to be described hereafter, which contains many specks of sulphuret of iron and of magnetic ore.

This line of attractions, noticed in T. 42, R. 29, may represent the north edge of a basin, of which the North iron belt, already described, is the south edge; but I incline to the hypothesis, that it is an independent ferruginous range. No outcrop or boulder of iron has been seen upon it in Michigan, and it is doubtful if it is of any economic importance, although of much geological interest, as helping to elucidate the structure.

Returning to the most easterly exposure of iron on the North belt, the Felch mountain, we find a different and less complete sequence of rocks. Except some boulders about one mile west, no marble can here be seen. The Felch mountain ore rests immediately upon, and is bounded on the south by hornblendic, micaceous and gneissoid rocks, which are undoubtedly Laurentian, thus shutting out the marble and quartzite, already described as existing under the iron to the west. No indications, which would suggest the presence of a second iron range, can be found here. Within half a mile north the hornblendic schists are to be seen. At the N. ¼ post of Sec. 31, about 1½ miles westerly, is a large exposure of quartzite, running east and west, and apparently dipping to the north, although the bedding is indistinct. This may be the equivalent of the north marble range, Sec. 36, T. 42, R. 30, for quartzites sometimes pass into marbles in the Marquette region.

The Felch mountain ore, so called, is in reality a dull red jasper-like quartzite, containing numerous thin lamina and minute gash veins of very pure specular ore. It has somewhat the appearance of the "mixed" or second class ore of the Marquette region (see Chap. III. A), differing in containing less iron, and in the fact, that the ore lamina have less continuity. Considerable amount of a similar rock can be seen on the Penokie iron range, Wisconsin. I have a two pound specimen of specular ore from the Felch mountain, which is as rich as any I ever saw. The deposit is somewhat magnetic, the east and west belt of magnetic influence having considerable breadth.

It is not at all improbable, that better ores may be found adjoining this on the north, or possibly still further north, in a geological position corresponding with the ore on Sec. 31, T. 42, R. 29.

In the south half of Sec. 36, T. 42, R. 29, about two miles west of the Felch mountain, Prof. Pumpelly and Dr. Credner observed a variety of the lower quartzite, the character of which is important in connection with the age of the Felch mountain deposit. It has been described as containing mica enough on its planes of stratification, to make it semi-schistose, is porous, and contains thin streaks of magnetic iron in crystals, with here and there cubes of iron pyrites.

The above facts lead me to accept the hypothesis already advanced, that the Felch mountain ore deposit is itself in the Lower Quartzite. If we suppose the mica contained in the quartzite exposed at S. ¼ post of Sec. 31, and in the S. part of Sec. 36, to be replaced entirely by specular ore, a Felch mountain ore would be the result. This hypothesis is supported by the fact, that the Cannon ore, Sec. 28, T. 47, R. 30, is a quartz schist, having specular ore in its bedding planes, and which in a short distance changes into mica. (See Chap. III., Mica schist.) It should be noted, however, that while the Cannon ore is micaceous, the Felch mountain is eminently granular. The Cannon, like the Felch deposit, is at the base of the Huronian series, resting immediately on the Laurentian.

It has already been mentioned that *Silurian sandstone* capped the iron bearing rocks on N ½ of Sec. 31, T. 42, R. 29; the same is true in places on Sections 34, 35, and 36, in same Township, as also in Sections 31, 32, and 33, in the Township east. Passing to the South belt, we find the sandstone covering the iron series in Section 25, T. 40, R. 31, in Secs. 30, 29, 23, and 36, T. 40, R. 30; also in Sections 9 and 10, T. 39, R. 29, and in Sec. 15, T. 39, R. 28 immediately north of the Breen mine, as well as at numerous other points, which it is not necessary to mention.*

Explorations eastward on the two iron belts of the Menominee region, reveal the presence of this sandstone and its accompanying overlying limestone (calciferous sand rock), in greater quantity, even to the point of entirely covering up the Huronian and Laurentian rocks, which is done, so far as known, from near the east side of the Menominee iron region, all the way to the Canadian line at the Sault Ste. Marie. Local magnetic attractions, discovered by United States surveyors at various points in this Silurian area, render it likely that the iron-bearing or Huronian rocks extend far to the eastward, connecting probably with the similar rocks of the north shore of Lake Huron, where they were first studied and named by the Canadian geologists. Pine explorers inform me, that they have observed dark-colored heavy rocks, which were somewhat magnetic, in the eastern portion of the Upper Peninsula. These may have been Huronian islands in the sea, in which the sandstones were laid down. This subject is discussed in Chap. II.

Like their equivalents in the Marquette region, the ore strata and accompanying rocks of the Menominee region usually conform in their strike with the general trend of the belts and ranges, and dip at high angles, thus presenting their upturned edges to the observer, and affording, where exposed, the best possible opportunity to observe the thickness of the beds and their mineral composition. But highly inclined strata, especially if they should be overturned, as is occasionally the case, are not favorable for making out the structure and sequence of the various beds. This question is farther complicated by the difficulty of distinguishing, in the case of the clay and chloritic slates, between the cleavage and bedding planes. The latter are sometimes very obscure, and have been confounded with the other, thus leading to erroneous results.

The geographical distribution of rocks in the Menominee region which has already been given in a general way, in connection with what has been said in Chapter II. concerning the structural relations of the Laurentian, Silurian and Huronian systems, leaves but little more to be said regarding the structure. The Laurentian area is the broad backbone of the great E. and W. anticlinal, on and against the north and south sides of which the iron series repose, dipping away from the axis; that is, the South belt south and the North belt north. This general structure, it will be observed, is similar to that presented by the Michigamme district on the south and the L'Anse-Huron bay districts on the north of the Marquette region, separated as they are by a great Laurentian anticlinal. It Is probable that the Laurentian area of the Menominee region may wedge out at a point just west of the Menominee river, in the same way as do the Laurentian rocks of the Marquette region in the west part of T. 49, R. 33. (See Map I.)

In order to bring out the structure more fully for the information of the explorer and miner, three geological sections will be given, two on the South and one on the North belt. Like most geological sections, they are to a certain extent ideal, but are intended to correctly present the facts, together with such inferences as seem to be warranted. I should note that Dr. Credner's corresponding sections differ considerably in the hypothetical parts from mine, as will be seen by reference to his paper already mentioned.

*These irregular patches of sandstone are not represented on the maps.

Geological Sections, Menominee Iron Region.

Section A.

Projecting the more important rock exposures of the eastern portion of the South belt on one plane, which may be taken at right angles with the strike of the rocks, that is, N. 16° E, through Sturgeon Falls, Sec. 27, T. 39, R. 29, the following series will be found (See Map No. IV.):—

At the falls of the Sturgeon, Sections 8 and 9, T. 39, R. 28, is a group of strata, which divide rocks unmistakably Laurentian on the N., from the lower Huronian quartzite on the S., and which Prof. Pumpelly and Dr. Credner regard as of Laurentian age, but which seems to me to admit of some doubt, as they conform with the bedding of both systems (all being conformable) and have lithological affinities with both.

Prof. Pumpelly describes them as follows, beginning with the uppermost strata:—

1. Talcose slates, soft, light-greenish, gray, with distinct ripple-marks.

2. Four beds of conglomerates, consisting of more or less rounded fragments of quartz, granite and gneiss, 15 to 30 feet wide. See Spec. 65, State Coll., App. B, Vol. II. This conglomerate has not been observed elsewhere, although a somewhat similar rock outcrops on Sec. 10, T. 42, R. 28.

3. Underlying the series are two beds of protogine gneiss, of reddish color, separated by a bed of chloritic schist; the upper one of the beds of protogine encloses a segregated vein, two feet wide, of a mixture of magnetic iron and sulphuret of iron, which does not promise to make a workable deposit.

North of this series, at the head of rapids on Sec. 9, T. 39, R. 28, unmistakable Laurentian rocks occur, but which appear to be conformable with the Huronian. The chief varieties found here as well as elsewhere in the Menominee region are,—a granite (in places porphyritic) syenite, mica-gneiss, with some mica-schist, hornblendic-gneiss and schists, chloritic and talcose gneiss, with some chloritic and talcose slates.

I. The lowest, geologically, and most northerly formation which is unmistakably Huronian in the South iron belt, is a *quartzite*, which outcrops conspicuously at the Falls of the Sturgeon river, Sec. 8, T. 39, R. 28 (not Sturgeon Falls), where it is not far from 1,000 feet thick, and rises to an elevation of over 200 feet above the river. It is

usually light-gray, massive, compact, and often semi-vitreous, with indistinct bedding; has more the appearance of vein quartz than the Marquette quartzites. In places it shows ripple-marks with great distinctness; the weather has no appreciable effect on it.

This formation outcrops conspicuously, forming high ledges on Sec. 9, T. 39, R. 28, on Sec. 1, T. 39, R. 29 and Sec. 28, T. 40, R. 29. A quartzite, believed to be the equivalent of this, outcrops near the N. W. cor. Sec. 26, T. 40, R. 30. The Felch mountain iron deposit is also supposed to belong to this formation, as has already been explained.

II. A quartzose *sandstone* and conglomerate rock, which has a lithological character more allied to the Silurian than the Huronian, seems to overly this quartzite on the S., outcropping near the S. W. cor. of Sec. 2, T. 39, R. 29, and on the E. bank of Sturgeon river, on Sec. 8, T. 39, R. 28. But little is known about it, and its existence as a member of the iron series is not absolutely proven. From its soft, friable character it would more likely be found under swamps than on elevations.

The marble outcropping in Sections 24 and 25, T. 40, R. 30, would appear to occupy the same horizon. The same marble may exist on this geological section, but it has not been seen; the formation we are describing may be its equivalent.

III. The existence here of a range of slightly *magnetic* ore is indicated by angular boulders of lean ore in the valley of the Pine river, Sec. 12, T. 39, R. 29, and by magnetic attractions, Secs. 7 and 8, T. 39, R. 28. It does not, however, outcrop in this vicinity. The hypothesis assumed for the structure of the South belt would make this ore the equivalent of the range known to exist north of Lakes Antoine and Fumeê, in T. 40, R. 30. It is possible, as will be seen hereafter, that this conjectured iron range may be the equivalent of the main iron deposit of the North belt.

IV. Crystalline *limestone or marble*.—This formation has an immense development in the South belt, far greater than in the other, its thickness being probably greater than that of the quartzite I. It is generally thinly bedded, and usually of a light-gray color, but is sometimes reddish, yellowish, or bluish.* The upper portion contains thin bands of slate, in which it resembles the marbles of the Marquette region, but differs from them in being freer from silica, less variegated in color, having fewer joints, as well as in being immensely greater in its extent, and more dolomitic. The Marquette marbles are indeed but calcareous beds in the Lower Quartzite (V.) of that series, there being no proper marble formation in the rocks of that region.

A piece of marble from near the Breen mine gave Dr. Rominger carbonate of lime, 61 per cent.; carbonate of magnesia, 34 per cent.; hydrated oxide of iron and manganese, 1 per cent.; and silicious matter, 0.25; which composition would make the rock rather a dolomite than a limestone. Specimen No. 66, State Collection, App. B, Vol. II., came from Sec. 11, T. 39, R. 29. Five specimens from this locality gave an average specific gravity of 2.81, approximately determined. Dr. Rominger gave attention to the value of this rock for building. (See his Report, Part III.) Large outcrops of marble occur on the south side of the Pine river on Secs. 11 and 12, T. 39, R. 29, and on the Sturgeon river, Secs. 17 and 18, T. 39, R. 28.

*The weathered surface is often rough, from minute ridges, caused by the more silicious layers, which best resisted the weathering.

V. The principal *iron ore formation* of the South belt overlies, on the south side, the formation just described. It is made up chiefly, so far as is now known, of silicious specular slate ores, corresponding nearly with the so-called flag ores of the Marquette region. There is generally such admixture of magnetite as to produce moderate variations in the needle, but no evidence of the existence of a large body of magnetic ore. Specimen 68, State Collection, App. B, Vol. II. is from Sec. 11, T. 39, R. 29. At the Breen mine some very good soft hematite occurs in the same formation, which promises to be in workable quantities. See Specimen 67, State Collection, App. B., Vol. II. This ore would probably be found elsewhere if sought for, but it never outcrops. A blackish, porous ore, hematitic in its character, containing 56 per cent. of iron and nearly 1 per cent. of manganese, was found in a pit at the ¼ post between Sections 9 and 10, T. 39, R. 29, but its extent was not determined. Boulders of the same ore were seen in other places on the range.

The best exposures of the hard ores of this formation in the vicinity of the Sturgeon river, besides the Breen mine, are in Secs. 11, 10, 9 and 6, T. 39, R. 29. These ores will be described more fully, and analyses given hereafter.

VI. On the south shore of Lake Hanbury, which lies in Secs. 9, 10, 15 and 16, T. 39, R. 29, is an extensive outcrop of *chloritic schist*, the most easily splitting planes of which strike west by north, and dip south at a high angle. A similar rock, believed to be the same bed, can be seen on the Sturgeon river, near centre of Sec. 13, T. 39, R. 29. South of Lake Hanbury, 200 steps, is a rock partaking of a dioritic character, but which is probably a harder granular form of the same schist. Such rocks often graduate into each other in the Marquette region (Chap. III.). This schist may probably underlie Lake Hanbury and the swamps easterly and westerly from it.* It is represented on the section as following in its foldings formations VII. and VIII., described below. It is at least possible that this formation may be the same as the Menominee river diorites and chloritic schists, IX. and X., there brought to the surface by another series of more southern folds. But this hypothesis is not assumed in this discussion.

*Since the above was written Professor Pumpelly has informed me that he observed a large outcrop of marble south of the iron formation III., in T. 40, R. 30, which will be described below under Section B. This marble may fill the apparent blank existing at Lake Hanbury.

VII. *Clay-Slate*,—At 350 steps south of Lake Hanbury, on lines between Secs. 15 and 16, T. 39, R. 29, is a bluish and greenish gray slate, showing indistinct contorted bedding, with prevailing dip to *north;* the cleavage planes of which strike about north 70° west, and dip 80° to south. Veins of white quartz occur in these planes. At 550 steps south of the lake, a similar slate is found dipping *north* under the quartzite VIII., next to be described. It is believed that these two outcrops of slate, are the opposite sides of a synclinal trough, which holds the quartzite.

In the N. E. ¼ of Sec. 20, T. 39, R. 29, is an outcrop of talcose clay-slate. In Secs. 29 and 39, T. 39, R. 28, are several outcrops of dark colored, finely cleavable, but indistinctly bedded clay-slates. It is assumed that all these outcrops are parts of bed VII., which is folded into a synclinal and partial eroded anticlinal, as represented on section A of Map IV.

I am not in possession of sufficient facts to demonstrate the precise relations of these beds to each other, but the general fact is established by the northerly dips observed by me on Secs. 14, 15 and 16, that there are at least two folds between the iron range and the Menominee river, which probably reduces the estimated total thickness given in Dr. Credner's paper (18,000 feet), one-third. See page 175.

VIII. Associated with the clay-slates south of Lake Hanbury, is a bluish gray *quartzite*, which weathers into a brown, friable sandstone,* and in places reticulated with fine veins of quartz. At 550 steps south of Lake Hanbury, on line between Secs. 15 and 16, T. 39, R. 29, this quartzite is underlaid, as has been mentioned, by the clay-slate, VII., the division plane dipping plainly to the north at an angle of from 45° to 75°; the same rocks with the same northerly dip were observed farther east, on Secs. 15 and 14. This quartzite may be simply a local bed in the clay-slate formation, hence not entitled to a distinct number. The marked contortions both in the clay slate and quartzite are noticeable, and point unmistakably to the presence of a great fold. The cleavage planes maintain their east-west strike and southerly dip.

*"Iron slate" is marked on the United States plats at this locality. The brown color of the quartzite has something the appearance of iron rust. The very feeble magnetic attractions existing along this range, indicate the presence of magnetite.

IX. This number is intended to include the soft *magnesian schists* (chloritic, talcose, and probably argillaceous) occurring so abundantly along the Menominee river, in the vicinity of the mouth of the Sturgeon, as well as at the several falls above. They will be more particularly described under geological section B.

X. This formation is designed to embrace the granular *dioritic* rocks which form the barrier of the Sturgeon and other falls above, for 20 miles. It varies considerably in character, but on the whole bears a strong family resemblance to the granular diorites of the Marquette region. A peculiar gray variety, occurring at Sturgeon Falls, Sec, 27, T. 39, R. 29, is illustrated by Specimen No. 65, State Collection, App. B, Vol. II. This is the formation, it will be remembered, which in its supposed westerly prolongation into Wisconsin, produces the falls in the Pine river, and near them becomes iron-bearing. If the hornblendic schists mentioned as occurring in T. 42, are Huronian, they are probably the equivalents of this formation.

XI.—South of X., on or near the Menominee river, in south part of T. 39, R. 29, are several exposures of what appear to be *magnesian schists* and *protogine*, the structural relations of which to the rocks already described have not been made out. A rock similar to the protogine was observed in Sec. 13, T. 42, R. 30, and would there seem to have about the same relative position to the North belt that this has to the South belt.

Geological Section B runs northeast by north, across T. 40, R. 30, cutting Lake Antoine, and passes near the head of Great Bequensenec Falls. (See Map IV.)

I. Lower *quartzite*.—This formation appears far more conspicuously in this section than in A, owing to the double fold hypothetically introduced to cover the facts observed in the N. ½, of T. 40, R. 30. The large exposure of quartzite lying against the Laurentian, on Secs. 1 and 2, and the numerous angular boulders on Secs. 7 and 8, with the outcrop of quartzite near S. W. cor. of Sec. 23, taken in connection with the granite exposures on Secs. 4 and 9, lead one to the conclusion that one bed of quartzite, forming a synclinal basin under the Pine river and an eroded anticlinal to the south, best reconciles the facts observed. The lithological and topographical characteristics of this quartzite have already been given under A, and need not be repeated.

II. This formation was represented on A by friable sandstone and conglomerate, not observed near this section; the blue and pink *marble* outcropping near centre of Sec. 25, and the marble at the N. W. cor. of Sec. 24, are assumed to belong to one horizon (as shown by map and section), which is supposed to immediately overlie the quartzite. There is no reason to believe that this formation has any great thickness.

III. The "shows" and “signs" of ore to which this number was attached on section A, have developed into certainty on this section, where, near the centre of the N. ½ of Sec. 20, T. 40, R. 30, a considerable outcrop of *iron ore* is seen in the bottom of a small ravine. It is a silicious, red oxide, resembling in its general character the great ore formation of section A. Its continuation eastward is made certain by the magnetic attractions on the south line of Sec. 22, by the iron boulders of N, E. ¼ of Sec. 27, and on the north side of Lake Fumeê, on Sec. 26. Except the slight attractions noted by United States surveyors, at N. E. cor. of Sec. 30, T. 40, R. 29, there is no connecting link, so far as known, between this deposit and the indications of this bed on A. It is not proven that they are identical. Dr. Credner, as will be seen by reference to his paper, believes the ores on the

north side of the lakes are the equivalents of those on the south, the two being connected by a synclinal fold.

IV. Crystalline *limestone or marble*. There are immense outcrops of this rock in the S. part of Secs. 34 and 35; large exposures on the S. shore of Lake Antoine; boulders on the W. side of Sec. 30, all in T. 40, R. 30, and a continuation of the boulders in Sec. 25, in the Township west. The apparent thickness is greater than was shown on A., which may be owing to a crumpling or short abrupt folding of this part of the formation; or, it may be due to an actual thickening of the formation to the westward.

Two outcrops referred to, deserve especial mention: that in the N. W. fractional ¼ of Sec. 29, contains beds of a sandy and almost conglomeritic rock, which is associated with thin beds of dark-gray argillaceous limestone. The outcrop on Sec. 35 is the largest marble outcrop in the Menominee region, it being over 1,200 feet wide. As the dip is at a high angle to the S., the perpendicular thickness of the bed cannot be less than 1,000 feet. The S. part of the outcrop shows bands of limestone alternating with thin seams of quartz.

V. The *main iron formation* is marked by an outcrop in the centre of S. E. ¼ of Sec. 25, T. 40, R. 31, and by another which forms the west end of a high ridge on line between Secs. 30 and 31, T. 40, R. 30, the two being connected by a line of magnetic influence. Attractions also exist near the south ¼ post of Sec. 34, T. 40, R. 30, and in the N. W. ¼ of Sec. 2, T. 39, R. 30, are iron boulders. There is at present (October, 1872) no reason to believe that the ore in Towns 39 and 40, R. 30, is less in quantity, or differs in quality from that already described under the corresponding formation of geological section A.

VI., VII. and VIII. The hypothetical place of these formations on section B, is covered by deep drift—constituting the sandy terraces of the Menominee river. No outcrops of any kind can be seen on this belt of rocks, either in Ranges 30 or 31, except a large exposure of marble observed by Prof. Pumpelly, just south of the ¼ post, between Secs. 32 and 33, which corresponds in strike and dip and in general lithological character with marble formation IV. Reference to the map will show that this rock has no observed equivalent on A, where, if it exists at all, it should be found under Lake Hanbury.

I must confess that the existence of this marble, but lately made known to me, points to the existence of folds in the neighborhood of Lake Antoine, not suggested by my geological sections.

IX., X. The chloride, hornblendic, and dioritic rocks embraced under these two formations are well exposed at the Great and Little Bequensenec Falls, and at Sand Portage, all in T. 39, R. 30. These falls afford an unsurpassed opportunity to study this series, which was carefully done by Dr. Credner, who made out the following section at the upper fall from north to south:—

a. Crystalline hornblendic rock, consisting of light to dark-green hornblende in crystalline masses, white feldspar, a little chlorite and some quartz.

b. Talcose rock, consisting only of fibrous talc, which forms a kind of soapstone in three heavy beds.

c. Fissile talcose silicious slates, of a reddish color, with small crystals of orthoclase.

d. Soft talcose slates of light green color.

e. Chloride slates, dark green, with spots and layers of clayish red oxide of iron.

f. Hornblendic rock, dark green, crystalline, coarse-grained to aphanitic, with specks of sulphuret of iron.

By the Little Bequensenec Falls the following series of strata is laid open, from north to south:—

a. Talcose chloride slates, with a great many segregations of quartz.

b. Hornblendic rocks, with much dark-green chlorite, and many specks of sulphuret of iron and magnetic iron ore, 35 feet.

c. Soft fibrous soapstone in two heavy beds, with some sulphuret of iron, 8 feet.

d. Talcose slates, fissile, with many layers and segregations of white quartz and red limonite.

e. Chloride slates, 10, feet.

i. Bed of hornblendic crystalline rock, 12 feet.

g. Chloritic slates with seams of iron pyrites, 30 feet.

h. Fibrous talcose slates, reddish, with bands of green color.

i. Chloritic slate.

Geological Section C. (North Belt). On line between Ranges 29 and 30, T. 42.

I. A *quartzite*, which is micaceous at S. ¼ post of Sec. 31, and in south part of Sec. 36, T. 42, R. 29, and ferruginous at the Felch mountain. The lithological character and stratigraphical position of this formation have been fully considered. Although it differs considerably in its character from the equivalent formation of the South belt, there can be little doubt but that it is the same.

North of this quartzite is a considerable breadth of low damp ground, with no outcrops.

II. Crystalline *limestone or marble*, of a quite pure snow-white, to reddish granular variety, outcrops immediately south of the iron on Sec. 31. In the southeast ¼ of Sec. 35, T. 42, R. 30, is an out crop of marble presenting very distinct bedding planes, which dip to the north. These two outcrops define a range parallel with the quartzite, and probably belong to this bed, II. Another out crop of marble near the centre of Sec. 35 cannot be reconciled as belonging to this formation, and there is some uncertainty as to whether it lies above or below the iron

formation. If below, then it would have the same relative position to the iron as the outcrop first mentioned above. More facts are needed to establish the relations of these marbles. As will be seen by comparing sections C and B, it is assumed that the limestones marked II., on each, are equivalents of this bed.

III. The great *iron-ore formation*, which extends easterly and westerly across Sec. 31, half way across Sec. 36, and probably much farther each way, has already been partially described. This bed Is apparently the equivalent of III. of the South belt, but it is certainly more extensive, and, so far as can be seen, contains better ore. If this hypothesis be correct, then the upper and main iron formation of the South belt has no representative in the North belt, unless it be indicated by the slight magnetic attractions already mentioned as having been observed in the north part of Sec. 36. The strongest indication of the continuance of this formation eastward is to be found, so far as known, just six miles due east, in the N. E. ¼ of Sec. 31, T. 42, R. 28, where Prof. Pumpelly observed numerous large angular fragments of specular iron ore, associated with fragments of marble. This deposit should, on this hypothesis, pass just north of the Felch mountain, in its eastward prolongation.* The quartzite near the north ¼ post of Sec. 31, T. 42, R. 28, would, on this hypothesis, be the equivalent of the before mentioned marble in Sec. 36, seven miles west.

*The blank space north of and above the iron formation III., on section C, is marked by no outcrops except Potsdam sandstone, which covers the Huronian rocks on Sec. 31, as has been already stated.

IV. Crystalline *limestone or marble*, containing crystals of kyanite, outcrops about 300 steps south of the north ¼ post of S. 36, T. 42, R. 30. Several outcrops of the same rock occur a short distance to the west, and a little south, indicating the probable existence of a large deposit of this rock. Except in the presence of the kyanite crystals, which gives to a weathered surface the rough character heretofore described, this rock has much the character of the marble, with corresponding number of geological sections A and B. Whether these marbles are equivalents is not proven, but it is assumed as being more in accordance with the facts than any other hypothesis.

V. An interesting fact in connection with the limestone outcrops on Sec. 36, just described, is the presence of a very noticeable magnetic attraction on both sides of the marble, or rather associated with it.

Prof. Pumpelly observed south of one of these outcrops of marble "strata made up of layers of quartz, magnetic iron and chlorite, containing garnets, and resembling some of the strata at Republic Mountain, Marquette region." These attractions are probably due to this rock, which is certainly but a poor representative of the great upper iron bed of the South belt.

VI., VII., VIII. No other rock was observed on this section for several hundred paces ; this space may or may not be filled by these formations, which, so far, have only been seen on geological section A. The numbers are introduced here, in order to carry along the hypothesis of structure which will best reconcile and present the observed facts.

IX., X. Just north of the north ¼ post of Sec. 31, T. 42, R. 29, is a large outcrop of gneiss, with thin layers of granite, and adjoining this on the north is the most southerly observed outcrop of the great hornblendic and mica schist series, the geographical extent and general structure of which have been fully considered. Whether this series of schists are the equivalents of beds IX. and X., which occupy the immediate valley of the Menominee, cannot be established. They have the same relative position to the iron ore, marble and quartzite series, and similarity in their lithological character. It must be admitted, however, that the lithological affinities of this series of rocks of the north belt are decidedly Laurentian rather than Huronian. The gneiss and granite outcrop, above described, may be almost regarded as a typical Laurentian rock in its appearance. If future investigations prove them to be Laurentian, a very troublesome structural problem would be presented here, as we would have Laurentian rocks conformably *overlying* beds, unmistakably Huronian. There seem to be fewer difficulties in supposing that the Huronian rocks of the Menominee region embrace lithological families not, so far, found represented in the equivalent series in Marquette region.

An important observation may be made here bearing on the variable thickness of the Huronian series, or else pointing unmistakably to tremendous folds in the rocks of the South iron belt,—it is this: the superficial breadth occupied by formations I. to VIII. inclusive, is nearly four times as great in the South belt as in the North. A portion of this difference may be accounted for by the thinning out of this series to the north ; but the folds figured in geological section A, and possibly others not determined, would, I think, account for the greater part of this discrepancy.* There are no evidences of any folds in the corresponding series in the North belt.

A range of marble associated with quartzite, chloritic and talcose rock, and overlaid by a chloritic gneiss, with beds of chloritic schist and gneissoid conglomerate, the whole dipping at a high angle to the south, passes about five miles north of the North belt. These may represent the north side of the trough or basin, of which this iron belt is the south outcrop. No iron has, however, been found, as far as I know, on this range.

Along the Menominee river, where it crosses this broad schistose belt which lies north of the North belt, is a series of north and south dips, observable at the Cedar, Long, and Norway portages, which point unmistakably to intermediate folds in these rocks, whose thickness, therefore, may not be very great.

*See page 169.

Nothing remains to be said regarding the Menominee iron region which is of practical importance to the explorer, miner, or capitalist, and which would properly

come within the scope of this work, except a statement as to the *quality of the ore*. The quantity has already been described as great, and the chances to mine all that could be desired. The distances by rail from shipping port and grades are most favorable. If the ores are of first quality, this region has a future which will only be surpassed, if it is surpassed, by the Marquette region, now developed to that extent that its ores produce nearly one-fourth of all the iron made in the United States.

Unfortunately at this time the question of quality cannot be fully answered, for the simple reason that up to the date of my last visit, in October, 1872, comparatively little exploring had been done, and iron deposits very seldom expose naturally their best ores; these have to be found by digging. This subject is fully treated in Chap. VII.; but I will repeat here that ninety-nine hundredths, if not nine hundred and ninety-nine thousandths, of all the ore outcropping in the Marquette region (and there is an immense amount of it) is not merchantable, according to the present standard for shipments. Soft hematite ores never outcrop; therefore if pure high grade ores be abundant in the Menominee region, they might not yet have been found from the little work that has been done.

The facts observed by me are as follows, taking the several iron locations in succession: —1st, The *Breen mine* on N. ½ of N. W. ¼ of Sec. 22, T. 39, R. 28, **South belt.** Three kinds of ore occur at this locality, the predominating variety (constituting perhaps four-fifths of all exposed) being a lean, silicious, slaty or flaggy ore, resembling the Iron mountain and Teal lake ores of the Marquette region. It varies in quality from a ferruginous quartz schist, containing but a few per cent. of iron, up to masses as good, if not better, than the second-class or flag ores of the Marquette region, with occasional richer streaks. Careful mining and selecting would produce an ore of this kind that should yield say 45 per cent. in the furnace, but it would be apt to "work hard" from the large amount of silica, and produce a hard iron, suitable, perhaps, for rail-heads. (See Iron Ores, Chap. III.) What percentage of the whole mass would be of this degree of richness, practical mining only can determine; from what could be seen in October, 1872, I should say not exceeding one-third.

The next variety in abundance is a soft, earthy, dark-colored hematite, resembling in its general appearance the Negaunee hematite ore of the Marquette region. A sort of irregular pocket of this ore was found lying in the first described variety, appearing as if it may have been produced by a partial decomposition and disintegration of the flag ore,—that is a secondary form of it. This hematite pocket, so far developed by the shafts and trenches, is of sufficient size to work advantageously, but is divided through the centre by a bar of very silicious ore. Several "shows" of this ore were found in other places, but none were proven to be of workable extent. See Spec. 67, State Coll., App. B, Vol. II.

The third variety of ore is best in quality, but, so far as known, least in quantity. It can be seen near the mouth of a drift on the south side of the ridge next the swamp, where a bed two or three feet thick was passed through, flag ore being found to the north of it. This is a hard, more or less porous, bluish, heavy, red ore, of a hematitic character, and has considerable resemblance to the so-called Jackson "hard hematite." It would undoubtedly work well in the furnace, and would yield not less than 60 per cent. of metallic iron. There are reasons to suppose that there may be a workable bed of this ore on the property; but judging from what is to be seen at the drift above mentioned, it may be under wet ground.

On the whole, it may be said of the Breen location, that the great amount of ferruginous schist there developed, and the tendency shown by it to pass into soft hematite, render it very probable that a considerable quantity of workable ore of this kind may exist. The absence of local magnetic attractions, and of boulders of rich hard ore, leads me to consider it doubtful whether any rich specular and magnetic ores, such as are now produced in the Marquette region, will be found here.

The ore range probably extends east and west, the entire length of the "80," or one-half mile, forming a ridge where the explorations have been made, from 20 to 30 feet high, bounded by a swamp on the south side. The whole iron series dip south, and are underlaid on the north by soft shaly magnesian and argillaceous rocks.

Sections 6, 9, 10 and n, T. 39, R. 29. The ores on these sections form what appears to be a continuous deposit, and are so much alike in their general character that they can be more commonly and briefly described together. Except a few trenches dug by the Canal Co. on Secs. 9 and n, and some test-pits sunk this season on Sec. 6, no work had been done on this range at the time of my last visit. Here, as at the Breen, the prevailing variety, in fact the only variety which I saw in quantity, was the silicious flaggy ore already described. The quantity of this ore is enormous, forming as it does the south face, and, perhaps, the great mass of a considerable ridge running west by north. The opportunity for attack by open cuts into the south face of this ridge is unsurpassed. Like the hard ores at the Breen, they vary greatly in richness,—from a quartz schist slightly impregnated with iron up to specimens, and even considerable masses which will yield 50 per cent., and occasionally a specimen that contains 60 per cent. of metallic iron. The prevailing variety, however, is represented by Specimen No. 68, App. B, Vol. II., from Sec. II., which contains from 25 to 45 per cent. of iron.

Dr. Credner reports having found, in "Cut D, on Sec. 11, 28½ feet of good fine-grained, steel-gray iron ore, with here and there a narrow streak of silicious ore, but in such a small proportion as not to spoil the good quality of the mass. The whole series gives a dark-red streak." Specimens designed to represent the average of this deposit gave Dr. C. F. Chandler 52 per cent. of iron. In another place he found a bed "6 feet thick, supposed to be very rich ore." I did not find these trenches (as afterwards appeared), although I designed to see all,

and had with me two men, who helped to dig them. Dr. Credner further reports an aggregate of 139 feet in thickness of "workable ore" on Sec. 11, but my own observations lead me to question this, unless the standard of furnace-yield be put considerably lower than at present. It is unwise, however, to predict at this time what thorough explorations may reveal.

The ore on Sec. 9 is very similar to that on 11, but on the whole (so far as can be seen) not so good: the same may be said of that on Sec. 6. Two smaller boulders of rich specular slate ore were found on the latter section, but no large ones. Occasional narrow seams of tolerably rich ore were found, one of them over one foot thick, but nothing that looked like a workable deposit. At the ¼ post between Secs. 9 and 10, north of Lake Hanbury, are to be seen several boulders of a black, porous earthy ore resembling somewhat varieties of the Negaunee manganiferous hematites; the same ore was found in place in a pit near by, and a large boulder of it near the center of S. ½ of N. W. ¼ of Sec. 6, and at other points. A hand specimen gave Mr. Jenney 56.44 per cent. of metallic iron, less than 16 per cent. of insoluble silicious matter, and nearly 1 per cent. of manganese. It is unlike the Breen mine hematite, and, in fact, unlike any Lake Superior ore I have seen. It is not improbable that workable deposits of it may exist, which being soft would not be likely to produce outcrops or boulders. I think it is well worth investigation. I have some reasons for supposing that this ore may be Silurian.

The next exposure of ore west of Sec. 6 on the south range is near the ¼ post between Sections 30 and 31, T. 40, R. 30. This ore is softer and more slaty than those already described, although belonging to the flag ore family. It is apparently more argillaceous, and outcrops conspicuously in several places west of the ¼ post, dipping at a high angle to the *north*, which would necessitate an *overturned dip* in order to harmonize with the hypothetical geological sections given on the map. The exposed bedding-planes are bright and specular, giving the ore the appearance of being richer than it really is. The ore exposed here may yield 45 per cent. in the furnace; see analysis No. 254, Chap. X.

From this locality we are led by a broad belt of very moderate magnetic attractions west by north for half a mile, to the iron ore exposed in the centre of S. E. ¼ of Sec. 25, T. 40, R. 31, where the Canal Company have done some trenching; the exposure here is not great, the ore being in a small ravine on high ground. It is intermediate in character between the flag ores noticed, but most like the last. I followed the attractions about one-eighth of a mile west, to a point where the hill seemed to be capped with Silurian sandstone.

I have now mentioned in order, beginning at the east, all the main exposures of ore in the south range of the South belt, which has already been referred to as the most regular and one of the most extensive deposits of ore in the Lake Superior region; whether it is absolutely continuous for the 16 miles intervening between the extreme exposures, can only be determined by expensive explorations or actual mining.

Passing from the south to the north range of the South belt, we have but one exposure to consider, that near the centre of N. ½ of Sec. 20, T. 40, R. 30. This is in a small ravine, down which, to the south and toward Lake Antoine, a rivulet has its course in wet weather; the water has uncovered a narrow surface of flag ore similar to that seen on the south side of Sec. 30, but less slaty. Iron boulders are strewn along the ravine for over 100 feet. This ore is a red oxide, but holds enough magnetite to give it a moderate magnetic power.

Ten miles northerly across the granite region, from the last mentioned locality on Sec. 20, bring us to the main deposit of ore in the **North belt**—that on Secs. 31 and 36, of T. 42, and Ranges 29 and 30. The great extent of this deposit, and its favorable situation for mining, have already been commented on; it only remains to notice the quality of the ore. It is more granular and massive than the flag ore of the south range, and, as a whole, contains less silica and more metallic iron. The natural exposures of ore in the ledge are greater, no digging or uncovering at all being required to reach a great quantity of the ore. The best ore to be seen outcropping, is just southeast of the centre of Sec. 31: the top of the cliff is here about 100 feet above the low ground at its base on south side; and for about one-third of this height is a ledge of ore, from the foot of which the surface slopes rapidly to the low ground, affording the best possible opportunity for mining. This outcrop was carefully examined for a distance of several hundred feet in length, and from the richest places to be found in it, 29 specimens of ore, of about one pound each, were collected, no two being broken from the same place. The specific gravity of these specimens was approximately determined on the ground, and was found to vary from 3.26 to 4.15, the mean of the 29 specimens being 3.71; this multiplied by 12, according to the empirical rule given under Explorations (Chap. VII.), gives 45 as the average percentage of the whole. An ore which actually analyzes 45 per cent. of metallic iron should yield say 47½ per cent. in the furnace, which is about what I consider this ledge of ore would work, if mined and sorted with ordinary care. Several ounces, chipped from five of the best hand specimens I could find, gave Dr. Wuth, of Pittsburg, 54.81 per cent. of metallic iron (See Analysis No. 98, Chap. X.). Separate analyses of ten hand specimens, selected from same locality by Prof. Pumpelly and Dr. Credner, gave Dr. Chandler from 49 to 64 per cent. of metallic iron, the average being 53.74 per cent. If this higher grade can be found in workable quantities (which is probable), then we should have a 55 per cent. ore, which, considering its granular and semi-porous nature, and the fact of its being a red oxide, would indicate an ore not difficult to reduce, and one which would sell in the present market.

No boulders were observed in this vicinity which would indicate a richer ore than the above of the red oxide variety, and no magnetic attractions were observed

which would suggest a workable deposit of magnetic ore, although all the ores of this region are slightly magnetic. As hematite ores do not outcrop, and as no explorations have been directed to finding such ores, nothing can be said regarding them. My impressions are that they will be found on Secs. 31, 32, or 36 of the North belt.

The Felch mountain ore was fully described when considering the lower quartzite. It is totally unlike either of the preceding varieties, and more closely resembles the "mixed ore" which accompanies the rich specular ores of the Marquette region. The laminæ of ore are very rich, analyzing from 63 to 67 per cent. of metallic iron; but the large admixture of quartzite (at least three quarters of the whole) would render it unmerchantable at present. It is by its constitution particularly well adapted to *stamping* and *washing*, and on account of its proximity to several rapids and falls in the Sturgeon river, is well situated to be worked in this way, when the market drives miners to this means of production, as it will sooner or later.

3. Paint River District.

Too little is known about the remote Paint river district, in Towns 42 and 43, Ranges 32 and 33, to enable me to give anything of interest regarding its geological structure. The Huronian rocks are extensively developed there, and contain deposits of hard hematite ore. I had the opportunity to examine only two localities, at the Paint River Falls, Sec. 20, T. 43, R. 32, and on Sec. 13, T. 42, R. 33. The ores are identical, and unlike any in the more easterly part of the Menominee region, in being richer in iron, freer from silica, and in containing more water. (See Analysis 68, Chap. X.)

Explorations now in progress will determine many of the unsettled questions regarding the ores of the Menominee region, especially of the South belt. I regret that I cannot embody their results in this Report, and thus give it a completeness that in the present state of my information is impossible.

CHAPTER VI.
LAKE GOGEBIC AND MONTREAL RIVER IRON RANGE.

An examination of this but little known iron-field was not contemplated in the original plan of the survey. But, having had occasion in the line of my profession to make some explorations there, a few of the general results obtained will be given, with a view of aiding future explorations, and of calling attention to a comparatively unexplored region. The probability of there being early railroad communication through this country, connecting the existing system of roads of the Upper Peninsula with the North Pacific, Minnesota and Wisconsin systems, now radiating from the west end of Lake Superior, attaches additional interest to this most western portion of the Upper Peninsula.

The facts observed and conclusions formed are the joint work of Prof. Raphael Pumpelly and myself, and have, so far as they bear on the stratigraphical relations of the four great systems of rocks, been in substance given to the public, in the American Journal of Science and Arts, Vol. III., June, 1872. Many rock specimens, gathered by us are minutely described by Mr. Julien, in App. A, Vol. II.

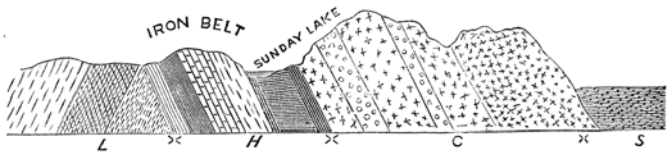
The iron range under consideration may be regarded as the eastern prolongation of the Penokie range of Wisconsin, as well as the western extension of the Marquette series, the whole being Huronian. The position of the range is tolerably well defined by magnetic observations and notes on the U. S. land office plats; on these we find mention of iron and magnetic attractions on Secs. 7 and 8, T. 47, N., R. 45, W., as also in Secs. 13 and 14 of the Town west. The belt of Huronian rocks, as made out by us, extends nearly east and west, through the north part of T. 47, Ranges 44, 45, 46 and 47, crossing the Montreal River in Secs. 16 and 21, of the last-named Township. Going east, the range was lost before it reached Lake Gogebic.

The geological boundaries of this range are fortunately of the most unmistakable nature, and render a detailed description of its position unnecessary. (See Map I.)

On the north is the high, broad, irregular ridge, or series of ridges, constituting the South Copper Range, the rocks of which are greenish and brownish, massive and amygdaloidal copper-bearing traps, their bedding being exceedingly obscure, with occasional beds of sandstone and an imperfect conglomerate. The strike of these rocks, so far as it could be made out, was east and west, with a dip to the north at a high angle, thus *conforming* with the Huronian rocks underneath.

Against and over the copper series on the north, abut the horizontally bedded lower Silurian sandstones, which are beautifully exposed on the west branch of the Ontonagon river, in Sec. 23, T. 46, R. 41. These sandstones form the surface rock, and occupy the broad belt between the two copper ranges from the region we are describing to Keweenaw bay, but taper to a point before reaching the Montreal river, in going west.

Fig. 12. Sketch showing Geological Section—looking west, between Lake Gogebic and Montreal River (in part ideal).



L. Laurentian rocks—gneiss, granite and schists, which are *non-conformably* overlaid by, H. Huronian—Clay slate, ferruginous and jasper schists, flag ores, quartzites and diorites, say 4,000 feet thick, which are *conformably* overlaid by, C. Copper-bearing rocks, chiefly greenish and brownish, massive and amygdaloidal traps, with occasional sandstones and conglomerate layers, which are *non-conformably* overlaid by, S. Lower Silurian sandstone, coarse quartz sandrock.

[12. Section of Gogebic and Montreal River Iron Range]

On the south of the iron-bearing rocks are a series of granites, chloritic gneisses and obscure schists, which,

except the latter, are unmistakably Laurentian in their lithological character, and are non-conformably overlaid by the Huronian rocks. The general structural relations of the four great systems here enumerated are shown in the accompanying diagram. As the *non-conformability* of the copper-bearing rocks and sandstones is doubted by some geologists, it should perhaps be stated that the actual contact was not seen. But the sandstones were observed lying horizontal, and affording not the slightest evidence of disturbance, within a few miles of highly-tilted copper rocks, which gave every evidence of having been elevated before the deposition of the sandstones. So far as my observation has extended, this rule is general; that is, no Lake Superior sandstone, which is unmistakably lower Silurian, has ever been found in any position other than nearly horizontal; and no rock which was unmistakably of the Copper series has been seen which was not considerably tilted. The fact that certain sandstones belonging to the copper series are very similar, if not lithologically identical with some of the lower Silurian sandstones, has helped to complicate this question. An interesting locality for study in this connection is the west fork of the Ontonagon river, just south of the Forest Copper Mine. I am not sure but that it affords an exception to the rule above stated, as at that point sandstones, *apparently* Silurian, dip south at an angle of 45°.

The best locality in which to study the character of the iron series in the West region, is on Black river and its tributaries, especially on the outlet of Sunday lake, T. 47, Ranges 45 and 46. Here will be found banded ferruginous jaspery schists, chloritic greenstones, brown ferruginous slates, black and gray banded silicious slates, silicious flag ores, several varieties of quartzites and clay slate. The whole series strike east and west, and dip north away from the granites and gneisses and under the copper rocks, at an angle of from 40 to 90°. Several varieties of the Huronian and Laurentian rocks of this vicinity have been examined by Mr. Julien, for descriptions of which see Appendix A, Vol. II. It will be observed from these descriptions that these rocks, although somewhat different from the Huronian series of the Marquette region, are still essentially the same; and I know of no good reason why merchantable ores may not be found amongst them. No ore, however, was found either in place, or in the form of boulders, which would pass for shipping ore in the Marquette region at this time. The absence of strong magnetic attractions renders it improbable that pure magnetic ores will be found here. The most encouraging indications observed pointed towards the existence of soft hematites, which may very likely be found of a quality and in quantity to pay for working. The best "show" observed was in the south ½ of the S. W. ¼, Sec. 18, T. 47, R. 46. It is on the north-easterly side of an east and west ridge, where there is a large exposure of highly ferruginous quartzite in places holding hand-specimens of hematite ore of fair quality. As this kind of ore never outcrops, on account of its soft, earthy character, and as we had no facilities for digging, nothing more definite was determined.

CHAPTER VII.
EXPLORATIONS (*Prospecting for Ore*).

1. How Failures have occurred, and how to avoid them.

The history of the development of a good many of our iron mining enterprises has been somewhat as follows:—The deposit is found, sometimes by accident, but often by systematic explorations made at the expense of corporations, firms, or individuals, by a class of men known as explorers; who are acquainted with woodcraft, are often miners, and who always have some knowledge of structural geology, the different varieties of ore, and the use of the miner's compass. A boulder of ore, red soil in the roots of a fallen tree, the variation of the magnetic needle, the proximity of rocks supposed to belong to the iron range, and often the outcrop of the ore itself, determines where digging shall be commenced.

If the indications are promising, before many marks are made the land is secured, if not already owned or controlled by those interested in the explorations. If government land, it is “entered" at the land office at $1.25 per acre, or $2.50 if within the limits of some railroad grant. If the land is "second-hand," already entered, it may be bought outright, or if the price be regarded as too high, a refusal is often taken with the privilege of exploring.

If the discovery is on the land of some railroad or mining company, it usually cannot be bought. In this case, all trace of the work done is often concealed, secrecy enjoined on all concerned, and the explorer lives in the vain hope that he may sometime have the opportunity to buy the land, an expectation in which he usually dies, as large corporations do not often sell iron deposits for small prices, if at all. Instead of this unwise course, explorers often sell their information to the companies owning the land, which they can usually do at a fair price. Our supposed exploring party having secured the land, begin to dig test-pits and trenches openly and systematically. The solid ledge is usually soon found, which may prove to be some variety of iron ore, perhaps pure, but far more likely a "mixed ore” or lean flag ore, hence not merchantable.

Specimens (which I am sorry to say are apt to be the best that can be found) are sent in as *averages* of the deposit. Experts pronounce them shipping ore, and common talk asserts that So and So have a "good show" for a mine.

Soon the test-pits, trenches and drifts develop a workable width and length of what seems to the explorers to be merchantable ore. "Mixed with a little rock perhaps in places," but this occurs in most mines at the start. Experienced mining men visit the new deposit, examine it carefully, and assert honestly that "it looks better than did the Champion or Barnum locations when they first saw them."

The explorers select what they believe to be strictly *average* specimens of the ore (an impossible thing as will appear), which are sent to some distinguished chemist who reports, perhaps 65 per cent. of metallic iron, and only traces of sulphur and phosphorus, and expresses the opinion that the ore will *work well* in a blast furnace, and is identical with other well-known Lake Superior ores. This report, with the certificates of good practical mining men, and the opinion of some geologist who may have examined the locality, satisfies the owners that they have a workable deposit of "shipping ore."

Next in order, if it has not proceeded simultaneously with the above, is the organization of a company under the general mining law of Michigan,* which prescribes not to exceed 20,000 shares at $25 per share, par value. The property above mentioned is put into the new company at a moderate price; some prominent man of character and means is found to take the presidency-of the company, his friends, with others, being "let in" on the "ground floor," and the None-such Iron Co. is organized and at work.

*App. I., Vol. II., contains an abstract of the Mining Laws of Michigan.

Building up a location is the next thing in order. To this end a contract is usually let to some French Canadian to build a dozen log houses for miners' families, a company's store, barn and shop. For this purpose the contractor lays out *fifteen different lines* on which to put the buildings, being governed in each instance by the ease with which the logs can be got together. In clearing for the foundations it is usual for the Frenchman to find a new deposit of ore better than the one first found, to which a part of the mining force is at once transferred, the location of the buildings being changed so as to avoid the fragments which blasting has already begun to throw. The condition of affairs at the new location is at this period about as follows:—houses are going up rapidly, stripping is being pushed to the utmost, several "pairs" of Cornish men are sinking shafts or blasting off the "cap rock" so as to get at the ore. The contract for a first-class wagon road to connect with the State road has been let at $2 per rod, and a party of engineers are at work locating a branch railroad to the mine, and it is confidently predicted that a considerable amount of ore will be shipped from the mine that season.

About this time the president of the company—an old iron man, who has made a fortune by smelting 40 per cent. ores with anthracite coal in Eastern Pennsylvania—and a part of the board of directors visit the mine. One of the directors is an eminent lawyer who helped to "place" the property, another is a stockbroker who had made a fortune in Wall Street, a third is a railroad king, and another a successful whisky distiller. None but the president knew anything of iron before they came into the company. He is of course amazed at the richness of the ore, and tells the captain in charge of the mine truthfully, that he is throwing away as good ore as he ever used in his Pennsylvania furnaces. All collect and examine numerous specimens, which are submitted to the president and captain for their judgment as to richness. Nothing less than 50 per cent. is found, and the average is much higher. The lawyer who has fine muscular sense and a consciousness of its possession, soon discovers that he can judge accurately of the percentage of iron by handling the pieces of ore, and speedily becomes an authority with the broker and distiller. Specimens are hefted which contain 59, 61, 62½, 68, and finally one fine-grained fragment of steely ore, which, after careful manipulation in each hand, it is decided contains 75 per cent. of metallic iron. The captain unhesitatingly admits that to be richer than anything in the Jackson mine. Rock is found in several pits, but the captain explains that it is only greenstone which "caps" the ore, and moves by the magnetic needle which is "dead 90," that the ore is there. Being in a hurry he may not have faced the instrument exactly east and west.

Having spent one half-day in the examination of their property, and becoming satisfied that it is first-class and will prove a profitable investment for themselves and friends, the company leave, having first instructed their superintendent to bend all his energies to getting out ore, without reference to quality, cost, or future condition of the mine—though the whole is not, of course, directly expressed. On their way East, the president perhaps sells a thousand tons or more to some furnace man who is a stockholder in the new company, and telegraphs back to the superintendent to ship it at once.

The foregoing sketch contains the elements on which many Lake Superior iron mining enterprises have been organized, and at the start operated. It is needless to remark that many such undertakings result in utter failure. In the copper region the proportion of failures is far greater, and in oil, gold, and silver enterprises overwhelmingly so. The average human imagination becomes temporarily diseased when stimulated by the chances of possessing hidden mineral wealth. Iron, being the least valuable of the metals, has less of this influence than the others, but is not entirely free from it.

It may interest those who are disposed to identify themselves with Lake Superior iron mining enterprises (and I believe no equal investment has paid better in past time or promises better for the long future) to know the cause of failure in such enterprises. Classifying them carefully, I find that about two thirds of the disastrous enterprises were based on deposits of ore the *quality* of which was mot merchantable: they were not rich enough in metallic iron. The extraordinary richness of Lake Superior ore is not generally known. I have reports from 40 furnace stacks in which these ores are smelted, which show that the average furnace yield of 250,000 tons of magnetic and specular ore for 1870 was 65 per cent.

The amount of high grade hard ore is so great that consumers can usually get all they require, and will not buy an inferior grade. For this reason experienced iron men from other regions have often been deceived; they had not a sufficient realization of this question of quality.

Marquette ores—which were rich compared with what they were used to—could not be sold on account of their leanness. The soft hematite ores are not considered in this connection.

The remaining third of the failures have come from a lack of *quantity*, the quality of the ore being satisfactory. It follows, therefore, that the question of first importance in a new iron mining enterprise is to know—First, the *average percentage* of metallic iron in the deposit. What will the ore, *mined in the usual way, yield on the average when smelted in the blast furnace?* Second, approximately or relatively, *how much is there of it?* The failure to answer these questions correctly at the start has caused the loss of over one million dollars in the Marquette region during the last ten years, and the business is still going on. Experience is an expensive school, but is always full; no sooner does one class graduate than a new crop of "freshmen" take their places.

I believe it is not impossible nor even difficult to ascertain, at a moderate cost, the average amount of metallic iron, in any given deposit, sufficiently near for all practical purposes, and whether there is enough ore to pay for working.

It is the business of the explorer to find ore deposits and to determine approximately their extent and richness, thereby avoiding such failures as have been described above. This subject will now be considered under the several following heads:—

2. Prospecting and Woodcraft.

As considerable part of the iron exploration work now being carried on in the Lake Superior region involves camping out and a knowledge of woodcraft, some facts regarding this part of the business will not be amiss here, and are the more necessary because very little reliable information on this subject can be found in any book with which I am acquainted. There are no roads through large districts of country, which, in consequence, can only be reached by boats or walking; in either case a considerable part of the labor is *packing*, which means transporting everything on the backs of men. This mode of transportation costs about $9 per ton per mile at the present time, which is twenty-seven limes as much as it costs to move freight on wagon-roads; it is, therefore, important to carry only such articles as are needed. Many an exploration enterprise has practically failed because the chief energies of the party were expended in carrying supplies and material which were not needed, while necessary things were left behind. It is safe to say that two times out of three, even in the case of experienced explorers, supplies do not come out equal. The party will be out of pork and have an abundance of flour, or the converse; will travel in a leaky canoe for the want of a little pitch, or be barefooted because they had no awl; or ragged for want of thread; or suffering for food, where there is plenty of fish and game, because the salt had failed; or have their supplies wet, for want of a piece of oilcloth. I have been in all these straits.

Organization of the Party.—Take the ordinary case of searching for mineral or timber, when an explorer and two men constitute the party. As packing is the heavy work, it is indispensable that all hands understand it. An average packer will carry 70 to 80 pounds and his blankets, but loads of 50 to 65 pounds are more common; across portages men often carry 100 pounds, and sometimes a barrel of flour weighing 200 pounds; but the packer who carries 70 pounds and his blankets, 10 to 15 miles per day, on a trail, or 5 to 10 miles through ordinary woods, has earned the $2.25 clear per day, which is the present average wages.

Next to packing, cooking is an indispensable qualification. No man is fit to go in the woods who cannot cook ; and many a woodsman, with a frying-pan and two tin pails, will, over his camp-fire prepare a better cooked meal, and in less time, than can be produced in one-third of the kitchens of the country, with all the appliances that belong to modern housekeeping.

An ability to handle a canoe in rapid water is almost as indispensable as the others. Three men with a month's supplies will require a 16-foot canoe, which will weigh, when dry, about 125 pounds, and can easily be carried across a portage by one man; such a canoe will cost, in the Menominee waters, at this time, $15 to $30. The Bad water Indian village is the chief source of supply.

Next to packing, cooking, and canoeing, an ability to travel through the woods, and locate himself, by the United States Land Office plats, or maps made from them, aided by a pocket-compass, is essential. A man who possesses these qualifications is a woodsman, and has a calling which, if he is honest and intelligent, will be profitable in the Lake Superior region for a long time to come. If, in addition to these requirements, he is a judge of timber, and can keep simple accounts, write letters, and locate himself by the "40," then he is fit to lead a party, and become a "pine-looker," or " cruiser." If he add to this, a knowledge of the more common rocks and minerals, and an ability to make rough maps or plans of ground, then he is an explorer. Such men can command from $4 to $6 per day clear, with full time, and often an interest in what they .find besides; or if they choose to examine lands (either timber or mineral) on their own account, they can usually sell their "notes" at so much per acre, subject to re-examination; or some one may purchase the land, paying the explorer for his services in an undivided interest in them. Notes of pine lands now sell readily at from 50 to 75 cents per acre.

Supplies.—Pork, flour and tea embrace all that is absolutely essential in the way of supplies, though sugar, beans and dried fruit are usually added; rice, oatmeal or wheat grits are also generally carried, and a little hard bread is convenient, to which a few pounds of cheese may be supplemented. Pickled ham, especially in summer, may take the place of part of the pork, and smoked beef is sometimes used.

The following table of supplies has been prepared with considerable care from actual experience:—

Rations Required for Three Men, One Month.

Rations.	Pounds.	Amount in percentage of the flour.*
Flour, biscuit or crackers, rice, grits or oat-meal, but at least ¾ self-raising flour (equal to 1⅓ lbs. per man, per day)	125	1.
Extra heavy clear mess pork about ¾; pickled ham, say ¼	82	.650
Beans or peas	20	.160
Sugar (coffee A)	18	.140
Tea (good young Hyson)	3	.024
Dried apples	10	.080
Cheese	4	.032
Salt	2	.016
Pepper	¼	.002
Baking powder (Durkee's or Royal), if self-raising flour is not used	2½	.020
Equal to $2\frac{85}{100}$ lbs. per man per day, or total	266¾ lbs.	

* Supplies purchased in the proportions given in this column should come out even.

Equipment.—A shelter or bake-oven tent is preferable, although a closed A tent is often used in "fly time" (June and July): the former is more cheerful, healthier and warmer, because it lets the fire shine in. The style sketched will hold three men with supplies: it requires 12 yards of cotton drilling, 36 inches wide.

FIG. 13.

Explorers' bake-oven tent.

[13. Explorer's Tent]

NOTE.—The stools shown in Fig. 13 do not belong to a camp outfit. They were introduced inadvertently by the engraver.

Two light explorer's axes, weighing with handles 2¾ lbs. for summer use and 5 lbs. for winter, each, are needed; if the exploration is for mineral, the backs or poles should be of steel. For three men a nest of two or three oval tin pails with covers, the largest holding 5 quarts, one frying-pan with socket handle, one 2 or 3 quart tin basin, one large spoon, one butcher or sheath knife, and a tin cup, plate, knife, fork and spoon to each man in the party, is all that is required.

If the party be large, a tin bake-oven will pay; it should be hinged so as to fold up. Canoes have already been mentioned : they are best for most kinds of river and lake service on account of their lightness, which makes them easy to portage, the ease with which they can be repaired with canvas and pitch (or resin and pork fat), and their suitableness for running rapids. But sometimes they cannot be procured, and in low water are more liable to injury from rocks than are boats; a skiff 2½ fathoms long, pointed at both ends, with flaring sides, and made of ½ inch boards, is a good substitute. Each man in the party should have a pocket compass, water-proof match box, and sheath knife, and there should be at least one leather and one tin map case in each party. Should the exploration be for minerals, a dip compass, and at least one exploring pick ought to be added. A small shovel will pay in such a party, but is seldom carried. A dial compass for use in traveling when there is local attraction, or in discovering the same, is often advantageous. I have found a small horse-shoe magnet and a pocket lens useful. Every party going in the woods should be supplied with the best maps that can be procured (Farmer's are the best I have seen), and always with exact tracings of the U. S. Land Office plats or maps of the Townships they propose visiting; these plats can be obtained at any U. S. Land Office and cost, if they show variations of the needle and geological notes, about $2.25 each at Marquette. The following are the locations of all the U. S. Land Offices in Michigan, with names of officers.

U. S. Land Offices in Michigan.

District.	Office.	Register.	Receiver.
Detroit	Detroit	F. Morley	J. M. Farland.
East Saginaw	East Saginaw	Wm. R. Bates	A. A. Day.
Ionia	Ionia	J. H. Kidd	J. C. Jennings.
Traverse City	Traverse City	Morgan Bates	Perry Hanna.
Marquette	Marquette	A. Campbell	J. M. Wilkinson.

The explorer cannot too carefully study his maps; next to personal examination in the field they are his great original sources of information. The surveys of the Upper Peninsula, as is explained in Chapter I., were made with great care, and embrace topography, timber, soil and geology.

Under sundries which will be found useful in camp, may be mentioned: Soap and towels, thread and needles, buttons, awl, strong twine, some cotton cloth, a file to sharpen axes, a few wrought nails if a boat is used, some extra pairs of moose-skin moccasins (for summer), fish-lines and hooks, extra compass, resin or pitch, blank U. S. plats, and fly-nets or "fly-medicine," or both in "fly-time." A large, stout, water-proof, tin match-box, extra note-book and pencils, paper and envelopes, are desirable. A short, light, single-barreled shot-gun, with bore large enough to chamber buck-shot, may be carried to advantage after the middle of August.

Mode of Working.—Mineral explorations, and especially those for iron, will only be considered under this head. The leading idea is, of course, to make a systematic and exhaustive examination of the surface for

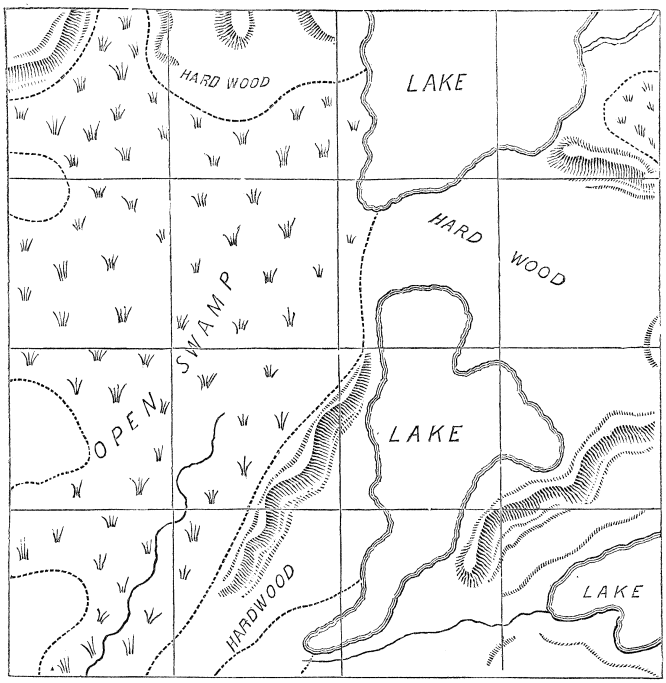
the mineral sought: to this end all outcrops of rock of whatever kind, and all boulders must be examined for some "sign" or "show" of mineral. As has been elsewhere remarked, the upturned roots of trees afford one of the best sources of information: the beds of rapid streams, which usually contain boulders and often expose the solid ledge, should be carefully examined. Any indication at all favorable should be followed up by digging. Next in importance to this kind of search is the use of the magnetic needle in discovering local attractions due to iron-ore; it is safe to assume that more than one-half the iron in the Lake Superior iron region is sufficiently magnetic to produce appreciable variations in an ordinary compass; and as magnetic ore will attract the needle at the same distance with equal strength when covered by rock, earth, air or water, this instrument is of great service to the explorer. Its use is fully considered elsewhere, as well as the geological principles applicable to this kind of work.

An explorer should make a careful sketch or map of each section examined, on a scale of 4 inches to 1 mile: on such a scale "a 40" is one inch square. On this should be marked in their proper places all streams, lakes, swamps, hills, etc., and all outcrops, with a name or sign indicating the kind of rock; colored pencils are convenient for delineating the different varieties of rocks. Opposite each such sketch should be a full written description of the rocks and minerals found, as well as notes on timber and soil.

The accompanying sketch (Fig. 14) of Sec. 29, T. 50, R. 30, from the note-book of the late A. M. Brotherton, a perfectly honest and thoroughly competent explorer, will serve as an illustration. To it is appended a map of the same section (Fig. 15), from the U. S. Surveys, which shows, valuable as these surveys are, and reliable, so far as the section lines go, they often are considerably in error in their representations of the interior of sections.

How to Recognize Iron Ores.—As a large majority of the explorers now employed are timber-hunters, they need not necessarily have a knowledge of minerals. I have, however, generally found these men more or less interested in rocks, and often very desirous of knowing how to determine the more common ores, so as to be able to note any they might find. To obtain a good knowledge, the study of a complete collection, or a residence at a mine, is indispensable. A few brief characteristics, only, will here be given, by which explorers may generally recognize iron ores in the woods.—First.—They are considerably *heavier* than any other rocks with which they are associated. Rich, magnetic, and specular ores, like those of the Marquette region, are nearly twice as heavy as the same bulk of the more common rocks, and five-sevenths as heavy as a piece of iron or steel of the same size. The soft hematites are much lighter, but are still appreciably heavier than the heaviest rock. As fine muscular sense and much practice are necessary in this business, the inexperienced explorer is advised, in every instance, to break pieces of rock of the same size as the supposed ore specimen, when, by lifting them together and changing from one hand to the other, the difference in weight will at once be felt if one of the specimens be iron ore. If the explorer Is provided with a pair of balances, as is explained hereafter, he may determine, not only as to whether the substance is iron ore or not, but also approximately the percentage of metallic iron.—Second.—As to color, *magnetic* ores are black, and when pounded with the axe give a black powder, which will adhere to the axe or pick. Red *specular* ores are often bright and shining on their weathered surface, almost like polished steel; they give a red powder when pulverized, which does not adhere to the axe. Soft *hematite* ores are reddish and brownish in color, are generally porous, and often soft and earthy, in character; when pulverized they give a brownish and sometimes a yellowish powder, which does not adhere to iron or steel. These characteristics are possessed by none of the rocks of the Marquette region.—Third. Magnetic ores attract the needle of the compass strongly, often causing the north end to point south. Other ores and rocks do not attract it, but a little magnetic ore is often disseminated through rocks, especially greenstone, thereby producing more or less variation of the needle, which may not indicate valuable ores.

Fig. 14. Sec. 29, T. 50, R. 30. Explorer's Sketch.

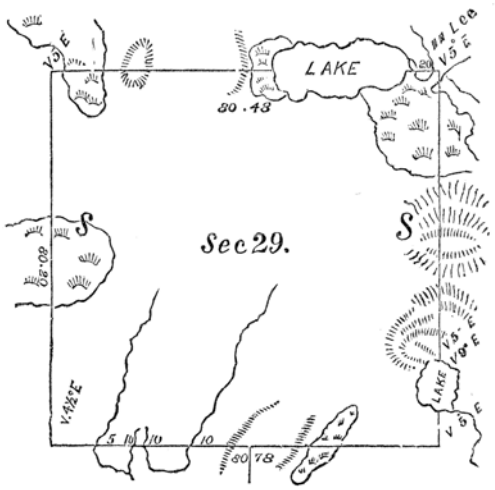


[14. Explorer's Sketch, Section 29—T. 50—R. 30]

The rock which is oftenest mistaken for iron ore is Hornblende, and the related Diorites or Greenstones. These rocks are heavy and dark colored, and often contain enough magnetite to give them some influence on the needle. Many an explorer has carried heavy pieces of this rock many miles through the woods, only to throw them away in disgust on meeting some one who had, perhaps, only so much knowledge of ores, as it is expected these few facts will impart. Some have persisted In their folly, and bought lands on which

experienced iron explorers could only find hornblendic rock. This rock differs from the ore, which it most resembles, in being *lighter*, and in giving a *light colored powder*, which does not adhere to iron or steel, as well as in other less important particulars, as may be seen by comparing the two, which should be done.

Fig. 15. Same Section, from U. S. Linear Surveys.



[15. United States Surveyor's Map, Section 29—T. 50—R. 30]

The text relating to the magnetism of rocks and use of the needle in finding ore might properly have been inserted here as a division under Exploration, of which subject It forms properly a part. But the amount of material which had been prepared on that subject, and other reasons, determined me to place it in a distinct chapter (VIII.), which follows.

3. Digging for Ore.

The exploration work above described is superficial, and will not usually determine whether a certain piece of land contains workable deposits of ore or not. Such examinations are usually made to determine whether lands are worth buying at government price, or as preliminary to a more thorough exploration. When we consider that soft hematite ores never outcrop, and that pure hard ores rarely do, it is evident that something more than looking over the surface is necessary. The excavations of earth and rock required in an exhaustive exploration of a piece of land are mining operations, and will be considered in another chapter. Only a few points will be presented here which bear especially on work of this kind.

This work is simply sinking test-pits and shafts, and opening trenches (costeaning) and drifts to expose the solid ledge. It rarely happens that such work need be prosecuted into the solid ledge. As has been before remarked, if there be pure ore at the locality, i will be almost certain to come to the surface of the ledge somewhere, and will there be found by digging through the earth. This may not always be the case, but it is safe to say that, as a rule, nine-tenths of all the money to be expended in exploring at any given locality, had best be expended in earth excavation.

There is a great deal of vague talk among miners and explorers of the Marquette region about "*cap rock;*" one would get the impression, from much that is said on this subject, that pure ores were always overlaid by rock. The fact is, however, that there are very few workable deposits of ore but what come to the surface, or, at least, connect with those that do, I should distrust any locality where "cap rocks" prevailed to any great extent; our iron-ore deposits are comparatively thin beds, which sit on edge, and come to the surface without wearing any "cap."* There are places, however, where the solid ledge has to be penetrated; when this is necessary, I think it had usually best be done by drilling. By means of hand drills, holes can be sunk 22 feet, and by means of the appliances used in sinking oil-wells to any required depth; an experienced miner will have little difficulty in judging of the material passed through by the drill mud, and if there is any question as to richness, it can easily be settled by an approximate analysis which will be described hereafter. The diamond drill gives the most valuable results, and has been used to some extent in this region, and still more extensively in the Lake Champlain region.

Exploring excavations should always be done by contract; a large amount of "test-pitting" has been done in the Marquette region at seventy-five cents per foot in depth for a 4 x 6 shaft, the miner being paid only for such shafts as were "bottomed," *i. e.*, the solid ledge reached and uncovered, whatever the depth or difficulties. For drifts 3 x 6 which bared the ledge, $1.50 was paid, and for open trenches a price proportionate to depth and width. Good miners can find themselves and make good wages at these prices in much of the ground in the Marquette region. Pits are sometimes sunk 35 feet, but the average depth does not exceed 12 feet. Mr. Colwell sunk 67 feet through sand on Section 24-47-28. Large boulders and water are the difficulties usually encountered; beyond 10 feet a windlass is necessary. A portable forge and mass of iron for an anvil are desirable, but picks can very well be heated in a hard-wood camp-fire and sharpened on a rock.

With regard to the significance of the material passed through, but one remark will be made; mixed drift, that is, large and small boulders, sand, clay, etc., is usually not very deep, 40 feet being the greatest depth I have observed, the average being less than 10 feet. Sand with no boulders is usually deeper and sometimes very deep.

*In the Menominee region true "cap rocks" are found in the horizontal sandstones which overlie some of the ore, see page 68.

4. Quality and Quantity.—Sampling.—Approximate Analysis.

Up to this point we have considered chiefly the question of finding ore regardless of *quality* and *quantity*. These are, after all, the vital questions, and their importance is rendered still more conspicuous by the statement, that there is at least twenty times as much ore in the Lake Superior region that is worthless from a lack of metallic

iron, as there is of merchantable ore, according to the present standard for shipment; and further, it is easy to find specimens of pure ore in almost any body of worthless ore.

To determine approximately the average percentage of metallic iron, proceed as follows:—Open two or more trenches or drifts entirely across such portion of the ore formation as is regarded fit to work. In the region we are considering, the ores usually dip at a high angle, so that the edges of the beds or strata are exposed by such cross cuts; free the solid ledge from all earth and loose material; then, with a heavy hammer, break off small fragments *every two inches across the entire bed*, without reference to whether the pieces are ore or rock. Wash all of those pieces, break them all into fragments of the size of grains of wheat, mix them up thoroughly, send a tea-cupful to a reliable chemist, and his return will be the practical average of metallic iron in the whole bed from which the pieces came.

Of course, in mining, the ore is sorted, so that we should expect to get a somewhat better yield from working the ore, than that found as above, but it is not wise to count much on this. If, after trying, say half a dozen cross cuts in this way, an average yield of fifty per cent. (50%) of metallic iron is not found, the deposit is doubtful; if less than forty per cent. (40%) it is of no value in the present market, should the ore be specular or magnetic. Nineteen times out of twenty, such *mechanical averages*, when honestly taken, would show a yield of less than forty per cent. (40%.)

The plan above described is somewhat expensive and consumes time, which is an important element where one is maintaining an exploring party in the woods. A method which can be used on the ground, and which will give results, according to my experience, within a few per cent. of the above in the case of the silicious or quartzose hard ores (the kind usually found), is the following:—Provide an ordinary swing balance which will sustain at least two pounds, and weights, the smallest of which should not exceed five grains, the whole costing less than $5. Break up numerous hand specimens across the ore deposits as before, wash and dry them. Suspend each in turn by a fine fish-line and weigh it in the air, afterwards weigh it when immersed in water. Divide the weight in air by the difference between the weight in air and the weight in water. The quotient will be the *specific gravity* of the specimen, and will range from 3.17 for very lean ores to 5.13 for very rich compact ores. The specific gravity so obtained, multiplied by thirteen, if the ore be rich (*i.e.*, above 55%), and by twelve, if the ore be lean (*i.e.*, from 40 to 55%), will give the approximate percentage of metallic iron in the specimen.

The mean of a large number of determinations, made with specimens selected promiscuously from the deposit, will give a close approximation to the average percentage of metallic iron in the bed. According to my experience, the error will fall within five per cent., which is nearer the truth than any man can determine by simple inspection. It must be borne in mind that this purely empirical rule applies only to Lake Superior *magnetic and specular* ores, and only to such as contain some form of quartz as gangue, which is true of nearly all. The numbers 12 and 13, given above, as multipliers, were derived from numerous analyses and specific gravity determinations made by Dr. C. F. Chandler, of New York, and J. B. Britton, Esq., of Philadelphia. This plan is not offered as a substitute for chemical analysis, but I believe will often prove useful in the woods, and may sometimes help in deciding whether it is worth while to have an analysis made. As has been before stated, unless the deposit is proven by analysis to contain an average of 50% of metallic iron, if specular or magnetic, and not less than 40%, if soft hematite, it is of doubtful value at the present time.

It would seem as if sufficient experience should enable us to judge of the quality of an ore at sight, or at least enable us to select an average specimen for analysis, without the laborious plan above described; but this is not the case, as is well known to those who have had experience in iron ores. It may be stated as an economic and psychological axiom, *that no man, however honest or skilled, can, on his judgment alone, select an average specimen of ore front a deposit; he will always choose a richer specimen than the average.* This would, of course, be very difficult from the technical stand-point, on account of the delicacy of muscle and skill of sight required; but the greater and insurmountable difficulty is in the human mind. We cannot help feeling that at a new opening there must be somewhere under our feet, or near by, better ore than we can see and the specimen selected is designed to be rather what we suppose, believe or hope the deposit to be, than an average of what we actually see and feel. I have numerous facts under this head, and am able to give an approximate mathematical expression to this form of human hopefulness. In eleven instances the difference between the *average by judgment*, and the *mechanical average* obtained as above described, varied from 6 to 24 per cent., averaging 11; the mechanical average being least in every instance; in each case I had reason to have confidence in the honesty and skill of the parties. It does not seem possible that such errors in average could exist, but they are constantly made, and will continue to be as long as iron ores and human minds are constituted on the present plan.

One of the fallacies which have caused innumerable disappointments in iron mining is the belief, almost universal, that ores grow richer in depth. This may be true of certain ores in some regions, but it is not true of the iron ores here being considered. They are just as good on top as in any part of their extent, and it may be stated as an invariable rule that if there be any good ore in a given deposit which is available for mining, it will somewhere come to the surface, except the earth covering in the Marquette region and the sandstone in the Menominee, which of course have to be removed when found. Hence a sufficient number of earth test

pits, trenches and drifts will usually find it, if it exists, without penetrating the rock. I do not mean to say that a deposit of ore may not grow thicker in depth; they often present this feature, and on the other hand sometimes grow thinner, and wedge out entirely. As has been before stated, by far the larger part of the money available for the exploration of any given locality should be spent in earth work.

While it is not difficult to determine with sufficient accuracy for all practical purposes the quality of a deposit of iron ore, as has been above shown, it is often impossible within a reasonable cost, to form so reliable a judgment as to the *quantity*. But a sufficient amount of judicious exploration will usually settle the all-important question as to whether the deposit is large enough to warrant development as a mine, future operations alone determining whether it will prove a great or small one. The method of doing this is obvious; many test-pits and trenches must be dug and drifts made where the earth is deep, the ledge of ore being thus laid bare in as many places as possible. No one engaged in making an exhaustive exploration of an iron-ore property should neglect the advantages of deep drill-holes; these can be sunk 20 feet with the ordinary drills employed at the mines. An inspection of the mud, and especially an analysis of an average of it, will prove of great value.

The annular diamond drill was introduced in 1870, at the Lake Superior mine, and gave very satisfactory results; the core gives almost as good an idea of the nature of the rock passed through as a shaft, and the cost is far less,—about $5 per foot. But being propelled by a steam engine, it is only adapted to work near communications; it cannot be taken into the woods.

In the case of magnetic ores great assistance in determining the extent and position of the bed can be derived from a proper use of the magnetic needle, which subject is considered in the following chapter. Attention will, in this connection, only be directed to one important fact; *worthless ores often attract the needle just as strongly as merchantable ones*. Now, as there are many times more lean magnetic ores than rich, it follows that a variation or dip of the needle may not, probably does not, signify a workable deposit.

CHAPTER VIII.
MAGNETISM OF ROCKS, AND USE OF THE MAGNETIC NEEDLE IN EXPLORING FOR ORE.*

1. Elementary Principles.

A FEW of the elementary principles of the science of magnetism, made use of in the following investigations, will first be given.

Magnetite, or magnetic iron ore, contains, when pure, about 72 per cent. of iron and 28 per cent. of oxygen. The unmixed mineral is black, or blackish in mass and streak, has a specific gravity of 4.9 to 5.2, and hardness of 5.5 to 6.5, which is somewhat less than that of quartz ; its crystals are usually octahedrons, and in the massive state it is often granular, and sometimes friable. Magnetite is one of the most abundant ores of iron in the United States, and, besides occurring in workable masses, is often disseminated through certain rocks, in grains, or in bunches and thin seams or laminæ, thus constituting what will be called "magnetic rocks" in this paper.

Its home is in the oldest rocks:—the primary (azoic, eozoic or archæan), as they have been successively termed. When it occurs in younger rocks, its origin can generally be traced to local metamorphism. The characteristic property of this mineral is its *magnetism*, with reference to which it is sometimes called *lodestone*. When brought near to pieces of iron or steel it often manifests an attraction for them, as it always does for another magnet. It hence causes the magnetic needle to deviate from its normal direction when brought near it. This property does not belong, in any marked extent, to any other mineral, and is the one which we have here chiefly to consider.

*A part of this paper was read before the American Philosophical Society, Philadelphia, and published.

A piece of magnetite, broken from its parent bed, and suspended by a thread, will take a position, as near as the mode of suspension will permit, corresponding with its original one. If a north and south line be marked on a specimen thus suspended, it would rudely and imperfectly answer the purpose of the magnetic needle; if with this piece of magnetite we rub, in a certain way, a slender bar of hardened steel, it in turn becomes magnetic, and, if properly mounted, will point north and south, and constitute a compass. Mounted in another way, so as to admit of vertical motion, the magnetic needle will, while pointing north, incline downward at an angle of about 76° at Marquette. This "dip," as it is called, increases to the north and decreases to the south.

Two magnetic needles made in this way present these phenomena: their north poles or south poles repel each other, while the north pole of one will attract the south pole of the other, and conversely. The same is, of course, true of two pieces of magnetite, or of a piece of magnetite and a magnetic needle; *opposite poles attract, and similar poles repel*. This property is termed *polarity*. From this it appears that the north magnetic pole of the earth must, in the light of the science of magnetism, be regarded as a south pole, because it attracts the north end of the magnetic needle. The *poles* of any magnet are understood to be those points opposite each other, and near its surface, where the attractive and repulsive power may be supposed to be concentrated. Any magnet, natural or artificial, exerts its influence or sends out its rays in every direction, like a luminous point. The limit of this influence may be designated as the *sphere of its attraction*. A magnetic needle within this sphere, and uninfluenced by other force, would point directly to the

centre of the sphere or focus of attraction. The force which holds it in this direction varies inversely as the square of the distance from the centre; hence practically (on account of this rapid diminution of power) we soon get beyond the influence of even a great natural magnet, like a hill of magnetic ore.

All the properties above designated, and numerous others not necessary to our purpose, appertain in general to a mountain of magnetic ore or rock, as well as to the delicate needle of a miniature compass. It is therefore evident that the magnetic needle should assist in determining the position and magnitude of rock formations containing magnetite. It has been extensively used in numerous places in finding iron ore, and to a far less extent, if practically at all, in this country, by field geologists, in determining the geographical extent, and, in part, lithological character of formations containing too little magnetite to give them commercial value, and which have already been designated *magnetic rocks*. The fact that all substances usually encountered in magnetical observations are transparent to the magnetic rays, or permeable by them, enables us to be certain of the existence of magnetic rocks or ores, though they be covered with water, earth, or non-magnetic rocks, to the depth of many feet, or even fathoms. *A given magnetic force affects the needle just as much through one hundred feet of granite as through the same distance of the atmosphere*. Dr. Scoresby gave a fine illustration of this fact, and an important application of the science of magnetism, by measuring, with great precision, 126 feet through solid rock, by observing the deviations in a needle, caused by an artificial magnet.

The earth itself may be regarded as a great magnet, which has the power of inducing this force (all magnets have a similar power) in masses of magnetite, and in all forms of iron and steel. We may suppose the force we have described above, as existing in the magnetic rocks and artificial magnets, to have been derived from the earth. An unmagnetized mass of steel or iron always manifests polarity induced by the earth, the upper or southerly portion being the *south pole*, and the lower or northerly end the *north pole*, in accordance with the law already stated. If the mass of iron of steel be elongated in form and made to stand nearly vertical, or to lie nearly in the plane of the meridian, this force is more manifest. To illustrate:—The upper end of all cast-iron lamp-posts attracts the north end of the needle, and the lower end the south. The magnetism thus induced in the wrought-iron pipes, lining the so-called magnetic wells of Michigan, would probably explain all the phenomena actually observed there. The law is, briefly: *the upper part of every mass (of whatever form and size) of iron, steel or magnetite, is a south pole, and the lower part a north pole*. This is, of course, true of magnetic rocks; hence almost universally the north end of the needle is attracted by such rocks, because it is the south pole of the rock which is uppermost and nearest. South pole or *negative* attractions, which are occasionally observed, come usually from faults or other divisional planes in the rocks; opposite poles being produced on opposite sides of such breaks which sever the mass; a precisely similar phenomenon can often be observed on opposite sides of the joints in railroad tracks.

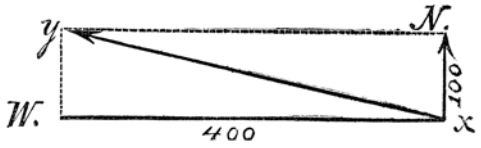
From this cause several natural magnets are often encountered in a short distance; and a needle, passing in a few feet from the sphere of the attraction of one of them, will turn round and point toward the pole of a neighboring mass which more strongly attracts it. Hence, in magnetic surveys, we have not the simple focal point first considered to deal with, but often several local centres of attraction, positive and negative, in addition to the directive force of the earth, all influencing the needle at the same time. The recent investigations in the use of "magnetism in testing iron for flaws" would undoubtedly aid in the study of the effect of faults on the magnetism of rocks. See Engineering (London), 1867, p. 550, and 1868, pp. 297 and 440. The magnetism of iron ships should also possess interest in the same connection.

The *direction* which a magnetic needle takes (allowing it to have universal motion), under the circumstances supposed above, and the *power* with which it holds to that direction, must be the mechanical resultant of all the forces acting on it. It cannot point in two directions at the same time, hence stands between, inclining to the greater force. The principle of the parallelogram of forces makes it easy to determine the direction of this resultant, and to measure with mathematical precision the power which urges it. To do this we must know the direction and intensity of all the forces.

As an example, suppose a magnetic needle which, uninfluenced by other force than the earth's attraction, points due north and vibrates 10 times in one minute, to be placed due east from a south pole in a magnetic rock; and that, in this position, the earth's directing force be exactly neutralized by an artificial magnet, placed south of the needle,—it is evident that a needle so situated will point due west, urged by the local force alone, and that its vibrations will be solely due to this force. Suppose, for example, these vibrations to number 20 in one minute, or twice as many as were due to the earth's force. Now remove the artificial magnet; what will be the direction of the needle, and what number of vibrations will it give, urged by the local and cosmical forces?

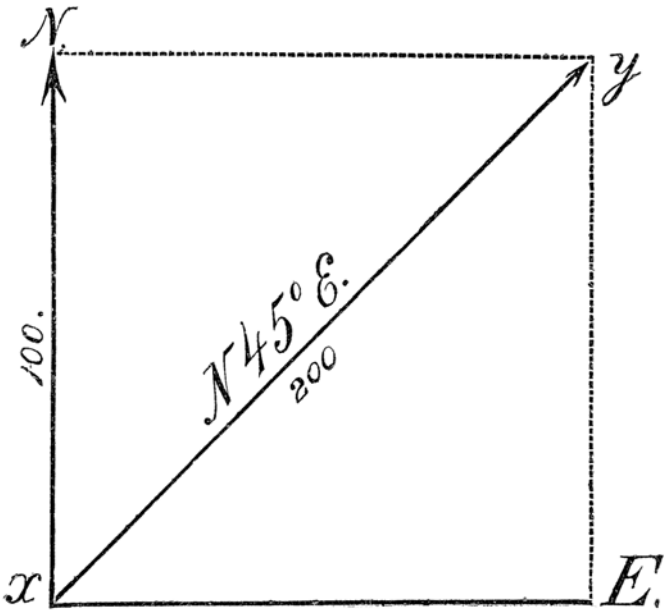
It is a law of magnetism that the force urging a magnetic needle is proportional to the square of the number of vibrations made in a given time; $10^2 = 100$ and $20^2 = 400$, hence the local force is four times as great as the earth's. Lay off in Fig. 16 the line x N due north, making it equal 100 on some chosen scale: lay off the line x W due west, making it equal by the same scale 400; complete the parallelogram by drawing the lines N y and W y parallel with the first lines. Draw the diagonal x y, it will be the resultant sought. Applying the protractor and scale we find its course to be N. 75° 53 W., and length to be 412.31, the square root of which is 20⅓, which would be the number of vibrations.

Fig. 16.



[16. Local magnetic attraction (magnetic triangulation)]

Fig. 17.



[17. Local magnetic attraction (magnetic triangulation)]

Suppose that in another locality the same needle pointed N. 45° E. and vibrated 14¼ times in one minute, what would be the direction and intensity of the local force? In Fig. 17 lay off the line x y N. 45° E., its length equal to the square of the number of vibrations = 200 ; complete the parallelogram as before. It is evident that the line x E represents the direction and intensity of the local force, which in this case is due east, and has a power just equal to that of the earth. Unfortunately the simple cases here presented seldom occur,—usually two or more local forces act on the needle at the same time.

In a similar manner any number of forces acting in as many different directions can be resolved. It follows that a magnetic needle, influenced by the earth's force, can never point directly toward a local magnetic pole, but will, with two exceptions which need not be named, always incline to point to the north of it.

It is evident that the degree of magnetism possessed by a needle, while it makes no difference with its direction, will affect the number of vibrations. Take the needle in the last case, and suppose it more highly charged; it will still point N. 45° E., but its vibrations will be increased in number just in proportion to the additional power imparted. Hence, in determining absolute terrestrial or local intensity, a standard for comparison is necessary; but this is not required in the work under consideration.

2. Magnetic Instruments—Dip Compass.

As the instruments employed in these observations are quite different from those used in Terrestrial Magnetism, which are described in the works on this science, a brief account of them will be given.

The Dip or Miner's Compass is a circular brass box, a common form being 3¾ inches in diameter, and ¾ inch thick, having a circular glass on each side, which permits a perfect view of the needle. The needle is 2⅞ inches long, weighs 13¾ grains, and is counterpoised so as to stand horizontal where there is no local attraction, the needle being permitted to *swing in a north and south vertical plane*, which is the position in which it is ordinarily used. The axis of the needle is of hard steel, its points resting loosely in conical cavities in agates, fixed in two arms projecting from the sides. Outside is a ring for supporting the instrument when observations are made, so placed that the weight of the suspended instrument brings the zero line of the graduated circle to a horizontal position. Although designed to be used chiefly for determining dips or inclinations of the needle due to local influences, it answers passably well for taking magnetic bearings when laid on its side, and is frequently used in this way in rough work.

As there is usually no means of throwing this needle off its points of support, the wear is great, and the instrument is often out of order. A person going out of the way of shops where repairs can be made, would do well to take two, and then have the means at hand for making ordinary repairs. These compasses generally possess each an individuality of its own, and one must know his instrument before placing much confidence in his results; they will seldom reverse, 30° difference in the two readings being not infrequent. A New Jersey iron explorer informed me that his Dip Compass always indicated 90° when faced west, and the true dip due to local attraction when faced east. He is said to have used one position in buying and the other in selling iron lands very successfully.

My compass was made by Messrs. W. & L. E. Gurley, of Troy, N. Y. I have since seen one made by H. W. Hunter, of N. Y., which promises well. A reliable dip compass is a desideratum.

This is exclusively a hand instrument, and has no support; nearly all the magnetic observations recorded in this paper were made on instruments held in the hand. This may seem rude and unscientific to precise observers of physical phenomena; but it was found by trial that the average error by this mode of observation was less than 3°, which was comparatively small in localities where changing the position of the instrument only a few feet often made 50° difference in the direction of the needle, and deviations of 180° from the normal direction were common. It is not necessary to observe the direction of the wind to the degree to construct a useful theory of storms. Had the accurate instruments and precise methods of terrestrial magnetism been employed, not more than 50 stations could have been

occupied with the time at my disposal, while with my rude methods over 1,000 stations were observed at.

The miner's compass above described is now in very general use in the magnetic iron-ore regions of the United States. The object here sought is to endeavor to point out new and perhaps better modes of using that instrument in finding iron ore, and incidentally to ascertain if it has any place in general geological field work. I have long believed that the magnetic needle can be so used as to give more definite information regarding magnetic ores and rocks than has yet been done to my knowledge. I did some rude and incompleted work in this field, at the Ringwood Iron Mines and elsewhere in New Jersey and Southern New York, the results of which are in part published in Prof. Cook's Report on the Geology of New Jersey. The observations of Prof. Cook and Dr. Kitchell on the magnetism of the iron ores of New Jersey, and the use of the magnetic needle in finding them, possess interest; see pp. 532-538 of their report. The map of the Ringwood Iron Mines, accompanying that report, exhibits a part of my own observations above referred to.

The idea of applying Magnetic Science to Geology is not at all new; years ago Bischoff, after citing numerous observations that had been made in various parts of the world by different observers in regard to the influence of mountains on the magnetic needle, concluded as follows: "Assuming that it is magnetic ore alone, either as masses or disseminated through the rocks, to which the magnetic influences are to be ascribed—and in my opinion this is quite unquestionable—it would seem that magnetic observations instituted with the same degree of care as those made by Reich, would be well adapted for the discovery of hidden beds of magnetic iron ore. Such observations might therefore prove eminently serviceable to the iron industry. Certainly it would be requisite first to ascertain whether mountain masses containing only disseminated magnetic iron ore, but extending over a considerable surface, would not produce as great an effect as beds of magnetic iron ore. Sabine's observations do not appear to favor this; but, however this maybe, the magnetic needle indicates the presence of magnetic iron ore where it cannot be recognized mineralogically, and demonstrates the very general distribution of this mineral."

My mode of observing was as follows:—To determine "variations" east or west,* the bearings of a standard line were taken as in ordinary surveys. Sometimes a solar compass was used, but oftener a pocket compass. The variations as shown by the miner's compass, termed "dips," were observed on this compass held in the hand generally in the plane of the meridian, hence the instrument would face east and west. Sometimes observations were made with the compass held at right angles with this position; that is, facing north and south. The instrument was always held in the hand and levelled by its own weight.

The *intensity* of the magnetic force for the three positions of the compass above designated, was measured by the number of vibrations† made by the needle in a unit of time, usually taken at ¼ of a minute. The vibrations varied from) to 60 in this time, 6 being the normal for my compass, due to the earth's influence. No attempt was made to eliminate the earth's attraction by neutralizing it with a magnet when the observation was made, or by computation. Of course, when the compass faced north or south, this was partially accomplished, because the earth's attraction would then be nearly in the direction of the axis of the needle. It must be borne in mind that the great amount of friction in this form of compass renders the number of vibrations only a rude approximation to the number which would be indicated by a delicately mounted needle.

*Declination, or the cosmical deviation of the needle from the true meridian, is not here considered.

†Half-vibrations would be the proper term, as the time from one point of rest to the next was counted and not the complete vibration.

The short needle of an ordinary pocket or dip compass, if in good order, will vibrate quickly and for some time where there is no local attraction. This motion is sometimes termed "working," and such normal "working," due simply to the earth's attraction, has often been mistaken by inexperienced persons for an indication of ore.

There is no better instrument for observing variations accurately than Burt's Solar Compass; but it is too heavy for explorers' use. I have found a convenient substitute for rough observations in the Pocket Dial Compass, which, used with a watch indicating local time, is rapid and sufficiently precise. This instrument, or an ordinary portable sundial, can also be used for running lines where there is local attraction; for rough work I have used it instead of the Solar Compass.

I hoped to have made some observations with properly constructed instruments, such as are used in determining the elements of terrestrial magnetism, in order to institute a comparison between accurate results and my own rude work; but the nature of such investigations requires more time than I have thus far had at my disposal. Fortunately Dr. John Locke made complete magnetic observations at several points in the Marquette Iron Region, which are recorded in "Smithsonian Contributions to Knowledge," vol. 3, pp. 25-27. One station was over magnetic rocks in Section 18, Town 47 north, Range 26 west, the geology of which he thus describes: "A loadstone in place broken into sharp angular fragments; here were two poles, 17.67 feet apart, one attracting the north, the other the south pole of the needle." Dr. Locke found the dip to be 42 deg. 53 min., when it should have been about 76 deg. The duration of 500 vibrations was 822 sec., when it should have been about 1,500 sec., and the calculated horizontal intensity was more than four times the normal force computed for that station. If Dr. Locke had occupied 500 stations on that section of land, he would have obtained different results at each, often differing more from each other than the foregoing do from the normal forces.

These observations, like all recorded ones that have come under my notice, have had *terrestrial magnetism* as their chief object; therefore the observers have avoided the very localities which to the geologist and explorer possess the greatest interest—those where local magnetic attractions exist. Dr. Locke calls attention to the importance of magnetic science to the geologist, and gives many interesting isolated facts bearing on the subject, particularly regarding the existence of magnetite in volcanic rocks, where it usually occurs.

Before dismissing the subject of instruments suited to magnetic surveys, I will call attention to a patent mariner's compass made by E. S. Ritchie, Esq., of Boston, in which the needle is entirely supported by a liquid having the same specific gravity, thus giving it universal motion. A needle so mounted and having the earth's attraction neutralized by a magnet, should point directly towards a local magnetic pole when brought within its influence, thus accomplishing with one observation and no calculations what requires at least two with the ordinary compass. For intensity Mr. Ritchie suggested the following mode:—Time the needle from the instant of its being let off at 90 deg. to its passing the resting point. I am of the opinion that a valuable instrument for miners and explorers could be made on Mr. Ritchie's plan.

A modification of the ordinary compass has been made which accomplishes the same thing in part. The agate support is fitted to the needle by a sort of universal joint, which gives the needle a vertical range through half a quadrant in addition to its horizontal motion. The only one I ever saw was made from the design of the late Wm. J. Amsden, Esq., of Scranton, Pa., who made some valuable magnetic surveys.* A pocket compass on a similar idea has lately been patented. A somewhat similar instrument has, I understand, been used for a long time in Sweden and Norway. On the same principle the ordinary surveyor's compass Indicates dips rudely. At the west quarter post of Section 7, Town 46 north, Range 29 west, being on the east side of Republic Mountain, I find marked on the U. S. Survey plat: "End of needle dips ¼ inch, variation 62 deg. west."

C. F. Varley, Esq., the English Electrician, suggested to me that a portable electro-magnetic apparatus could be constructed, with which might be determined the direction and distance to the pole of a magnetic rock by some simple observations and computations. An instrument of this kind would have considerable value in connection with magnetic needles, especially where the magnetic ore or rock was covered with considerable thickness of other material. In 1867 Mr. Varley, with a view to detecting electric currents, if any existed, made some observations both in the copper and iron-bearing rocks of Lake Superior; he found such currents in the mines of native copper, but none in the iron mines. The instruments employed were rude, having been extemporized on the spot. I do not know whether he has published anything on this subject.

Professor Joseph Henry has suggested in a letter that it is "highly probable that the abnormal variations of the magnetic elements in our iron ores are due to electro-*magnetic* action rather than to magnetic."

*Messrs. Gurley now make a dip compass which gives the needle limited lateral range.

3. Geological Sketch of the Magnetic Rocks.

In order to make the perusal of this subject to a certain extent independent of the remainder of this report,* a few facts regarding the geological position and lithological character of the magnetic rocks of the Marquette region will here be repeated, the subject having been more fully considered elsewhere.

Rocks of the four oldest geological epochs yet made out on this-continent are represented on the Upper Peninsula of Michigan; two belonging to the Azoic, one to the Lower Silurian, and one between these, of questioned age. The equivalency of these with the Canadian series has not been fully established, but the nomenclature of the Canadian geologists will be employed provisionally.

*Many persons have asked for copies of this chapter who do not expect to get the whole Report.

The Laurentian of the Upper Peninsula is like that of Canada in being largely made up of granitic-gneisses, but differs in containing no limestone so far as I have seen, and little, I may say practically no iron ore, and very little disseminated magnetite. Next above the Laurentian, and resting on it non-conformably, are the Huronian or iron-bearing rocks; these are also called by the Canadian geologists “the lower copper-bearing series." This series comprise several plainly stratified beds of iron ore and ferruginous rock, varying in the percentage of metallic iron from 15 to 67 per cent., interstratified with greenish tough rocks, in which the bedding is obscure, which appear to be more or less altered diorites, together with quartzites (which pass into marble), clay slates, mica schists, and various obscure magnesian schists. The maximum thickness of the whole in the Marquette region is not far from 5,000 feet.

While the great Huronian area of Canada north of Georgian bay bears, so far as I am aware, little or no workable iron, and derives its economic importance from its ores of copper, the Marquette series, supposed to be of the same age, are eminently iron bearing, and have as yet produced no copper. It is doubtful if in the same extent and thickness of rocks, anywhere in the world, there is a larger percentage of iron oxide than in the Marquette series. In the order of relative abundance, so far as made out, the ores are the *flag*, the red *specular* hematites, soft or brown *hematites*, and *magnetites*. These all exist in workable beds, and all as disseminated minerals in rocks usually silicious. The geological distribution of these ores of iron in the Huronian series will be considered in another place. The geographical distribution is less understood; so far there seems to be the greatest concentration of magnetic ores in the

Michigamme district of the Marquette region. From this, the relative proportion of magnetite seems to decrease as we go east, north, west and south, although there is a considerable magnetic attraction in the Menominee or southern iron region.*

Next younger than the Huronian are the copper-bearing rocks of Keweenaw peninsula, which extend westward into Wisconsin, the age of which has led to much controversy; good authorities having placed them in different epochs, from the Azoic to the Triassic. Recent observations made by Prof. R. Pumpelly and myself go strongly to confirm the view, if we have not positively demonstrated it, that they are non-conformably overlaid by the Silurian, and are therefore related to the Azoic. The relations of the copper-bearing rocks to the Huronian are not fully made out. In tracing the dividing line from Bad river in Wisconsin to Lake Gogebic, Michigan, last fall, a distance of sixty miles, we found them nearly, if not precisely conformable, but widely different in lithological character.

*See Appendix H., Vol. II.

With regard to the magnetism of the copper-bearing series, the United States surveyors mark considerable variations at several points on the Land Office plats, due in all probability to disseminated magnetite in the trappean members of the series, although good authorities have ascribed these variations to electric currents. My own observations on the magnetism of these rocks have been limited, but lead me to believe that it is far less in amount and less persistent in character than is usually the case in the Huronian, indicating that the magnetite (to which I ascribe the attractions) is perhaps an accidental rather than essential constituent, and small in amount. Macfarlane found less than one per cent. in one of the Portage lake traps.

The next series of rocks in ascending order are the horizontally-bedded Lower Silurian sandstones, which skirt the south shore of Lake Superior nearly its whole length, called by Foster, Whitney, and Dr. Rominger, Potsdam, and assigned by the Canadian geologists, under the name St. Mary's, to a later period. They have not been proven to be magnetic, although strong magnetic attractions have been observed over this Silurian area, as will be explained hereafter.

To recapitulate, we have: 1. The Laurentian granite and gneiss, practically non-magnetic; 2. The Huronian iron-bearing rocks, often highly magnetic ; 3. The copper series, slightly magnetic; and 4th. The Silurian rocks, without magnetism. This classification is intended to apply mope particularly to the rocks of the Marquette and Menominee regions proper, embracing the central and southern portions of the Upper Peninsula; and even here, as has been noted above, there are exceptions. This sketch of the Marquette rocks, in the light of the distribution of magnetite, would be incomplete, did I not mention the fact that this mineral is very generally present in the form of fine sand in the drift in the region I am describing. If one moves a magnet about in the sand of a creek it is rarely that *magnetic sand* will not be found adhering. I have never seen it accumulated in quantities that would point towards its being utilized; nor have I ever observed a local variation which I ascribed to the mineral in this form.

We will now return to the Huronian or highly magnetic series, taking up its structure in some detail. About nineteen lithologically distinct beds or strata make up the series; of these, six and probably seven are generally so magnetic as to cause considerable variations in the needle. These beds vary from forty to several hundred feet in thickness, and strike and dip in all directions, and at all angles. The prevailing strike, however, is easterly and westerly, and the dip at high angles, often vertical. These rocks frequently outcrop, when we have no use for the magnetic needle in their study. Again, they are covered by deep drift, where magnetic observations, or workings, can only reveal them.

In order to study the magnetic characteristics of these rocks more minutely than could be done in the field, two hundred and twenty-two specimens, covering all the more common varieties, were collected and are deposited in the cabinet of the University of Michigan; they are fully described under lithology in this Report. Fifty-four, or twenty-four per cent., were found to possess some degree of magnetic power as manifested by their influence on a magnetic needle; each specimen being in turn made to touch each end of a mounted needle. If it had the power to lead it 20 deg. from its normal direction, the specimen was said to be feebly magnetic, and strongly magnetic when the needle followed the specimen round the circle if held about half an inch from it. Of these fifty-four specimens, thirteen were feebly magnetic, twenty-nine magnetic, five decidedly magnetic, and seven strongly magnetic.* None would, however, lift ordinary carpet tacks. Twenty-four, or nearly one-half, possessed polarity in some degree. Thirty were simply magnetic, with no *polarity* that could be detected by the rude means employed: in some instances the specimen would repel the needle at half an inch distance, but would attract it if placed in contact. Such specimens were rated as possessing polarity. All of the strongly magnetic specimens were rich in magnetite and possessed polarity, and it is not improbable that all would have been found to possess it if tested by more delicate means. Von Cotta, however, speaks of magnetic Iron ore which possessed no polarity. The specimens generally attracted the south pole more strongly than the north. When examined, they had been collected about three months. Whether they would have shown more or less magnetic power if tested when freshly broken, I do not know. Dr. Kitchell says that under certain circumstances fragments gain magnetism.

*Appendix H gives the percentage of material lifted by the magnet in twenty-one specimens of Lake Superior ore, together with the color of the powder.

In 1860 I saw a powerful loadstone for its size, in the possession of Professor Trego, of Philadelphia, which he had picked up in New Jersey twenty-two years before. I once collected a number of pieces of loadstone in the Bull Mine, New York, which in the mine would lift small nails; in a few days two-thirds of them had lost this power. This may have been due to the fact that in the mine the nails themselves were made magnetic by induction.

Regarding the *location of the poles* in magnetic rocks, the laws of magnetism would place them near the surface, or next divisional planes or terminations of masses. Observers are generally agreed that Iron ore is most magnetic near dykes or volcanic rock. Quoting again from Dr. Kitchell, "Geology of New Jersey," p. 535: "The extent of the magnetic qualities of iron ores depends on their position with respect to the surface; the nearer to the surface the greater will be their magnetic properties. This appears to depend on the action of surface water and atmospheric agents, for it has been frequently observed that ore, when first taken out of a mine at a considerable depth, possessed but slight magnetic properties, but on being exposed, to the atmosphere for a few months or years it would increase so much that excellent specimens of loadstone for experimental purposes could be selected therefrom. Seams of ore that contain numerous joints and fissures, through which water and atmospheric agents pass, possess more decided magnetic properties than those which are more compact and free from crevices and fissures."*

These remarks of Dr. Kitchell possess much interest. I have but one fact that bears on this question;—an average sample made up of numerous fragments collected by myself of the Iron Mountain Missouri "surface" or boulder ore, contained only about one-fourth as much magnetite (as measured by the amount lifted with a horse-shoe magnet) as did a specimen of "quarry" (ledge) ore selected at the same time and in the same way.

*If a fact, is this due to the contact of air and water, or is it because the seams necessarily produce small independent magnets.

Classifying the magnetic ores and rocks of the Marquette region economically, the merchantable ores, according to the present standard of richness, would not constitute two per cent. of the whole; the balance being ferruginous quartzites and schists possessing no present value as ores. The merchantable magnetic ores have so far all been found in one formation near the middle of the series, and that is not all pure ore by any means; therefore, when an ore-hunter finds an "attraction" in the Lake Superior region, the chances of his having found a mine are not more than one in fifty. Neither the strike nor dip of the formation seems to affect its magnetic power. This depends, so far as my observations throw any light on the question, chiefly on the percentage of magnetite entering into the composition of the rock. Prof. Cook—"Geology of New Jersey," pp. 537-8—says that the magnetism of iron ores was influenced by the "pinch and shoot" structure so prevalent in the iron mines of New York and New Jersey. He points out the analogy between these regular pod-shaped masses—:"shoots" of ore,—pitching downward in a northerly direction and an iron bar in the same position; both become magnetic and have polarity.

The "pinch and shoot" structure exists in the magnetic ores of the Marquette region, but is obscure, and in strike and dip there is no parallelism between our rocks and those of New Jersey, as is shown elsewhere. Yet our ores must usually be more strongly magnetic than those of New Jersey ; for Prof. Cook says: "It is generally conceded that ore, covered by thirty feet of earth, will attract the needle, and 'large veins' have disturbed it when covered by fifty feet of earth." Now at five and even fifty times these distances horizontally, the needle is often deflected in the Marquette region, and at the Spurr Mountain the needle indicates a dip of 70 degrees at an elevation of 94 feet above the ore.

With regard to the *associations of the various ores* it may be said, that magnetic and specular ores are often found together, as are also the specular and soft hematite ores; but so far the magnetites and hematites have not been found in juxtaposition. If we suppose all our ores to have once been magnetic, and that the red specular was first derived from the magnetite and the hydrated oxide (soft hematites) in turn from it, we have an hypothesis which best explains many facts, and which will be of use to the explorer. As a rule it may be assumed that the hard ores of the Lake Superior region, even although they be rated as red specular, contain a sufficient amount of magnetite to cause some local disturbance in the needle; there are exceptions to this rule, but they are rare. In some instances, especially in the Menominee region, the disturbance is slight, but enough to be noticed by careful observation. It should be noted that the L'Anse Iron Range, so far as known, contains no magnetic ore whatever.

4. Explanation of Magneto-geologic Charts, Plans and Sections.

Having now briefly stated those elementary principles of Magnetism which are involved in our subject, described the instruments employed and their use, and sketched the geology of the rocks whose magnetic forces we are to study, we are fully prepared to examine the results of the observations made, and to draw such conclusions and make such applications as the facts seem to warrant.

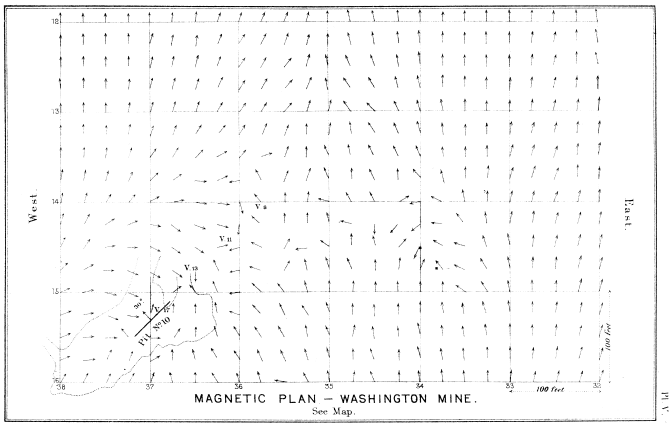
It has been found necessary to introduce a few terms which may be new in describing the graphical representations of the phenomena observed. No work to which I could gain access contained expressions such as portions of our work seemed to require. Figures I and 2, Republic mountain chart (No. XI. of Atlas), are copied in part from the geological and topographical map of Republic mountain, which see for explanation of geology, relief of ground, and geographical position.

Magnetic observations were made across the entire Huronian series lapping on the Laurentian on each side, along survey lines 26 and 30, which run N. 53° E.; the observations being taken for a considerable part of the distance every 25 feet. The arrows in Fig. 1 indicate the directions which the needle actually pointed under the combined influence of terrestrial and local attraction. The angle between these arrows and the meridian is the *variation* in Azimuth (called simply variation) and ranges, as will be seen, from 0 to 180°. The direction of the arrows, although sometimes irregular, leaves no doubt as to which are the magnetic rocks.

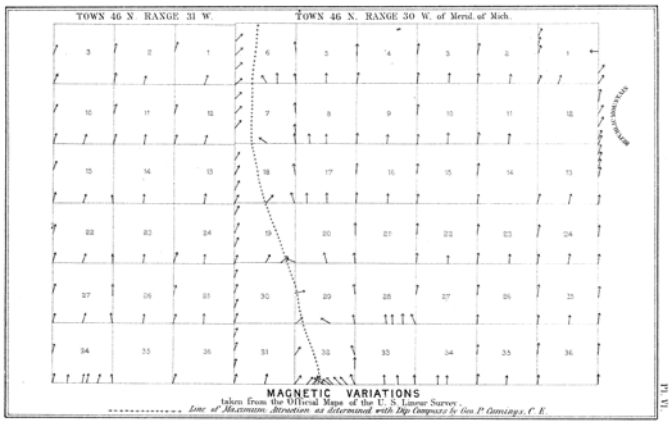
The full significance and value of the common compass in locating magnetic rocks and ores is better shown in Plate V., which represents variations observed at the west end of the Washington mine, embracing the West Cut or Pit No. 10. The stations indicated on the Plate refer to survey lines shown on the map of the mine, No. VIII., to which reference is made for information regarding the geology and topographical features of the locality. A glance at this figure will bring to the mind of all familiar with magnetic experiments, the plumose forms assumed by magnetic sands or iron filings resting on paper and influenced by the magnet. Our figure may be regarded as representing the laboratory experiment greatly magnified. As to the irregularities shown by some of the arrows, it is probable that if the magnetism of ordinary magnets could be studied minutely, as with microscopic needles, that corresponding irregularities would be observed in the directions and polarity of the forces, not unlike those seen on this magnetic plan of the Washington mine. If we admit, as we are forced to do from these facts, that magnetic rocks present phenomena entirely analogous to artificial magnets, then it is not difficult to decide as to the cause of the phenomena exhibited on the sketch before us.

The dotted, line is designed to indicate the position of maximum variation, or rather the position of the force which causes the variation. The observations made for *intensity* along this line, indicated by vibrations (six being the normal number), confirm the indications of the horizontal compass. There can be no doubt but that nearly under this line, at no great depth, is a large amount of magnetite; whether free enough from rock to constitute a merchantable ore, explorations only can establish. Since this plan was made, work has been resumed at Pit No. 10, and a tolerably regular bed of ore revealed, having the strike and dip marked on the plan, which coincides closely with what might have been predicted. The relationship of this deposit with the others constituting the mine will be considered elsewhere. This magnetic plan, as well as Fig. I, Republic mountain chart, shows, that while the variations are governed by a uniform law away from the lines of maxima, within these lines great irregularities of direction exist.*

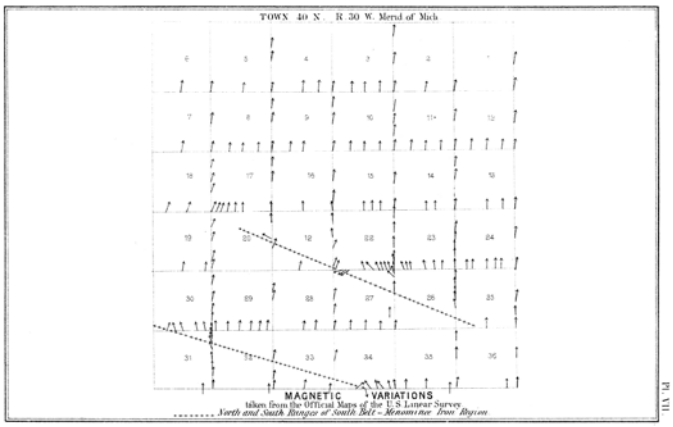
*Since the above was written, I have, by the kindness of Mr. F. Firmstone, of Easton, Pa., been able to inspect some magnetic charts of New Jersey localities, made by the late Mr. Amsden, of Scranton, which are excellent.



[V. Magnetic plan of part of Washington Mine]



[VI. Magnetic plan of T. 46—Rs. 30 and 31]



[VII. Magnetic plan of T. 40—R. 30]

Passing from Plate V., which represents but a small area, over which the magnetic observations have been very numerous, to a magnetic plan of a large surface, with widely separated observations, we have in Plates VI. and VII., copied from the United States Land Office books, a fine exemplification of the significance of local magnetic variations.

In Plate VI. the magnetic rocks run nearly north and south,—which direction, as has been heretofore stated, produces the maximum variation. It will be seen that the needle is influenced at a distance of nearly, if not quite two miles, and that the variation diminishes rapidly as we depart from the line of maximum attraction. The

disturbances recorded on the north-east part of this plan are due to Republic mountain.

Plate VII. represents one of the iron townships in the Menominee region. The variations are scarcely so great, nor do they extend so far as in the other. As the two iron ranges represented run much more nearly east and west in this case, it is interesting to observe the difference in the behavior of the needle. These plans are additional proof of the value of the Linear Surveys to the explorer, a point to which I have often referred.

Figures 3 and 4, Chart XI., Atlas, are *magnetic sections* along lines 26 and 30 of plan. The arrows indicate the direction of the dip-needle vibrating in the plane of the meridian. The normal direction is the horizontal line; the arrow head indicating north end of needle should therefore normally point to the right hand side of the chart. It will be seen that the dip, like the variation, often attains the maximum of 180°, that is, the north end points south.

The colored curved lines express approximately the *intensity* of the local magnetic force; their ordinates being the number of vibrations made by the needle in one quarter of a minute, on a vertical scale of eight vibrations to the inch. The *blue* line records the observed vibrations of the *horizontal* needle, the others of the dip-needle. The *black* line refers to the needle vibrating in the plane of the meridian (compass *facing west*). The *red* line refers to the needle vibrating in an east and west plane (compass *facing* south.)

Fig. 2 is a magneto-geological section on the line A—A' of Fig. 1. The upper curve represents a projection on one plane of the maximum intensities of all the curves of Figs. 3 and 4. The lower curve, Fig. 2, has reference to variations and dips, its ordinates being proportional to the maximum variation in direction of the needle, caused by the magnetic rocks. It is intended as a sort of summary of the facts expressed by all the arrows denoting directions, as the upper curve is a general expression of the intensities. It will be observed that the summits of the lower curve, Fig. 2, which indicates maximum variation, are always northerly from the centre of the magnetic bed. This is as it should be, because the greatest *variation* takes place before we reach the local magnetic pole, when approaching it from the *north*. The intensities, on the other hand, are greatest directly over the magnetic rocks. It should be borne in mind that the intensity of a magnetic force is really proportional to the square of the number of vibrations in a given time; but in these investigations the actual number of vibrations has been used in constructing the sections, as being more convenient.

In addition to the facts observed during this survey, which are recorded on the Republic Mountain Chart, and various figures in this volume, certain others, obtained from the United States Land Office, plats of Towns 46 and 47 north, Ranges 29 and 30 west, will be employed, besides those already given from the same source.

The discussion of the facts in our possession falls conveniently under two heads:—First, Regarding the entire Huronian series as a unit, and the comparison of its magnetism with the Laurentian system. Second, A study of the magnetism of the individual beds of the Huronian or iron-bearing rocks, in detail. Republic mountain and vicinity afford an excellent opportunity for both these investigations.

The Magnetism of the Laurentian System or Granitic Rocks.

The Federal township plats above referred to, cover an area of, say twelve miles in diameter, of which Republic mountain is the centre; at least nine-tenths of this territory is Laurentian. The variations of the needle noted are from two to six degrees east, averaging four and a half degrees, which may be regarded as the declination of the needle at the date of the surveys of this locality, due to cosmical causes. From this and similar facts covering the whole Marquette region, we may conclude that this oldest system of all known rocks has here no beds of magnetite, nor does it now contain magnetite as an essential constituent mineral, nor indeed oxide of iron in any form. Prof. Pumpelly and myself found slightly magnetic rocks in the Laurentian south of Lake Gogebic, and the professor mentions in his report to the Portage Lake and Lake Superior Ship Canal Company "a deposit of iron ore in the Laurentian gneiss and hornblendic schist series on Sections 10 and 15, T. 41 N., R. 29 W.," in the Menominee Iron Region, from which I have seen specimens which do not look very promising. One or two other places are mentioned where magnetic beds occur in the Laurentian, but they are exceptional, the rule being as has been stated. But everywhere in the region we are considering, over or near the Huronian Series, the Government surveyors note variations. The approximate boundary between these two systems of the Azoic in some parts of the Upper Peninsula could indeed almost be delineated from their surveys by magnetic variations alone.

Magnetism of the Huronian Series as a Unit—Republic Mountain.

No special observations were made to determine the extreme limit to which its magnetic influence extends. The Federal surveys would make the distance over one mile, and Durocher mentions that he was told in Sweden that "important beds of iron ore produced deviations in the needle up to the distance of nearly two kilometres," or over one mile—*Annales des Mines*, 5 Series, Vol. 8, p. 220. The Federal surveyors note a variation at the northeast corner of Section 7 (See Fig. I, Republic Mountain Chart) of 25° west, agreeing very nearly with my observations corrected for the change in declination since the survey was made. This corner is at least 600 feet from the nearest Huronian bed, and probably 900 feet from any member of the series containing magnetite. Judging by the direction and intensity of the magnetic force as exhibited by the needle, as we

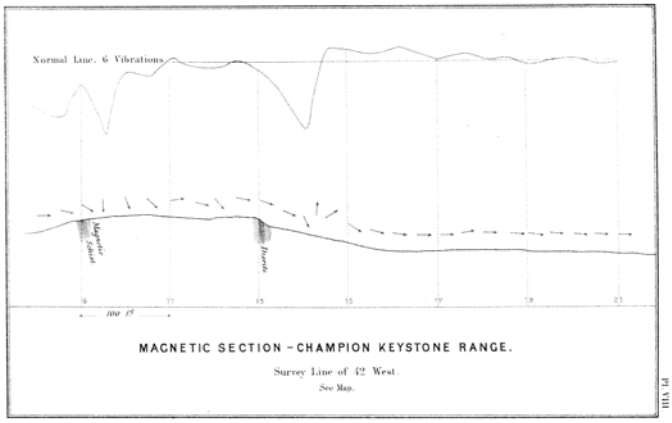
approach the mountain from the northeast (see Figs. 1, 3, and 4), it seems probable that the bed which chiefly produced the effect was No. VI, and still more distant ores. If this be a correct inference, we have the phenomenon of a magnetic needle deflected 25° from its normal direction by a bed of rocks containing not to exceed 33 per cent. of magnetite, distant 1,500 feet horizontally. The facts from the U. S. surveys given above show that the needle is sometimes influenced to a much greater distance.

Passing to the south-west side of the Huronian basin we find the influence exerted by the magnetic rocks to gradually diminish as we recede from their edge, which is believed to be under the Michigamme river. See Fig. 1. Here we find the needle varying 15° at a distance of at least 800 feet from the nearest magnetic rocks.

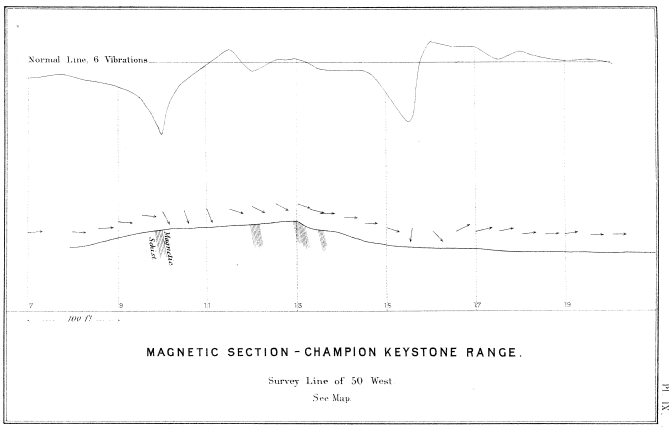
An inspection of Fig. 1 shows that the variations of the needle are much greater on the north-east than on the south-west side of the mountain, which should evidently be the case from the fact that to the south-west the terrestrial and local forces are more nearly in the same line than on the north-east side; hence in the latter case the mechanical resultant (direction of the needle) would form a greater angle with the direction of the earth's force (magnetic meridian) than in the former.

The question of the distance to which magnetic ore and rocks will attract the needle receives some additional light from the Champion Mine, Plates VIII. to XV. It is evident in this case that the magnetic force of the ore is felt to a distance exceeding 700 feet to the north of the mine. To the south there is less certainty, because of the other magnetic rocks (see sections) which underlie the ore in that direction. It is probable that careful observations would detect the influence of this remarkable deposit of ore through an east and west zone, which in places would attain a breadth of 2,000 feet or more, one-fifth of this area showing a magnetic dip of 90°; but this does not prove the existence of 400 feet of magnetic rocks or ore, by any means, as will be seen below.

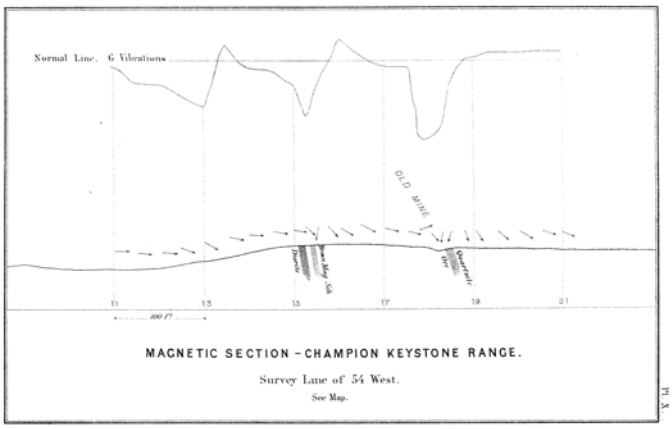
At the Spurr Mountain, which is an east-west deposit of highly magnetic ore like the Champion, Mr. Lawton observed just south of the range 23 vibrations in a quarter of a minute; going south the vibrations diminished somewhat regularly, until at 600 feet the needle vibrated but ten times in a quarter of a minute. At 300 feet north of the mountain the needle settled indifferently in any direction, owing to the fact that the terrestrial and local forces just balanced each other at that point; further north the vibrations increased somewhat irregularly, owing to the presence of slightly magnetic rocks, until at 1,400 feet six vibrations were observed in a quarter of a minute. There must of course be points north and south of all magnetic belts where the vibrations would be equal and normal, but these limits were not reached, the observations proving only that the magnetic belt at Spurr Mountain is over 2,300 feet wide.



[VIII. Magnetic Section Champion-Keystone Range]



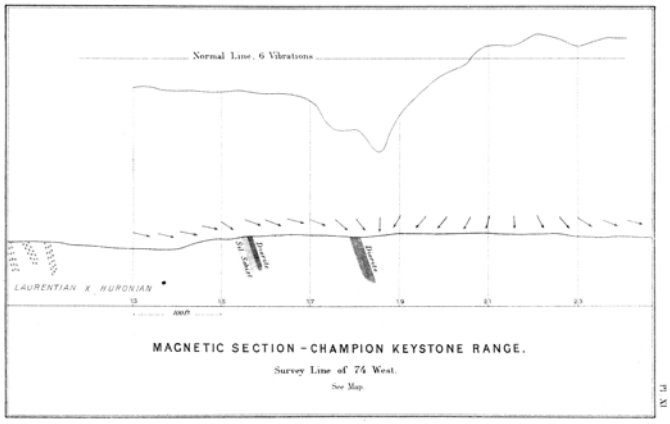
[IX. Magnetic Section Champion-Keystone Range]



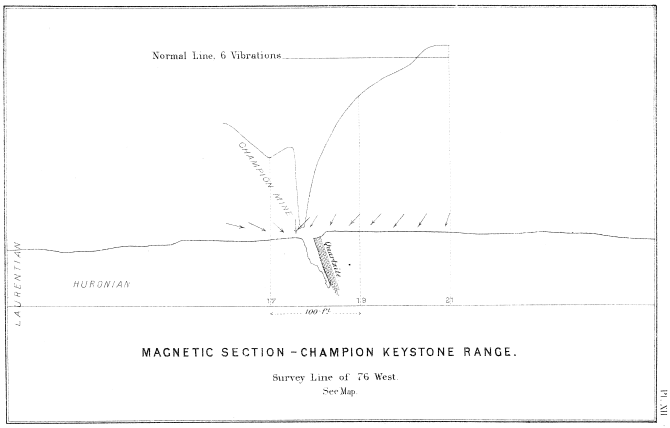
[X. Magnetic Section Champion-Keystone Range]

It may be asked why the very silicious magnetic rocks of the Republic Mountain influence the needle at a greater distance than the pure ores of the Champion Mine. It is not at all certain that this is the fact; the limit of the influence has been determined in neither case. The stratigraphical conditions, however, are quite different. The strike of the Republic mountain rocks being north-westerly, is far more favorable for producing variations than is that of the Champion deposit, which is east and west. It is quite evident that a north-south deposit of ore would cause greatest variations (see Plate VI.) and an east-west deposit least. If, in the latter case, we conceive the power to be equally distributed along an

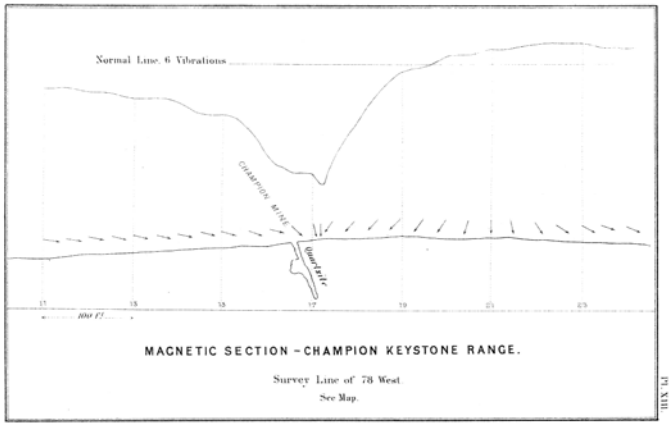
east and west mathematical line, there would be produced no variations at all in a horizontal compass. Again, there are four highly magnetic beds at Republic Mountain, while at the Champion there is only one.



[XI. Magnetic Section Champion-Keystone Range]

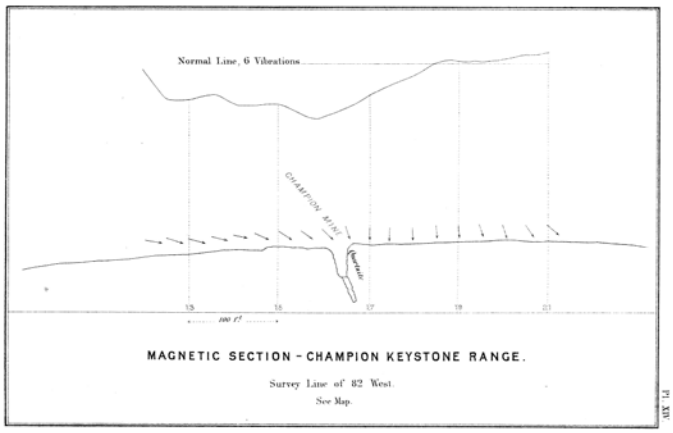


[XII. Magnetic Section Champion-Keystone Range]



[XIII. Magnetic Section Champion-Keystone Range]

Regarding the polarity of the magnetic force: (1) In every instance the north end of the horizontal needle was drawn towards the magnetic rocks; hence, north-easterly of Republic Mountain, the variation was west; and south-westerly, the variation was east. (2) With the dip-needle vibrating in an east and west plane, the north end pointed westerly, or towards the mountain on its northeast side. (3) With the dip-needle vibrating in the plane of the meridian, on the north-east side of the mountain, the south end inclined downward, producing a "negative dip," as shown in Figs. 3 and 4, and this increased as the magnetic rocks were approached until the needle turned entirely over. This apparent *negative* attraction was probably in reality only the effect of an attraction for the north end of the needle, which inclined to the magnetic rocks by the shortest road. Why the north end of the needle moved upward instead of downward (which was apparently just as short a road) as it approached the magnetic rocks over the non-magnetic Laurentian, I can only explain as follows,—which hypothesis may also explain instances other than this where slight negative attractions have been observed over granitic rocks, for example, south and south-east of the Champion mine. My needles were always counterpoised near Negaunee or Marquette, which towns are built on the Huronian. Of course an effort was made to get away from the magnetic members of the series; but this evidently would be impossible if their influence extends to the distance of one half mile. Magnetic rocks would probably be found throughout the Huronian belt by boring less than 1,000 feet into the earth, owing to the basin-like structure of the series. It is probable, therefore, that my needles were counterpoised under the influence of some *positive* magnetic force; hence, when taken over Laurentian rocks containing no magnetite, they would show "negative" attraction. If this hypothesis is correct, then the negative attraction referred to above is explained.



[XIV. Magnetic Section Champion-Keystone Range]

Regarding the *intensity of the magnetic force* exerted by Republic mountain as a whole, but one observation need in this place be made. The vibrations are greater on the south-west than on the north-east side, or exactly the converse of the variations. The Magneto-Geologic Sections of the Champion and Keystone Range (see Plates VIII. to XV.) present the same phenomenon.* As the needle is carried north from the Champion bed, its vibrations rapidly diminish in number until they become *less* than the normal number due to the earth's magnetism; after which, on going still farther, the vibrations will increase until the normal number is reached: but in going south, the diminution is far less rapid, and the number of vibrations never falls below the

normal number. The same was observed at the Spurr as is noted on page 226.

The obvious reason is this: when the needle is south of the local force, both it and the terrestrial force act in the same direction, producing a maximum effect; but when the needle is north of the local force, it can evidently be influenced only by the greater force less the smaller. In the first case the mechanical resultant is the sum, in the other it is the *difference* between the two magnetic forces. This readily explains the difference in the slope of the curve of intensity north and south of the magnetic poles, so noticeable in the magnetic sections.

*The survey lines on the Magnetic Sections, Plates VII. to XV., refer to Map of the Champion Mine, No, VII., which should be examined in connection with them.

Republic Mountain.

A glance at the directions of the needle as indicated by the arrows in figures 1, 3, and 4 of Chart XI., will impress one with the conviction that there is no direction in azimuth, or inclination which the needle does not assume in crossing the series of rocks. The north end of the needle never points north, often east and west, and sometimes south ; while in the dip-compass it turns a series of somewhat irregular somersaults, pointing habitually downward, but often towards the zenith. The needle may be said to "box the compass right and left," as we may suppose that feat accomplished by a drunken sailor. A second glance at the arrows will show us that there is much method in the madness of our ge-go-sence;* the needle very generally tends to point toward the blue or red-colored rocks, which contain magnetite, while it is comparatively indifferent to the green, gray, and salmon colored, which contain little or none of this mineral. The particular significance of the variations and dips will be more fully discussed below.

We will leave for the present the consideration of the direction of the magnetic force expressed by the arrows, and return to the sub-ect of the *intensity of the force as expressed by the colored curves* (see page 223). Nothing is more evident on the chart than that these curves indicate with great certainty the position of the magnetic beds over which they are more or less convex, producing summits; and more or less concave or flat over the non-magnetic rocks, pointing literally as a finger in some instances to the location of the magnetic force. Comparing the three curves in figs. 3 and 4, it appears that:—(1) The red line (compass facing south) oftenest rises higher than any other over the magnetic rocks; and sinks lower away from them. It has also fewer changes in direction than the others. (2) The black line (compass facing east-west) falls lower than either of the others over the magnetic rocks. (3) The blue line (compass horizontal) often has an extreme depression, where the others have an extreme elevation.

These, the most obvious generalizations from the curves, are explained by the principles of the mechanics of forces already mentioned.

Fearing there may be some confusion from representing the same element-*intensity* by three curves, I suggest the following conception: Suppose an observer to be provided with a horizontal compass having a blue needle and two dip-compasses, one provided with a black and the other with a red needle. Suppose, further, these to be mounted for observing at the same station, but so far apart as not to influence one another; the blue needle moves in a horizontal plane, the red needle in a vertical east and west plane, and the black needle in a vertical north and south plane. Suppose, further, a powerful magnet to be placed (1) directly under or directly over the station, it is evident that only the black and red needles will be influenced. (2) If placed north, the blue and black needles only will be influenced. The directive force in this case would be a maximum; because the magnet's power is added to the earth's, both acting in the same line. (3) If the magnet be placed directly south, the red needle will again be uninfluenced, but the black and blue needles will indicate a minimum of intensity instead of a maximum, for their directive power will be the difference between the force of the magnet and that of the earth. (Places have been observed where the needle gave us no vibrations in any position from this cause. A fine illustration occurs in Fig. 3, Chart XI., Station 24, where there must have been a very strong pole to the south of the station; but this pole is evidently north of Station 24, Fig. 4, where the greatest intensity was observed.) (4) If the magnet be placed east or west of our supposed station, the effect will be the same; the red needle will be most influenced, blue next, and black not at all.

We are now fully prepared to explain the phenomena presented by the colored curves.

(1) Why does the red line usually rise higher over the magnetic rocks, and sink lower away from them, and why does it fluctuate least? When the needle vibrates in an east and west plane, its axis points north,—that is nearly in the line of the directive force of the earth, which it thus partially neutralizes; giving the local forces full power. As these are much stronger than that of the earth at short distances, we should expect the result observed over the magnetic rocks. Away from them, the earth's force being nearly neutralized, we should have the minimum of intensity as is shown by the red line. That the changes in direction in this line are less frequent and less abrupt than the others, indicates, I think, that if the earth's attraction was entirely neutralized and the error of observation reduced to a minimum, the curve derived from the magnetic force resident in the rocks on any particular cross-section might be more regular than any shown in the chart. It is reasonable to suppose that the red curve has most significance in our investigations. (2) Why do the black and blue lines fall as a rule lowest over the magnetic rocks? Suppose a local force, about equal to the earth's, to exist directly south of a dip-compass placed in the plane of the meridian, or of a horizontal compass; we should evidently have a minimum of intensity, because the terrestrial and local forces would balance each other.

The marked exception to this rule over formation XI., Fig. 4, is evidently due to the fact that the magnetic power resident in beds X. and XII. just balance each other, and as the directive power of the earth is neutralized in the case of the red line by the direction in which the needle is held, we have a point of comparative equilibrium. (3) Why does the blue curve sometimes present depressions opposite the summits of the others? This is readily explained by supposing the local force to exist directly under the station; its force would then be entirely neutralized by the centre-pin of the horizontal compass, while having its full effect on the dip-needle in both positions.

*A Chippewa word for magnetic needle, signifying "little fish," in allusion to its wiggling motion.

5. Diminution of Intensity due to Elevation.

All the observations for intensity above considered were taken at an elevation of about 4 feet from the surface. Sometimes the rocks came to the surface, sometimes there were several feet and perhaps yards of drift between; it is therefore an important practical question to ascertain what effect the elevation of the needle has on the number of its vibrations.

The difficulty of attaining any considerable elevation at which to observe intensity, renders our observations on its rate of diminution due to elevation or vertical distance of little value. The theory of the sphere of attraction and law of decrease of force, as the square of the distance from the centre, has been mentioned; but with several local forces acting on the same point (the case usually presented in nature), the law is greatly modified, the decrease being in a less ratio. This subject possesses especial interest in connection with the determination of the depth at which magnetic rocks, producing a given disturbance, will be found; therefore, the few observations made, unsatisfactory though they are, will be given. At Republic Mountain a staging was erected in the windfall, by means of which eight equidistant observations were made; the lower one on the magnetic schist, the upper one 14 feet above it. The results were as follows:

Elevation in feet.	Vibrations.		Remarks.
	Facing west.	Facing north.	
0	56	53	On surface of schist.
2	41	41	
4	33	30	
6	27½	30	
8	19	23	
10	15½	24	
12	18	24	
14	12	20	

At another point near the above, and over the same magnetic rock, the following vibrations were observed:

Elevation in feet.	Vibrations.		Remarks.
	Facing west.	Facing north.	
0	60	60	On surface of schist.
3	50	49	
6	36	37	
9	25	26	
12	18½	18	

The observations have all been represented graphically, but as no law was apparent, and as the figures can be easily reproduced, they are not given. The first table gave the most regular curve, but still too angular to attempt the application of a mathematical formula. They do not seem to me to afford a basis for calculation, as to how high the appreciably magnetic influence of these rocks would extend. I have an impression, however, without being able to give any reason, that it would be considerably less than one half mile, which was shown to be the distance to which the influence of the same rocks extended horizontally. I cannot consider it probable that a needle would dip where an earth covering of over 2,000 feet exists, if such a case were possible. At the Champion mine, by the aid of shaft house No. 2, an elevation of 44 feet above the ore was attained, and the following observations made:

Elevation in feet.	Vibrations.			Remarks.
	I.	II.	III.	
0	18½	17½	23	Level of surface of ore in shaft.
18	19	17	17	Surface of ground.
32	16½	16½	16½	Girder of shaft house.
44	15½	..	15	Girder of shaft house.

At other points at the Champion mine, 25, 32, 33 and 40 vibrations were observed, the compass being within 5 feet of the ore. The diminution here is quite regular and nearly as the distance. If the rate continue, the vibrations should reach the normal number (six for the instrument used) at about 150 feet; but it is highly improbable that this law would hold for the whole height.

The difference between the rate of diminution at the two localities is very marked; at Republic Mountain an elevation of 12 feet in one instance reduced the vibrations from 60 to 18½, in another 14 feet elevation reduced the number from 56 to 12. At the Champion 44 feet elevation made an average of less than 4 difference in the vibrations. In this comparison the following geological differences must be borne in mind.

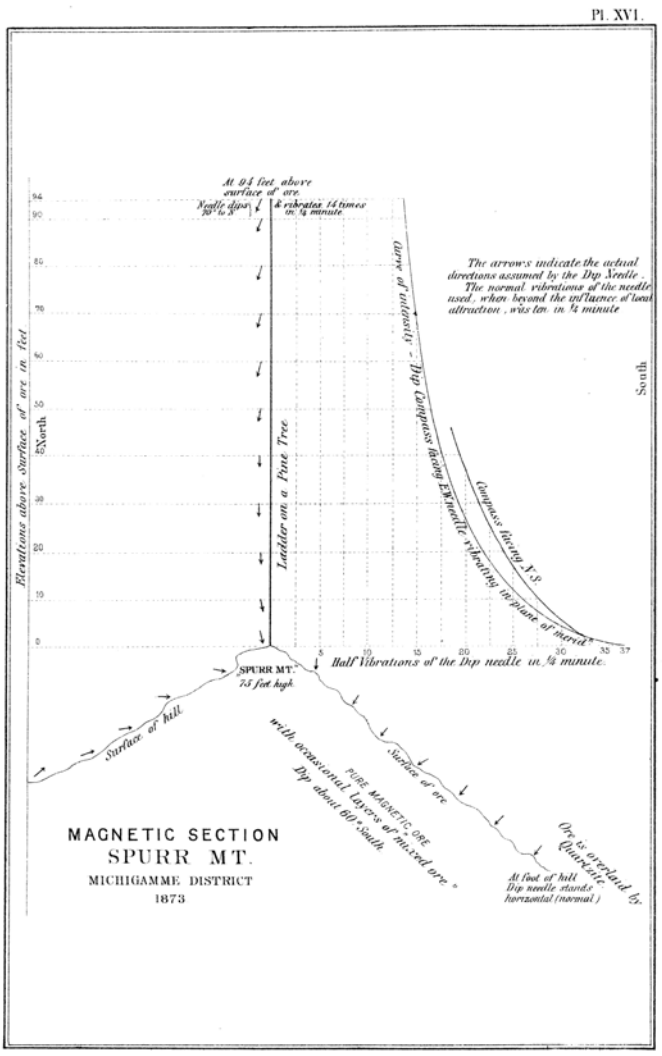
The Champion deposit at shaft No. 2 is a heavy bed of nearly pure black oxide running east and west and dipping north at an angle of 68 degrees, and it is the only magnetic rock in the vicinity. The Champion deposit loses its magnetism in going west, specular slate taking the place of the magnetite in that direction. The Republic Mountain bed over which the observations

were made (No. X.*) is, on the contrary, a silicious schist, containing not to exceed 33 percent, of magnetite, (the merchantable ores of Republic Mountain, of which there are large deposits, are in bed No. XIII., and are mostly specular hematites.) This magnetic bed X. is associated with others of a similar character, all striking north-west and south-east and dipping nearly vertical. The specimens of these magnetic schists which were examined possessed marked polarity. The Champion deposit evidently contains far more magnetite within the same sphere of influence than the Republic Mountain.

There is no doubt that variations and dips are a much more delicate and ready means of observing slight magnetic attractions, than vibrations when observed with the hand instruments employed. In one instance at Republic Mountain the dip at 12 feet elevation was 30 degrees, at 9 feet 50 degrees, at 6 feet 70 degrees, at 3 feet 77 degrees, at o or on surface of rock 105 degrees. It appears that the magnetic poles of the Champion bed are more deeply seated than those at Republic Mountain, which seem to be at the surface. This may be due to the fact that the upper part of the Champion deposit is mined out. Sets of careful observations made for considerable heights, both for dip and vibrations, would possess great Interest, especially if made over beds of ore or rock, the position and character of which were known. In a record of over three thousand magnetic observations made by me in Michigan, Missouri, New York and New Jersey, I have not in more than six instances found the needle in the dip-compass above described to vibrate over 40 times in a quarter of a minute, and in no instance in which this rate was observed was the needle removed more than 5 feet from the magnetic mineral. Of course in the same needle the vibrations will vary with the degree of magnetism that has been Imparted to it, and the condition of the instrument in other respects. I have had a rude standard, and when my needle fell below that it was overhauled, so that the numbers are relatively correct. I do not remember to have observed over 15 vibrations in a quarter of a minute, or one per second, at a greater distance than 50 feet from a magnetic bed, and usually this number of vibrations would indicate a distance not exceeding 25 feet in the Marquette Iron Region.

*The Roman numerals refer to the order of the beds of the Huronian series, counting upwards from I. to XIX.

Since the above observations were made and recorded, the development of the Michigamme district has permitted observations to be made at the *Spurr Mountain* which throw much light on the subject of the diminution in dip, and intensity due to elevation. The following table records the observations made,* and Plate XVI. represents the general law of diminution graphically. The observations were carried to an elevation of 94 feet by means of a fortunately situated pine-tree, up which a ladder was constructed. While there are minor irregularities, due wholly or in part to errors of instrument, the presence of nails in the ladder, and personal error, the average curve is remarkably regular, and points, as most of the other facts do, to a far more rapid rate of diminution near the surface than at a considerable elevation.



[XVI. Magnetic Section Spurr Mountain]

It is not to be expected that the law of decrease of magnetic force would hold at this locality. Had the local force been concentrated in a focal point directly under the tree, and the force of the earth been neutralized, then we might expect the law to be discernible. Some useful practical rules may be readily drawn from the table and plate under consideration.

1. If, in a locality where magnetic attractions prevail, we find considerable difference in the number of vibrations between the compass, when in contact with the ground, or held six feet above it, we may conclude the ore is very near the surface; if there is but little difference, then the ore is probably deep. 2. The amount of the dip gives but little clue to the depth of the ore. If the Spurr Mountain had been covered by a hundred feet of earth, water, or non-magnetic rock, we would have found at the surface a dip of about 70°, and it is probable, if not certain, that if it were possible to make observations to the north of the mountain, at the same elevation, a

greater dip than 70° would be found, due to the changed direction of the local force.

*Mr. C. M. Boss rendered great assistance in these observations.

Observations for diminution of magnetic force in vertical direction—(Needle vibrating in north-south plane)—Spurr Mountain.

Height.	Dip.	Vib. in ¼ min.	Remarks.	Height.	Dip.	Vib. in ¼ min.	Remarks.
0	100°	37	On surface of ore.	25	93°	20½	
2	100°	33		26	93°	20	
4½	100°	30		27	92°	20	
6	100°	28½		28	92°	19½	
7	100°	27		29	92°	19½	
8	100°	27		30	92°	19½	
9	100°	27½		31¼	91°	19	
10	100°	26		32½	90°	18½	
11	100°	25½	26 facing south.	33½	90°	18½	
12	96°	24½		34½	90°	18	
13	100°	24		35½	88°	18½	
14	96°	24½	24½ facing south.	36½	88°	19	
15	98°	23		37½		18	
16	96°	23½		41	88°	17½	
17	95°	23½		42¼		17	
18	95°	23		45½	86°	17	
19	94°	22½	23 facing south.	48		17	
20	94°	22¼		52	80°	16½	
21	94°	21½		56	80°	16½	
22	93°	22		63	78°	16	15 vib., faced N., dip 86 E.
23	92°	21½		68	80°	15	15 Vib., faced N.
24	93°	20½		79	78°	14½	13 " " "
				92	72°	14½	13 " " S.
				94	70°	14	13½ " " S.

6. What is the significance of a dip of 90° or "dead 90°."

As there is a general impression among those who have made but little use of the dip-needle in exploring for iron ores, that a variation of 90° signifies merchantable ore directly under the feet, it is important to ascertain the exact purport of such great fluctuations in the direction of the needle. For the present we will leave out of the question the unpleasant fact that in 19 cases out of 20, if not 99 out of a 100, the mineral producing the dip would, if found, prove to be only a ferruginous schist or magnetic rock instead of merchantable ore, and consider the case often presented where there is a *dip of 90° at a place which is not underlaid by magnetic mineral*, or where there is none within several hundred feet. In such cases there are generally two, approximately parallel lines, of 90° dip, one over the ore, where the vibrations are very *quick* (always more than the normal number). The second line (the one we are now considering) will always be found north of the first, and along it the vibrations will be slow, always less than the normal number.

A moment's inspection of almost any magnetic section (Plates VIII. to XIV.) will illustrate the fact and suggest the cause. If we hold a dip-compass over a highly magnetic bed the needle will indicate 90°, pointing directly towards it. Moving north, the needle will continue to point towards the ore, that is, be turned backward, thus varying or dipping more than 90° from its normal direction. Continuing north, we soon get so far from the local influence, that its power ceases to entirely overbalance that of the earth, and the needle commences to return to its normal direction. In doing so it must evidently somewhere stand again at 90°, which means simply, that the local force to the south and the earth's force to the north, are so related in intensity, that the resultant is a vertical line. Still going north, the dip grows less and less until the boundary of the local attraction is past, and the needle returns to its terrestrial allegiance. It is evident that no such phenomena can occur to the south of the magnetic bed, for the terrestrial and local influences acting in the same direction, no "dead" points could occur.

This "dead 90°" line, then, instead of proving the immediate presence of ore, proves just the reverse if the phenomena are presented as above, which is the case at the Magnetic, Champion, Spurr, and Michigamme mines, and at one place at the Washington mine. There may be ore under this line, but it will always be deep and have little or no influence in producing the phenomena observed. Rule:—When there is a dip of 90°, and the vibrations *exceed* the normal number, we may conclude that the magnetic mineral is under our feet, or very near us to the south. If, with the same dip, the vibrations are *less* than the normal number, we may conclude that the magnetic bed producing the effect is south of us, and may be at considerable distance. This rule will evidently apply only where there is one strongly magnetic bed not very deep, which is the most common case. If there be several beds, as at Republic Mountain, the application of the principle is more difficult; but in the nature of force, some modification of the phenomena must be presented by all magnetic rocks.

It is worth remarking that the south belt of 90° dip, is more sharply bounded, especially on its south side, and usually narrower, than the north belt.

The lower curve of Fig. 2, Republic Mountain Chart, illustrates what has been said above; the summits of the curves showing the maximum dips are north of the magnetic beds, while the summits of the curves showing the maximum intensity (see upper curve, same fig.) are over the centres of the magnetic beds.

This subject would be incomplete without considering the case, quite common, where a zone of local attractions has but one line of 90° dip, or to make the case general, but one line of maximum dip whether it be 90° or less. It may be said that this last expression, covers the whole question, but with ore-hunters "dead 90" has a peculiar significance, and it is for them that I am writing. This case (one line of 90° dip) is illustrated in some of the Champion mine sections. A few words will explain how it flows out of the first case.

If we follow the two lines of 90° dip to where the earth covering becomes very deep, so that our distance from the magnetic mineral considerably reduces its influence, our two lines would evidently be merged into one, and continuing on to where the earth was still deeper, which has the effect of raising us above the ore deposit, this maximum dip would become less than 90°.

This maxima line would evidently correspond with the south line of 90° dip in the case first supposed, that is to say would lie nearly over the mineral producing it. With

great depth of earth covering, it can be proven that it would lie to the north of the magnetic bed.

An inspection and consideration of the facts presented in the Spurr Mountain magnetic section given above, will, I think, convince any one of this without the aid of the rigid mechanical demonstration which the problem admits of.

I have seen large amounts of money unsuccessfully expended in digging for iron ore for want of a knowledge of the simple principles set forth above, hence I have dwelt longer on this point than its importance to the general subject would seem to warrant.

7. Additional Practical Suggestions and Rules.

The facts given above, with others in my possession, enable us to answer provisionally the following practical questions:

I. Can we by means of the magnetic needle determine the order of superposition or succession of beds of the iron-bearing rocks?

Comparing the magnetic sections obtained at the Republic mountain and Champion mines, it is evident that, while there is considerable variation in the details, the salient features agree remarkably, pointing towards the same order and same lithological character in the rocks. A number of other sections made within 10 miles of the above-named localities, across the same belt of rocks, gave the same general result.

It is therefore asserted with much confidence that where a magnetic section similar to these is found in the Michigamme district, a corresponding geological section will be found beneath the surface; and that, as a rule, there will be less difference in the magnetic sections than in the topographical, which we know depends greatly on the underlying rocks. But whoever expects to find many places where so complete sections can be obtained as these localities afford, will be disappointed, for they present rare opportunities for studying the structure and magnetism of the Huronian series.

In places the covering of drift will be so deep as greatly to reduce the intensity, making it exceedingly difficult to observe with ordinary instruments, as was the case at the Cannon location. Again, the lower magnetic rock, beds VI., VIII., and X., are in places far less magnetic, containing sometimes very little magnetite, as is the case south of the Washington mine. In other places the lower magnetic rocks may be entirely wanting, owing probably to a fault, as at the west end of the Champion. On the north shore of Lake Michigamme there is a magnetic bed above XIII. (the ore formation), being therefore younger than any member of the Republic mountain series. In other places XIII. is wanting, and when present it is sometimes highly magnetic, as at the Champion, and again it holds very little magnetite, as at Republic mountain, the pure ore there being mostly specular hematite, as has been elsewhere observed.

With all these uncertainties, however, the results of magnetic surveys cannot but be valuable in the exploration and development of iron properties, and in the solution of all questions of structural geology in regions of magnetic rocks. In such rocks, I believe, their value to the geologist is only second to topographical work, and, considering the cheapness of magnetic surveys, they may often pay best if means be limited.

Detailed magnetic observations, if made with precision, ought to throw light on the lithological character and intricacies of structure of these rocks, and on the nature of the magnetic force resident in them. This could not, however, be undertaken; the work done is more than was contemplated in my instructions and more than was justified by the means at my disposal.

II. Is it possible to determine quality—i.e., the percentage of iron—in a magnetic rock by means of the magnetic needle? In other words, can the needle alone make us sure we have a workable deposit of ore under our feet?

This is the most important practical question connected with this subject, and is the one constantly presented to the miner and explorer. Magnetic observations should always be made in connection with topographical and geological surveys; whether these take such names, and are based on instrumentation, or whether they be such rude work as the explorer is constantly doing, but which are as much topographical and geological as the other, and often quite as valuable. A judgment of the commercial value of a bed of magnetic ore should, of course, be based on all the facts available. *If nothing more was known than what the magnetic needle revealed, I would not venture an opinion as to whether it was merchantable ore or magnetic rock which produced the phenomenon*. In the Marquette Region, as has been before observed, the chances are at least fifty to one that a worthless ferruginous rock is the cause of any observed attraction. But this case never occurs; we always know something more than the needle reveals. One of the most important uses of the needle, and one for which it can within, certain limits be depended on, is in tracing magnetic beds in the direction of their strike *until some outcrop*, which may give us the information sought, is found. I have in this way traced magnetic beds for many miles both in the Marquette Region and in New York and New Jersey.

Preparatory to the examination of any particular range of ore, the explorer should thoroughly study up, with his own instrument, the phenomena presented at some exposed or developed part of the range he is exploring. This will give him data relating to variations, dips, and vibrations, which can be used where the rocks are covered and unknown. By means of the quickness of the vibrations, or of the rapidity with which they decrease as the compass is elevated, he may judge approximately of the depth of the drift, and so of other phenomena.

III. Does the magnetic needle afford the means of determining the absolute thickness of a bed of magnetic ore or rock?

My observations do not permit an affirmative answer to this question, especially if there be much earth covering. A study of all the magnetic sections which have come under my observation, indicates that, while in some instances the comparative width is plainly shown, the boundaries between the magnetic and non-magnetic rocks are not generally brought out sufficiently to warrant a definite expression as to thickness. We should expect this, because the magnetic influence is centred in the poles of the masses, and towards such foci the needle tends to point.

IV. Can we by means of the magnetic needle ascertain the direction and depth of a local magnetic pole? In other words, can we determine the thickness of rock or earth covering which overlies a given magnetic rock?

Often I think we can, with much precision, locate a point in the surface over the pole and determine its depth, by making what may be called a *magnetic triangulation*. Proceed thus: Remote from any magnetic rocks, neutralize, by means of a bar magnet, the earth's influence on the needle of a solar compass. The needle will then stand indifferently in all directions, and will not vibrate. Record carefully the distance and position of the neutralizing magnet; the compass is then ready for use. Set it up near the magnetic pole to be determined, and fix the magnet in exactly the same relative position it had before. The earth's directive power on the needle will again be neutralized, and the needle will point as nearly towards the local pole as its mode of mounting will permit; mark the line indicated by the needle on the ground; remove the compass to one, or, better, two other positions, and repeat the operation. If there is no other local force to interfere, the three lines must intersect in one point, which will be directly over the pole whose position is sought. By using a dip-compass in a similar manner, it is evident that the data to determine the depth, by the simple solution of a triangle, would be obtained. The fact that several local poles often influence the needle at each station renders this operation difficult in practice;—we should endeavor to find a place where but one strong pole exists.

A magnetic needle having universal motion, like Mr. Ritchie's, would evidently determine both position and depth at the same time; but a solar compass would have to be used to fix the position of the artificial magnet used in neutralizing the earth's force, unless it be fixed by an observation on the North Star, or by a meridian line brought in from a non-magnetic area.

V. When considering the magnetism of the rocks of the four great geological epochs represented on the Upper Peninsula of Michigan, I observed that considerable magnetic variations were noted by the Federal surveyors, over rocks of Silurian age, which had never been observed to be in themselves magnetic. In some instances these variations had been observed over a limestone, supposed to be Trenton, and at a distance of 75 miles from the nearest Huronian, or other (known to be) magnetic rocks.

This phenomenon may be due either: 1. To the presence of magnetite in such rocks, due to local metamorphism or other cause. 2. To accumulations of magnetic sand in the drift; or, 3. To the underlying Huronian rocks, which may be supposed to exert their influence up through the overlying Silurian.

Without having made a study of any of these localities, I incline decidedly to the latter hypothesis, as accounting for the known facts better than either of the others.

Should this prove true (and I hope to settle it at some future time) it may lead to a novel and interesting application of the science of magnetism to some important questions in geology—the determination of the thickness of sedimentary rocks by *magnetic triangulation* in places where it would otherwise be difficult to arrive at such thickness. It might also enable us to work out the structure and distribution, in a rough way, of these oldest rocks which underlie great Silurian areas, which would in no other practicable way be possible, thus throwing light on the nature of the rocky bottom of the ancient seas.

On the same principle we can, of course, trace magnetic iron belts under water. I have in many instances made very satisfactory magnetic observations from a canoe in the inland lakes of the Upper Peninsula. The bottom of Lake Superior may be thus partially mapped. Silt and sand will make no difference with the needle; it looks through everything but iron.

I have endeavored in the above to set forth plainly just what has been done in this comparatively new field, to give the results obtained, and to call attention to those principles which underlie the use of the magnetic needle in exploration for iron ores. The time and means at my disposal were meagre, my instruments imperfect, and I had no precedent to follow. I am persuaded that the subject is worth the attention of the explorer, miner, geologist, and physicist.

There has been a good deal written bearing on the subject of the Magnetism of Rocks, my references having very much increased of late. I had proposed to examine these authorities before writing this paper, but unfortunately the best libraries of Michigan do not contain any of the works referred to, and not being able to have abstracts made in Eastern libraries, I have derived no benefit from these authorities.* Could I have examined the results of the magnetic observations which must have been made in the great iron regions of Sweden, Norway, and Russia, I should probably have found my meagre results anticipated, and this article might not have been written. I am confident, however, that the Huronian rocks of Michigan have never been magnetically studied, and it may be that the methods that have been used in Europe are not such as would commend themselves to Lake Superior explorers, miners, and surveyors, who require cheap, light, and simple instruments that admit of rapid use.

The State of Michigan, or those interested in her Iron Regions, may at some future time see fit to have this subject thoroughly investigated. To that future investigator I commend my notes, trusting that he may find them a reconnoissance of his rich field of labor.

*Gilbert's Annalen (German) contains several papers. See volumes 3, 4, 5, 16, 26, 28, 32, 35, 44, 52, 53, and 75.

CHAPTER IX.
METHOD AND COST OF MINING SPECULAR AND MAGNETIC ORES.*

the iron ores of the Marquette region are mostly extracted in open excavations; hence the process is more nearly allied to quarrying. Several attempts at underground work have been made, which have not, on the whole, been successful. The Edwards mine has been almost entirely wrought by candle-light. The slate ore pit No. 1 of the New England mine was worked in the same way, as is also the Pioneer furnace pit of the Jackson mine.

The Champion mine was opened systematically for underground, work, with two levels, sixty feet apart, and three shafts at distances apart along the bed of about 200 feet; but this idea has been so far modified that one-third of the ore of this mine is now extracted by daylight. The Cleveland mine has recently commenced to mine considerable ore underground.

Several other mines have, from time to time, worked underground stopes, but so far only temporarily; if such stopes could not be opened out to daylight, they have usually been abandoned. In brief, it may be said that no considerable amount of ore has as yet (1870) been mined underground in this region, and of that so mined very little has been taken out at a profit, and I may add that it seems to be the belief of the most experienced mining men that this state of things will hold for some time to come, for reasons which will appear.

Nearly the same remarks may be applied to the mines of the Iron Mountain region, Missouri, the ores of which are very similar in character to those of Marquette. Some of the New York and New Jersey magnetic deposits are also wrought open, but this is the exception, underground mining being there the rule.

*Two papers on this subject read before the American Institute of Mining Engineers and the American Society of Civil Engineers, and published, are embodied in this chapter.

The following brief sketch of the geological structure of the Marquette iron deposits will indicate some advantages of the method of mining employed; the subject being more fully considered in the chapters on the geology of the Marquette and Menominee regions, and illustrated in maps Nos. III. to X. of Atlas. See also Plate VIII., representing Edwards mine.* The iron-bearing or Huronian series of rocks are stratified beds, the principal ore formation being overlaid by a quartzite, XIV., and underlaid by a diorite, or greenstone, XI. This ore formation is made up, first, of pure ore ; second, of "mixed ore" (*i.e.*, banded jasper and ore); and third, a soft, greenish schistose, or slaty rock (magnesian), which occurs in lens-shaped beds which alternate with ore, thus often dividing the formation into two or more beds of ore, separated by rock. Usually the beds of both ore and rock thin out as they are followed in the direction of the strike from a centre of maximum thickness, producing irregular lentiform masses. Since their original deposition, if we may assume they were laid down under water, the whole series, including the iron beds, have been bent, folded and corrugated into irregular troughs, basins and domes, which often present at the surface their upturned edges of pure ore, standing nearly vertical. A cross-section, finely illustrating this structure, can be seen on the west of the great south-west opening of the Lake Superior mine. It is locally known as the "Big W," which letter is plainly suggested by the sharp folding of rock and ore. See Fig. 7 and View IV.

[IV. Lake Superior Mine, “Big W”]

The fact that, as a rule, the richest ore is found near the upper part of the formation, and the most jaspery part near the base, has led to the separation of this formation into two beds, Nos. XII. and XIII.

This structure, involving sudden changes in the amount and direction of the dip, from horizontal to vertical, would evidently necessitate, in the case of underground work, constant changes in the plan of attacking the ore, as well as in the mode of supporting the roof.

The magnetic iron deposits in the Eastern States may also be regarded as true beds, but are far more regular in strike and dip, extending downward at a high angle to an undetermined depth, and appearing more like veins. If folds exist, they are much deeper and more regular than in the deposits under consideration. The Marquette ore deposits are often very thick, 50 feet being not infrequent, which makes ordinary timbering difficult, if not practically impossible; while the eastern deposits, so far as my observations have extended, are seldom over 20 feet, and average considerably less than that thickness.

*Many copies of this chapter will be distributed separately, rendering this geological résumé necessary.

The "pinch and shoot" structure, suggesting what are termed "chimneys" and "courses of ores" in some metalliferous mines and which is very apparent in the New York and New Jersey mines (practically dividing the ore into pod-shaped masses, the axes of which "pitch" in the planes of stratification in a direction quite different from the dip), can at this time be best observed in the Marquette region at the Edwards mine, Plate XIX. and Map No. VIII. Atlas. The intervening barren streaks where the hanging and foot-walls come near together, and which therefore divide the "shoots," form excellent supports to the overlying rocks and give the mine great security, as all who have worked deposits having this structure will testify.

The soft schist mentioned as occasionally bedded with the Marquette ores, often constitutes the hanging wall in parts of the mine, but does not possess the requisite strength to make a good roof. It is impossible to support such rock with occasional timbers or pillars, for it will scale off between the supports, demoralizing the men, if not actually endangering their lives. Even when the works reach the solid quartzite XIV, which, as has been stated, is the true hanging wall-rock of the ore formation, it is sometimes not safe, particularly near the surface. These facts make open workings a practical necessity at the start, and the great economy of breaking ore from high stopes with heavy charges of powder induces a continuation of the method, even when the rock covering has attained a thickness of many yards, and underground work would seem to be advisable. It is, indeed, hard to say what thickness of solid rock a Marquette mine-superintendent would hesitate to remove if it covered a large deposit of ore. Forty feet of earth and nearly as many of quartzite (as hard as granite) have been "stripped," and the thickness of rock is daily growing greater as the beds of ore are followed in depth.

It may be said, and I do not know but that it is a canon of mining, that all mines, which sooner or later have to be wrought underground, should be systematically opened as mines at the start, but this is not Marquette practice; and I have undertaken to describe, and, so far as I am justified, defend the methods there employed. It would be difficult to convince our people that, having a large deposit of pure ore before them of unknown form and size, covered often by but little earth, and backed by perhaps a small amount of money in the company's treasury, it is best to incur the delay and cost incident to sinking and drifting to open ground already opened by nature and ready to win. Wrought as open quarries, several of our mines have paid their way from the start, while, had they been opened on a regular system of mining, they would have required an investment of $50,000 in plant and improvements before shipments could have begun, and at least one year's time. Such facts settle such questions with American capitalists; and with the uncertainties which attend the opening of new mines in new districts, the high rate of interest in this country, and uncertainty of tariff legislation regarding iron, it may be a question whether this hand to mouth—quick return—let the future take care of itself— view of the question, is not in a certain degree defensible.

The appearance of our mines is anything but pleasing. They consist of several (sometimes of ten or more) irregular elongated pits, often very large and generally more or less connected, having usually an easterly and westerly trend imposed by the strike of the rocks. Everywhere are great piles of waste earth and rock, which are often in the way of the miner, and which in some instances have been handled over three times.

There are two principal advantages in open works. First, the preparatory work is all reduced to the simplest and safest kind of pick and shovel, hammer and drill, horse and cart business; such as can be let to the common run of mine contractors. On the other hand, underground mining involves sinking, drifting, timbering and elaborate machinery, all of which require skilled labor and large investments. In an isolated cold country like Marquette, the *quality* of the labor demanded is an important consideration. The second advantage, already mentioned, is the great economy in cost of drilling and explosives which high stopes in open works permit. These elements of cost are important items in all mining where hard ores are encountered. It is believed that they have been reduced to a minimum in the Marquette iron mines, where holes two inches in diameter are sometimes sunk 22 feet, and 15 feet is common. Such holes are not fired directly with the blasting charge, but are “shook" several times first, that is, fired with small charges which produce cracks and cavities about the bottom of the hole; when these are large enough to contain a sufficient amount of powder, the lifting charge is put in and the great mass thrown down. Twenty kegs of powder, of 25 pounds each, are sometimes fired at once, and from five to ten kegs is not an uncommon charge for a stope hole. By this method 5,000 tons of material have, in some instances, been removed at one blast, and one-third of that amount is quite common at some of the mines. In this way the entire cost for labor of drilling and explosives has been reduced, for a single blast, to less than three cents per ton. But the average cost is of course much greater, being at some of the mines 50 cents for all the drilling and powder consumed in the mine; about one-third of this is for block-holing the large masses thrown down by the stope holes, which are often so large that they have in turn to be broken by powder. The cost of powder and fuse for the hard ore mines, it is believed, does not exceed ten cents per ton. In some of the New York and New Jersey mines, which are worked underground, I am informed that these items cost much more. In the Persberg mines, Sweden, the drilling and explosives cost 65 cents per ton of ore in 1870.

It may be inferred, from the above description, that Marquette iron mining does not differ essentially from ordinary rock excavation on public works, being work that may be let by the cubic yard or ton. Until quite recently this has been very near the truth, tire difference being in the skill and care required in separating the ore

and rock which are often mixed together in the deposit. But these palmy days are rapidly passing for most of the mines now worked. An increase of water and greater cost of handling incident to increased depth, and, what is still more costly, the increase in thickness of the rock covering, will soon require, in fact does now (1870) really require, more expensive plants, different methods, and more skill.

The transition from the present system of quarrying to the future method of underground mining, which will have to be made in the Marquette region, will be a critical period, and will possess great interest, as affording a solution of a mining problem such as may not yet have been presented anywhere. Attempts at its solution have already been made, but, as has been remarked, very little ore has as yet been extracted at a profit by candle-light. To recapitulate, the system adopted will have to meet the case, 1st, of beds of ore varying, often abruptly, in thickness from o to 50 feet; 2d, of beds varying in dip from nearly vertical to horizontal, and passing by a curve of small radius from one inclination to another; 3d, of beds varying in character of hanging wall from a solid quartzite, which will stand with ordinary supports, to a soft schist, which can only be kept in place by a continuous support, or by actual filling in—"remblais." Again, the axes of the folds are not horizontal, but sometimes "pitch" at angles of 30 degs. or more in the direction of the strike, producing a fourth troublesome feature. See Map IX. Now, when we consider that the dressed ore is expected to yield 65 per cent. in the furnace, and is seldom worth on the average over $4 or $5 per gross ton on the cars at the mine, including royalty, the general character of the problem will be understood.

In New Jersey, with perfect regularity in the dip, better hanging walls, thickness within the limits of easy timbering, cheaper fuel and labor, and material which breaks easier than that of Lake Superior, the ores of several well-known mines, I am told, cost fully this amount.

Steam machinery for hoisting and pumping, which has cost from six to not less than fifty thousand dollars, has been erected at most of the Marquette mines, as shown by the table at the end of this chapter. In 1870, however, not much more than one-half of the entire ore product of the region was handled by steam, and much less than this proportion of all the material, the balance being done by horses, the use of which, however, is decreasing.

From these facts it may be inferred, that while the cost of breaking ore may have been reduced to a minimum by the system of mining employed, not so much can be said in favor of the methods of handling the ore from the miner's hands to the cars. The expensive horse and cart, swing derrick and whim, are in too general use, and the roads over which the loads are hauled are often not above criticism as to grades and surface. The causes which have led to this extensive use of horses are considered in another place.

The local staff of a Lake Superior Iron Mining Company usually consists of the *agent*, who is often secretary or treasurer of the company, and whose duty it is to take general charge of the company's business, except selling the ore, which is commonly done by a special agent in Cleveland, who may or may not be an officer of the company. This agent supervises the accounts, makes the payments, attends to shipping the ore and to ordering supplies, and often assists in selling ore. One man sometimes represents more than one company in this capacity. A majority of the agents reside in Marquette. The *superintendent*, who by custom has the title of captain, always resides at the mine, directs the work, and is in the main responsible for it. On him as much or more than on any other officer of the company does the success of its operations depend.

The offices of agent and superintendent are sometimes united in the same man. Large mines have a *chief clerk*, who is practically assistant superintendent. Next in order of rank are the foremen, master mechanics, and time-keepers. For names and addresses of agents, superintendents and managing officers, see Statistical Table, Plate XII. of Atlas.

The *organization* of the force of two large mines in the summer of 1870 is shown below. The first mine (I.) shipped the greatest amount of ore, and the second (II.) did most of its dead work in the winter, the aggregate shipments for the two, for that year, being 300,000 tons.

	I.	II.
Contractors engaged in stripping, sinking, etc..	77	7
Company account, men, laborers and mechanics on miscellaneous work.....	65	32
Total employed in *dead work*.....	142	39
Contractors breaking ore.....	117	114
Company account, men breaking ore.....	—	25
Total at *mining* proper.....	117	139
Carpenters and wagon-makers.....	6	6
Blacksmiths and helpers.....	17	10
Total mechanics employed in *repairing*....	23	16
Drivers and stable-men.....	20	12
Engineers and firemen.....	11	8
Loading ore from stock-pile.....	18	—
Total *handling* ore.....	49	20
Superintendent and clerks.....	3	3
Foreman, blaster and watchman.....	6	7
Total *staff* at mine.....	9	10
Total force employed.....	340	224

This force was employed during the period of shipments, hence of greatest activity; after the close of navigation, in November, it would probably be reduced 25 per cent. Less than one-half of the men employed have families, many single men going "outside" in the fall and returning in the spring.

One large mine, the best managed in the region, expended in 1872, 51,000 days' work all told, of which 48 per cent. was by contractors, and 52 per cent. by the day or on company's account: it produced about 2¼ tons of ore for each day's work.

The *wages* of the men employed in and about the mines, in 1869 and 1870, were about as follows: Common labor was nominally $1.80 per day for most of the time, but by far the largest part of the mining work was done under contracts. Contractors made, clear of costs, from $60 to $77 per month as high and low averages; $70 is probably near the mean of the whole. It was not uncommon for a "pair" (two or more men working jointly) to make $100 per month each, and again the earnings will fall so low as barely to pay board; but such are extreme cases. Leaving out the staff of the mine and the contractors, the wages of all others, mechanics, engineers, firemen, drivers, but mostly common laborers, averaged in 1869 and 1870 about $2.12 per man per day. Mechanics received from $2.50 to $4.00. In 1872 the wages of men and contract prices were from 25 to 50 per cent. above the figures here given.

The *nationality* at three mines, which employed an aggregate of over 600 men, was in 1870 as follows, expressed in percentages:

Irish	31
English (Cornishmen)	27
Swedes	18
Canadians (French)	5
Americans	5
Germans	4
Norwegians, Danes, and Scotch	10
	100

The relative proportion of the Irish element is decreasing; a few years since nearly all the men employed at some mines being of this nationality. The percentage of Cornishmen is increasing, owing largely to a want of work in the copper region. These men are skilled miners, and do a large part of the sinking and drifting. Swedes are rapidly gaining in numbers, many of them having been miners in their own country.

The exodus of Swedes to the United States apparently threatens to depopulate that country. There can be little doubt but that a more genial climate and better food will Improve the lower class, from whom the emigrants come. Statistics of the population of the Upper Peninsula are given in App. G, Vol. II.

The unit of measure and comparison in the following table is the *gross ton of merchantable ore*. The ore is the object of the miner's efforts, and the tons sold measure his business. The items of cost in all that follows express the expenditure per ton of ore mined, prepared for market, and loaded on the cars. In instituting a comparison between these figures and those obtained by the civil engineer on public works excavations, where the cubic yard of vacant space is the ordinary unit of work accomplished, it must be borne m mind that the labor incident to sledging up and sorting out the ore from the rock considerably enhances the cost of mining.

In order to more intelligently follow the methods of working the Marquette mines, we must classify the various items of cost under appropriate heads, and assume some absolute cost per gross ton, as near the actual fact as possible, as a basis of comparison of these items with each other, and with other mining regions.

No discussion of the question which leaves out the *cost*, would possess much practical interest; but all who have undertaken to obtain such facts for publication, know the difficulty, and will not place implicit reliance on the accuracy of what follows. $2.64 per gross ton will be assumed as the entire cost of mining the hard ore, and delivering it in the cars ready for shipment (in 1870); but 4 this sum does not include interest on capital, expense of selling, royalty or mine rent, nor depreciation of the mining property. The cost of mining the soft hematite ores is considerably less, and the methods much simpler.

Royalties or mine rents have not become settled; there are not many leased mines; one of the best of its kind (the New York) pays but 20 cents per ton for first-class specular ore. In other instances 75 cents is paid for a lean hematite. Time and experience will settle these prices on an equitable basis. See Atlas, Tables XII., XIII.

Before dismissing the subject of royalty or mine rent, which is not again noticed in the following discussion, I will make a few remarks. Marquette mines, as has been stated, are generally owned and worked by the same parties, hence royalty does not enter directly as an item of cost, but it exists in substance, and may be called *depreciation of the mine*, an item in the cost of ore often not sufficiently considered. One of the best organized and successfully operated iron companies in eastern Pennsylvania place this item at fifty cents per ton of ore. That is to say, every ton of ore sent from a New Jersey mine (which they own) is charged with fifty cents over and above its cost, as shown by the mine accounts, and a like sum is credited to the capital stock account, or to a sinking fund. This fifty cents stands for the original cost of the ore in the ground, and is all the more real, that it was paid in advance in the price of property and improvements. Any mining company which fails to recognize this principle is doomed some day to serious disappointment. Whoever has had experience with charcoal blast furnaces, which so rapidly sink their capital by the consumption of timber, will be fully alive to the importance of this matter. It is a delusion to suppose that our mines will not eventually be *exhausted;* iron ores do not grow; a ton shipped from a mine is gone forever, and the property has one ton less remaining, and is therefore worth less money. Continued shipments will eventually exhaust any and all deposits. Abandoned pits, in which no ore can be found, now exist at all of our mines, and in this class are some that two years ago were the best. The Andover mine, New Jersey, once presented as good opportunity to break ore as any pit now worked in the Marquette region; but about 150,000 tons aggregate product exhausted the mine, and to-day

the owners do not know where to find a ton of merchantable ore on the property. I do not wish to be understood as predicting the exhaustion of the whole region; I think Marquette will produce iron as long as that article is wanted. New deposits of rich ore will be found, and leaner ones, which now have no value, will be worked, and the old deposits will be followed deeper; but this implies new mines, the building up of new locations, new railroads, new men and more capital. What I wish to say is, that unless present holders of average Lake Superior iron mining stocks are receiving fair interest on their investments, and in addition are being paid back the capital they have invested at the rate of, say, 50 to 75 cents per ton of ore sold, they are not doing a good business.

Therefore the $2.64 assumed in the following table should be increased by this royalty, making it $3.14. Commission for selling, interest and exchange, insurance and expenses of the general office of the company (including salaries), will increase this sum to at least $3.50, which will more truly represent the actual cost per gross ton of ore on cars and sold. This, from the amount assumed before as selling price, leaves from 50 cents to $1.50 per ton for interest on all fixed capital invested; in an exceptional condition of the market, like 1872 and 1873, the margins are of course larger.

There may be no better place than in this connection, to speak of another fruitful source of the disappointments which are sometimes experienced by stockholders. I refer to those delusive "*permanent improvement accounts*" better named permanent disappointment accounts, which are too often kept open, and in which are too frequently placed awkward sums which should properly go to running expenses, and be paid for by the pig-iron, ore, lumber, or whatever is produced. After the necessary real estate is bought, the mining or manufacturing plant built, and the business of production actually commenced, the improvement account should be closed forever. Some kinds of business, in some places, under some managements, may permit an opposite course, but the above is the only safe rule. If in any particular year an extraordinary expenditure is made which is not likely to be repeated, a part of it may properly be held in some open account, in order that it may be distributed over more than one year's product. But this is a different thing from piling up a permanent account under the delusion that the property is enhancing in value.

There are few kinds of business in which there is more danger from this cause than in iron mining, for not only is an iron-ore property depreciating from the exhaustion of the ore, but at any time it may be still more depreciated by unfriendly tariff legislation, for which the iron-master must be prepared.

TABLE *showing the Approximate Cost of Mining the Specular and Magnetic Ores of Lake Superior, made in* 1870.

General heads under which cost of mining is classified.	Elements of cost, not including royalty or depreciation.	APPROXIMATE COST OF EACH ITEM. In per cent. of the whole. Items.	Totals.	Based on a total cost of $2.64 per ton. Items.	Totals.	Amounts. Labor.	Supplies.
I. Dead work (preparation).	1. Explorations	00.6		.015		Eighty per cent.	Twenty per cent.
	2. Sinking shafts	01.5		.040			
	3. Drifts and tunnels.	06.1		.160			
	4. Roads	00.6		.017			
	5. Stripping earth and rock	13.2	28.1	.350	.742	.620	.122
	6. Miscellaneous work and minor improvements*	06.1		.160			
II. Mining proper (labor). Drilling.	1. Ledge holes (in stope)	04.2		.110			
	2. Block holes (in fragments)	04.9		.130			
Other work.	3. Sledging, sorting, and loading	13.3	39.8	.350	1.050	1.050	....
	4. Handling rock	09.5		.250			
	5. Miscellaneous work	07.9		.210			
III. Mining materials and implements ("mine costs"). Explosives.	1. Powder and fuse.	03.6		.095			
	2. Nitro-glycerine	...†		...†			
Tools.	3. Steel (drills)	00.7		.018			
	4. Tools other than drills	01.6	11.9	.043	.313	.103	.210
Repairs.	5. Blacksmiths' supplies	01.8		.047			
	6. Blacksmiths' labor.	04.2		.110			
IV. Handling ore from miners' hands to cars, and pumping. By horses.	1. Teaming, labor of drivers and stablemen	05.7		.150			
	2. Forage	04.2		.110			
	3. Carts, sleds, harness, etc.	00.2	15.6	.006	.413	.272	.141
By men.	4. Loading ore from stock pile	01.3		.035			
By steam.	5. Labor, supplies, and repairs	04.2		.112			
V. Management and general expenses.	1. Salaries and office expenses. 2. Tax of all kinds.	04.6	04.6	.122	.122	.062	.060
		100.0	100.0	2.64	2.64	2.107	0.533

* Does not include exceptional permanent improvements.

† No reliable figures obtained.

In order to institute a comparison between American open-excavation mining and the systematic underground work of Sweden, I append the following table, for which I am indebted to Prof. Richard Akerman, of Stockholm:—

COST OF MINING ORE IN PERSBERG MINES, SWEDEN, 1870.

In currency.

General heads under which cost of mining is classified.	Elements or items of cost, not including royalty or depreciation.	In percentage of whole.		Based on a total cost of $2.20 p. ton.	
		Items.	Totals.	Items.	Totals.
I. In the mine	1. Boring	22.73	38.66	.50	.85
	2. Powder	5.82		.13	
	3. Priming reed	0.84		.02	
	4. Clay	0.50		.01	
	5. Candles, augers, and sledges	2.33		.05	
	6. Charcoal	0.44		.01	
	7. Auger whetting	3.20		.07	
	8. Shooters' fees	2.80		.06	
II. Water drawing (or pumping)	1. Water drawing	3.50	3.50	.07	.07
III. Bringing up the mountain (hoisting rock and ore)	1. Putting into the ton	4.68	11.17	.10	.26
	2. Receiving	1.11		.03	
	3. Down freight	1.10		.03	
	4. Hoisting	2.74		.06	
	5. Oil and lines	0.28		.01	
	6. Mine tubs and ladders	1.26		.03	
IV. Dressing	1. Dressing	8.12	8.12	.18	.18
V. Picking and washing	1. Picking and washing	5.65	5.65	.12	.12
VI. Buildings	1. Buildings	16.45	16.45	.36	.36
VII. General expenses	1. General expenses	16.45	16.45	.36	.36
		100.00	100.00	2.20	2.20

Professor Akerman furnished also these explanations:—

a. Our drill holes are about one inch in diameter and cost 7½ to 12 cents currency, per foot, when boring downwards, and twice as much when boring upwards.

b. Powder costs 11½ cents, dynamite 43 cents, and ammonium powder 40½ cents per Swedish pound (the Swedish lb. equals .93 of the English).

c. The reason why blasting with us is more expensive than with you, must partly depend upon stronger mountain ground and partly upon the small diameter of our augers.

d. “Dressing" on the Persberg table is to be understood as sledging and sorting.

e. "Picking and washing" is a kind of after-sorting by hand of the smaller pieces (of which about a third of the ore consists), got partly by blasting and partly by the first sorting.

f. “Buildings" include timbering in the mines and all buildings made for pumping and hoisting.

g. "General expenses" include some benefits for the laborers, such as domiciles, potatoes, gardens, expenses for schools, medicine, administration, etc., etc.

h. “Down freight" is the cost for bringing down the ore a short distance from the mines to the lake-shore, where it is sold.

i. Water power is used at Persberg both for pumping and hoisting.

j. Our miners receive from 48 to 75 cents per day, besides what I above called benefits.

k. The mining costs at Persberg are among the highest in Sweden.

The titles of the several heads under which mining costs may be divided, and the number of the items, depend on the object sought: the classification employed in the Marquette table, seemed best adapted to the presentation of the facts in hand. It will be observed that the form of the Swedish table differs materially and is of course better adapted to underground work, and to a more careful and laborious selection of ore.

I believe that considerable advantage would accrue to many of the Marquette mines, if the accounts were so kept that cost sheets similar to the foregoing could be prepared from time to time. It is well known that the cost of mining varies greatly in the different mines, some costing twice as much as others. This difference is often largely owing to natural causes, but sometimes it is, in part at least, in the management. There is no better way, in fact there is no other way, of stopping "leaks" of this sort, than by first finding where they are.

A comparison of such cost sheets from different mines, for the same time, or from the same mine for different periods, would indicate at once to which items the excessive cost belongs, and thereby direct the attention of the management to the leak. I therefore venture the opinion, that a carefully prepared cost sheet is one of the first steps in attempting to reduce the cost of ore.

In the detailed description of methods which follows, the items will be taken up in the order of the table.*

*For detailed descriptions of all the mine workings as they were at the close of the season of 1872, see "Appendix to A. P. Swineford's History of the Lake Superior Iron Region," being a review of its mines and furnaces for 1872, published by the Marquette Mining Journal.

1. Dead Work.

This general head embraces all the work and costs incident to getting ready to mine the ore, and is subdivided into—1. Explorations (embracing only such searches for ore as are in progress from year to year about the mine). 2. Sinking shafts. 3. Drifts and tunnels. 4. Roads for wagons. 5. Stripping earth and rock, or uncovering the ore. 6. Miscellaneous work and minor improvements. The entire expenditure for dead work is 74 cents per ton of ore produced, which equals 28 per cent. of the whole cost.

1. **Explorations.**—More or less digging of test-pits, sinking shafts, drifting, trenching, and sinking drill holes is constantly in progress at most of the mines. My facts indicate that this work varies in amount from one-half to

three cents per ton at the producing mines, being of course greatest at the new locations. It is not carried on systematically, being pushed when there is an increased demand for ore, or some old pit shows signs of failing, and again entirely discontinued. The price paid for pits 4 feet by 6 feet, and not over 10 feet deep, is from 30 to 60 cents per foot, depending on the ground; when so deep as to require a windlass, 50 to 75 cents and up to $1.25, if the shaft reach the depth of 30 feet and is wet. Drifting in firm earth will cost about the same per foot, depending on the depth below the surface and nature of the earth. Drill holes sunk by hand, material 15 feet deep, will cost from 75 cents to $1.00, and if deeper, considerably more per foot. There seems to be no reason why more use should not be made of the drill in this work. By means of a simple spring pole, such as was used in early days in the oil region, holes could be easily sunk 100 feet, which is as deep as it is usually necessary to go at this time. An experienced miner will judge very accurately of the ground passed through by the mud, and if there was any doubt, chemical analysis would determine the nature of the material; the mud furnishing a strictly average specimen, so desirable in an analysis for practical purposes. As has been mentioned, the *annular diamond drill* was introduced last season (in 1869) at the Lake Superior mine with success. A hole 130 feet deep was sunk at a cost of about $5 per foot; the core produced furnished very satisfactory knowledge of the substance passed through. The drill did not perform as well at the Washington mine, where several holes were sunk, the deepest 96 feet. In two instances the annular diamond bit got fast in an oblique seam and two were lost; not counting loss of diamonds, the work cost about $1.50 per foot: whether larger bits, a different setting of the diamonds, or more experience would overcome this difficulty, I do not know. It is a matter of great importance, and is worth thoroughly working out. As the subject of exploration for ore has been fully considered in another chapter, it is not necessary to treat it farther here.

2. **Sinking Shafts.**—This work, which forms so large an item of cost in some underground mines, varies in the Marquette Region, so far as I have ascertained, from 1½ to 5½ cents per ton of ore. Our open and comparatively shallow workings do not call for many shafts or winzes; the deepest shaft in the region is now (1870) not over 200 feet. The prices for this work range from a mean of $22.50 to $31.50 per foot in depth, depending on the hardness of the ground. In some mines, extreme prices range from $15.00 to $40.00, and even more if the shaft be very wet. Miners are often permitted to select the size most advantageous to themselves, which may be four feet by six; but eight by twelve feet is more common. The material is generally hoisted with the ordinary hand windlass, but sometimes with a horse-whip or whim, the miner having to deliver the stuff at the mouth of the shaft. From 10 to 15 per cent. of the price received by the miner for sinking has to be expended in *mine costs; i.e.*, powder, fuse, candles, steel, tools, etc. No charge is made against him for smith's work. Sometimes the contract is let at so much per foot of shaft and so much per ton of ore, which gives the miner an interest in separating ore from rock.

3. **Drifting and Tunnelling.**—This element of cost varied more widely than any other, and might have been divided into two: (1) Drifts designed to open ground for stoping; and (2) Tunnels or adits for drainage and transportation of ore, the latter being of the nature of a permanent improvement. But on the principle that permanent improvement accounts are often permanent disappointment accounts, and to be avoided, and considering the fact that this kind of work is actually going on year by year, and must do so as long as the mine is worked, it does not seem wise to separate it from the current cost of getting ore. Ordinary 4 x 7 drifts cost, in hard ore, from an average of $22.50 to $24.50 per foot, the miners delivering the material behind them, and paying their own costs, as in the case of shafts.

Tunnels large enough to admit railroad cars and small locomotives cost from $30.00 to $50.00 per foot. The Washington tunnel, now over 1,100 feet long, and timbered a considerable part of the way, cost an average of about $40.00, not including rails. The timbered portion is twelve feet wide at the bottom, ten feet at the top, and ten feet high in the clear. No machinery has yet been brought to bear on either sinking shafts or drifting; the labor required is more than one-half expended in drilling holes for blasting. The subject of drilling is fully considered under its proper head.

4. **Making Wagon-Roads.**—The great amount of team-work employed about the mines requires a complete system of roads for summer and winter use. These are sometimes expensive on account of rock-cuts, costing, in some instances, as high as four cents per ton of ore in the early stages of work.

5. **Stripping Earth and Rock,** or uncovering the ore. This constitutes on the average nearly one-half of the dead-work, and is one of the largest single items in the whole cost of mining. So far as my inquiries extended I found it to vary from 20 to 52 cents per ton of ore. This cost is necessarily increasing at all of the mines worked as open cuts. It is simple rock and earth-work, the material being removed on wagons, carts, or sleds, drawn by horses. The advantages of light railroads and small locomotives do not seem to have commended themselves for this work. There would, of course, be considerable danger of destroying tracks from blasting, and it often happens that not much work has to be done in one place; still there is no doubt but that a large saving would be effected by substituting steam for horses in portions of this work, as will be more fully considered hereafter.

The aggregate amount of material which has been handled in stripping is very great. Thirty and even forty feet of earth have been removed, and nearly as great a depth of rock; but this is the experience in open workings everywhere. I have seen twenty-one feet of earth and soft, shaly rock stripped from a nearly horizontal bed of

44 per cent. Clinton ore in Western New York, which did not average over thirty inches thick. In South-eastern Kentucky I found the rule among the miners of sub-carboniferous ores to be, that it would pay to remove a foot of earth for the sake of an inch of ore, which does not differ widely from the Western New York practice. In both of these instances the stripping was nearly the entire cost of mining, and labor was much lower than in the Marquette region. The usual contract price for removing ordinary earth (sand, clay, and boulders mixed together) is fifty cents per cubic yard, the digging costing about one-half, and the hauling one-half. Hauls vary from 100 to 800 feet. The highest price paid for excavating any considerable quantity of rock in open cuts, which has come to my notice, was $3.00 per cubic yard, equal to $24.00 per fathom, or about $1.00 per ton. This was a very hard jasper rock, containing but little ore. Large quantities of rock have been excavated and hauled over 500 feet at the Lake Superior mine for $2.50 per yard. The soft greenish schist, so common at all the mines, can be moved for from $1.00 to $1.40 per yard, including hauling. When a good face can be obtained on the overlying quartzite, which is likely to constitute the greater part of the rock to be moved in future, it should be broken down and loaded on wagons for from $1.50 to $2.00 per cubic yard.

The amount of money which it will pay to expend in stripping of course depends chiefly on the quantity of ore uncovered. If we assume fifty cents to be the maximum expenditure per ton of ore for this work (this amount has been greatly exceeded), the problem of what thickness of rock may be stripped admits of an easy theoretical solution. One cubic yard of solid ore (allowing for wastage on account of associated rock) may be considered to yield three tons of merchantable ore, which, at the allowance above assumed, would give us $1.50 to be expended per square yard in stripping a bed of ore only one yard thick. Hence in this case it would pay to remove nine feet in thickness of earth, or about three feet in thickness of rock. But suppose we have a bed of ore twenty-four feet in vertical thickness, which is a more common case, what amount of earth or rock would it pay to remove under the assumed limit of expenditure? Twenty-four feet of ore will yield twenty-four tons per square yard of surface, which, at fifty cents per ton, gives $12.00 available for stripping per square yard. This sum would remove twenty-four feet thickness of solid rock; or a foot in thickness of rock may be stripped for every foot in thickness of ore uncovered, at a cost of fifty cents per ton of ore. The same expenditure will remove three times this thickness of earth.

An important and often neglected question connected with this subject is, *where to deposit waste*, that it may be out of the way of future mining operations. Some material has been already handled twice in the Marquette region, and I know of a mine in Southern New York where the same earth was three times handled before it was finally permitted to rest. In a new region, like Marquette, where comparatively little thorough exploring has been done, it is often difficult to decide where waste piles will be out of the way for all future time. If a drill hole were put down for fifty feet in rock, and no ore found, it would be safe to say, that if ore existed under that spot, it would have to be mined under ground; hence, that so far as future stripping was concerned, a waste pile placed there would be out of the way. A very common practice in under-ground work, in some mining regions, is *to fill up the worked-out places with the waste*, and this can undoubtedly be done to advantage in some instances in open works, although it has not as yet been practised in the Marquette region. The trouble is to find out when a pit is exhausted—it is so common to break through a thin layer of rock and find a bed of workable ore behind it. But there are parts of most mines where the foot-wall has unquestionably been reached, and if any doubt exists, a few deep drill-holes will settle the point. When this is the case, and the foot-wall has a sufficiently gentle slope to permit of its holding materials deposited on it, it will, I think, be often found advantageous to use it to support a waste pile.

For the sake of illustration, take the New York and Cleveland Mine workings, which are adjacent. In this instance the slope of the foot-wall is so steep that it would probably be necessary to cut in it a rude step on which to rest a rough retaining wall, which could be built of blocks of quartzite swung across from the hanging-wall by means of a derrick. The triangular space thus formed would hold all the waste rock for a long time to come, and would afford a minimum haul. It might not answer to deposit earth in such positions, as heavy rains would be likely to wash it into the pits. The dip of the foot-wall in this, as well as in most cases, will, I think, become flatter in depth, so that a better opportunity will be afforded for a second similar waste receptacle at greater depth, if one should be required.

6. **Miscellaneous Dead Work.**—Under this head are included several items which were not of sufficient importance to require separate treatment. Improvements such as dwellings, shops, fences, tracks, trestle-works, pockets, docks, whims, skip-ways, pumping-fixtures, etc., etc., occurring from year to year, are embraced here. These items are in part embraced under "Building" in the Swedish table. This head was originally also designed to cover those exceptional expensive improvements which are of occasional occurrence only, and the cost of which might properly be distributed over several years' product. Additional facts, however, lead me to believe that the amount given (16 cents per ton) is too small. The expensive pumping and winding plants now being erected, and which will continue to be built for a long time to come, increase the cost of the ore materially unless we charge them to permanent improvement accounts, which is not altogether a safe course, as has been already pointed out.

II. Mining Proper, or Breaking Ore.

This general head embraces all the labor incident to blasting the materials down from the solid ledge, breaking it up into fragments that may be easily handled, the separation of the ore from the rock by hand and loading. The average cost of this is $1.05 per ton of ore produced, which equals forty per cent. of the whole. The character of this work will be sufficiently well understood from the table and the following explanation:—

1. **Ledge or Stope Holes.**—The drilling or rock-boring is now (1870) entirely done by hand. The steel used for drills is 1¼ inch octagon, with a bit 2 inches, making a hole nearly 2¼ inches in diameter. Drills vary in length up to 24 feet. English steel is used at some mines, but a majority use American steel, and the most experienced men who have employed both- inform me that the drill steel made by Hussey & Wells and Parke Bros., Pittsburgh, answers as well as the best imported steel, and much better than the average. The drill is turned by one man sitting and struck by two standing, with eight-pound hammers, at the rate of about thirty-six blows per minute each. In this way from nine to eleven feet of hole are sunk per day, the men working usually on contract. The price of stope holes ranges from 60 to 80 cents per foot in depth, the mean being not far from 75 cents; no mine costs have to be paid out of this price. When there is a large proportion of block holes, which admit of the use of smaller steel, the whole drilling of a pit is often let at from 60 to 65 cents. Very deep holes, say from fifteen to twenty-two feet, are sometimes sunk with still larger bits, which about doubles the cost. In these cases two men are required to turn the drill and three to strike.

The cost of drilling ledge-holes per ton of ore, varies from a mere trifle in the case where one twenty-two foot hole throws down 4,000 tons, as has been done, to a very large item on low stopes with perhaps tight, hard ground. From 3 cents to 25 cents per ton may be regarded as extreme averages, although 35 and even 48 cents have been reached, for short periods, under very unfavorable circumstances. The price given in the table (n cents) approximates to the average for hard ores; this number divided into 75 cents, the average cost of drilling per foot, gives, say 7, which should represent the number of tons of ore broken per foot of stope-hole drilled. The data obtained directly under this head confirm this amount, which is also equivalent to about two cubic yards per foot of hole.

The depth of stope-holes varies from two to twenty-two feet, the short ones being employed in "taking up bottom," that is, in squaring the stope so as to give the best chance for the deep holes. The average of 1,500 holes of all kinds in one part of the Washington mine was four feet nine inches, but the stopes which furnished this result were below average height. It is believed that nine or ten feet would be nearer the average for deep holes, and say three and a half feet for the short ones.

2. **Block-Holes.**—The masses of rock and ore loosened by the heavy blasts already described, are often so large that they have in turn to be broken with explosives, which operation is termed block-holing. The amount of this work varies from almost nothing in some pits and in certain mines, to four-fifths of all the drilling required in others, the maximum being reached on high stopes of hard, tough ore. Over two hundred block-holes have been employed to one stope-hole in the Cleveland Mine, one hole being-required to every two to four tons of ore. Block-holes sometimes produce fragments so large as to require block-holing in turn, before they are made small enough to be mastered by the sledge. These holes vary in depth from eight to twenty-four inches, the mean ranging near one foot. With nitro-glycerine the holes need not be so deep as for powder. One inch octagon steel is often used in this work, making a hole nearly 1½ inches in diameter. The drilling is performed as in the case of stope-holes, but usually only one man strikes.

In the same ground, the same drill-gang will sink more than twice the number of feet of block-hole in a day with small steel, than of stope-hole with large steel,—ranging from twenty-four to twenty-seven feet. In open mines of strictly hard ore, this work costs more than stope-holes, and is set down in the table at 13 cents per ton. This amount added to the 11 cents given as the cost of stope-holes per ton, equals 24 cents for the total cost of the labor of *drilling* required under breaking ore:—this would also equal about 70 cents per cubic yard, which would pay for one foot of two-inch drill-hole. But this is by no means the whole; the work of sinking and drifting, which is set down as aggregating 20 cents, is more than half drilling; and a part of the cost of rock-stripping is also for this work. I estimate that 40 *cents per ton of ore* is not far from the actual price paid for this kind of labor in the hard-ore mines, equal to fifteen per cent. of the whole cost. On this estimate, not less than $300,000 were paid out for drilling in1870. This work, from the favorable circumstances under which much of it is done in open excavations, no scaffolding being required, is by far the most purely mechanical labor performed about the mines. While the absolute cost of this item of drilling is very large, and can undoubtedly be reduced by the use of the *power-drill*, it is, as compared with some other mines and regions, small. Our open cuts or quarries afford far better facilities for blasting than under-ground mines. In one Southern New York mine the drilling cost, in 1870, $1.25 per ton of ore, or forty per cent. of the whole cost of mining; in a large magnetic mine in New Jersey, it cost from 60 to 80 cents per ton of ore. In the Persberg mines, Sweden, when the ore cost, in 1870, $2.20 currency per ton, the drilling was 40 cents per ton, equal to twenty-three per cent. of the whole cost, being considerably more than ours, absolutely and relatively. When we consider that the average of wages in Sweden is not far from 65 cents per day, or say one-fourth of what is paid Lake Superior miners, it would seem as if Sweden would be a good field for a power-drill.

The facts relating to drilling have been given in much detail in the hope that inventors and owners of rock-drilling machines may become acquainted with the wants of the Marquette region in this regard. I have had

my attention called to several of these machines, but have not had opportunity to make such investigation of their respective merits as would justify an opinion. I have no hesitation in saying that a machine which would do the work required at a less cost than it is now done (75 cents per foot) would find ready sale, and every facility would be afforded for experiments.

I need not here remark that a power-drill, adapted to Marquette iron mines, must be portable, as it would have to be shifted every few hours; and I should say that two men, or at most three, should be able to handle it on a ragged rock surface. Again, it must be capable of being set up anywhere, to accomplish which, I think that movable tripod, telescopic legs, like those with which engineers' instruments are often supplied, would be convenient.*

*Since the above was written the Burleigh Drill has been tried at several mines with varied success. My facts are quite insufficient to enable me to form a judgment as to its fitness to do the required work, or to know whether it has had a fair trial.

3. Sledging, Sorting, and Loading.—In considering this item, it must be borne in mind that the ore and rock have not only to be broken so that they can be removed, but must be made so fine as to be easily separated, and so that the pieces can be fed into a Blake crusher. This work requires more muscle and as much skill and care as any other done at the mine. Eighteen to twenty-three pound sledges are employed, and the difference in results, between the experienced miner who strikes the lump of ore the right blow in the right place, with this immense hand hammer, and the tyro, is very great. Contracts for sledging and loading, which sometimes include a little block-holing and short tramming, have been let at prices varying from 20 to 50 cents per ton. The loading usually costs not to exceed 10 or 12 cents, the balance being chiefly sledging. There is a wide difference in the texture of ore, some kinds requiring five times as much sledging as others. On the whole, Marquette ores break with much greater difficulty than those of the Eastern magnetic mines. With poorer ground worked and the market more in favor of buyers (which makes them more exacting on quality), the cost of this element will be increased.

Drops, similar to those used at foundries to break old castings, have been employed to break very hard lumps of ore, but the expense of getting the lumps of ore to them has caused this plan to be abandoned. In the copper region powerful steam hammers have been used for a similar purpose, but the same objection as that given above would apply to their introduction at the iron mines. It must be borne in mind that a lump of iron-ore is not worth more than about one-hundredth part as much as a lump of copper of the same weight, and therefore will not bear as much handling.

A steam miner who can walk up to the lump of ore and sledge it to pieces where it lies is what is wanted. Nitro-glycerine or duallin breaks the material finer, producing by its explosion more of a smashing effect than powder, and thereby requiring less sledging. There is no doubt, as is elsewhere stated, about the advantage of employing these new explosives in block-holing.

4. **Handling Rock.**—In addition to the rock which overlies the ore, considered under stripping, at most of the mines more or less rock is found mixed with the ore through the mines, which has to be removed during the process of mining. The proportion varies from none up to one-half of the whole, and often for short periods more than this; the average at this time is believed to be twenty per cent. The 25 cents placed against this item in the table is intended to cover the cost of sorting out and handling this rock under average circumstances. This cost will be increased as poorer grades of stuff are worked.

5. **Miscellaneous Work.**—The 21 cents opposite this item in the table is no more than sufficient to pay for foremen, repairs of tracks and roads, wheeling, tramming, blaster, sometimes hand-pumping, and such securing of the workings as may be necessary, etc.

III. Mining Materials and Implements, embracing "Mine Costs."

This general head is subdivided in the table into Explosives, Tools, and Repairs, which are in turn itemized, as will appear below. The expense incurred here is 31⅓ cents per ton of ore produced, equal to about twelve per cent. of the whole cost.

1, 2. **Explosives.**—Powder and fuse and nitro-glycerine. The present (1870) is an unfortunate time to collect statistics regarding the cost of explosives, for the reason that nitro-glycerine is to a certain extent on trial, and most of the mines employ both it and powder in the same pits, making it difficult to separate the results. The place of the new explosive cannot be said to be wholly fixed in our mines. It is more powerful than powder, bulk for bulk, or weight for weight; can be used in wet as well or better than in dry ground, which is very important in some places; it has so far proved no more dangerous than powder, and its fumes have not been found objectionable. As has been stated, the fragments resulting from its use are usually smaller, hence require less sledging, and, it being more powerful than powder, less drilling is needed.

In the case of wet holes intended for sand-blasting, nitro-glycerine can often be used in small charges to produce cracks which carry off the water and thus prepare the way for the powder. Overhanging loose rock can often be advantageously brought down by a flat cartridge of glycerine.

In short holes, 3 to 6 feet, glycerine will sometimes break two or three times as much ground as powder, thus making the saving on the drilling more than balance the extra cost of the explosive.

The quantity of glycerine used per hole, of course, varies with its depth and other circumstances, and is at the Washington and Republic Mines, according to Captain Peter Pascoe, as follows:—

Depth of hole.	Glycerine.
3 feet	¾ lbs.
4 "	1½ "
5 "	2¼ "
6 "	3½ "
8 "	5 "
10 "	7 "
12 "	10 "
14 "	14 "
16 "	18 "
18 "	21 "
20 "	24 "

There can be no doubt but that the use of this explosive hastens work. Sinking and drifting can be more speedily done with it than without.

Whether it is suited to breaking the great masses from the solid ledge remains to be seen. Certainly it cannot be used to fill the cracks produced by shaking, where heavy sand blasts are required; and it is doubtful whether drill-holes large enough to contain the requisite amount of the blasting oil can be profitably employed; two or more holes could be used, but this would greatly increase the cost of drilling. It certainly costs I per ton of ore mined than powder, but how far this greater cost is balanced by other advantages experience must determine. It is significant that in 1870, being the next year after its introduction, over $40,000 worth was sold in the Marquette region at $1.50 per pound. In 1872 about 40,000 pounds were used, the price being $1.25 per pound. The Painsville Ohio Co. erected (1871) a factory near Negaunee. Duallin and giant powder have recently been introduced.

The figures given in the table, and in what follows, refer exclusively to powder, the nitro-glycerine element having been eliminated as far as was possible. Fuse costs about ½ cent per ton, leaving 9 cents per ton for powder, which, according to the data obtained, varied from 7 to 10 cents. The price of powder ranged from $3.75 to $4.50 per keg of 25 pounds. Therefore an average of 45 tons of ore should have been broken with one keg of powder, or about ½ pound of powder to one ton of ore. This, it must be remembered, does not express the actual work of the powder, on account of the amount of rock moved in addition to the ore—in one instance 23,000 weighed tons of material required 320 kegs of powder, or 72 tons per keg. In another instance 31 kegs threw down 3,500 tons (approximate) of quartzite, or 113 tons per keg. One mine, which produced over 100,000 tons of ore in 1869, consumed for all purposes one keg of powder to every 43 tons of ore produced. The waste material in this case did not amount to over 20 per cent., hence about 52 tons, or, say, 18 cubic yards of material, were moved per keg of powder. The consumption of explosives per ton of ore must increase as the mines grow deeper, either by the greater amount required to remove the rock covering, or by the less favorable opportunity afforded for blasting, if the ore be won underground.

In one group of New Jersey mines, the powder and fuse in 1870 cost 18 cents per ton; in another mine in Southern New York, 14½ cents; in Sweden, at the Persberg mines, 15 cents. All of which figures considerably exceed those reached in Marquette, which is proof of the economy in explosives from working iron mines as open quarries as long as possible.

3. **Steel.**—The use of steel drills has already been described, and reference made to the brands in use. My data, which are far from complete, under this head, indicate that the cost of steel per ton of ore ranges from ¾ to $3^{3}/_{10}$ cents, averaging perhaps $1^{8}/_{10}$ cents; the price of steel being 20 cents per pound. This would give about 11 tons of ore, or about 3 cubic yards per pound of steel consumed, which is less than the data obtained direct on this point seemed to indicate.

It is the practice of some mines to charge the ore contractors 2 per cent. on their contracts for wear of steel, which agrees nearly with the above. At other mines the steel is weighed at the end of each month, and the contractor charged with the shortage, whatever it be.

4. **Tools, other than Drills.**—Cost about $4^{3}/_{10}$ cents per ton of ore. The Ames No. 2 D-handled, square, and round-pointed, strap-backed, solid steel shovel is the favorite.

Washoe picks, Nos. 5 and 6, and Powell, same numbers, both railroad (25 inches long), and pole (19 inches long) are extensively used. Certain mines make their own picks after a fashion of their own.

Solid steel crow-bars, both single and double-pointed, are used.

Solid cast-steel sledges, both American and chrome, weighing from 16 to 18 pounds, and often 25 lbs., are extensively used.

Solid cast-steel striking-hammers, 8 to 9 pounds, and in some instances 11 pounds, are employed.

5. **Blacksmiths' Supplies.**—This item is largely made up of coal and iron, steel being embraced under another head. Charcoal was formerly used exclusively for working steel; but mineral coal is now employed with good results at most mines. The table shows this item to be a trifle less than five cents per ton of ore.

6. **Blacksmiths' Labor.**—This is largely sharpening drills. The number dulled per day by a gang of three drillers will average about 75, in hard ore. One blacksmith and helper will sharpen about 275 drills per day often hours. The 11 cents marked opposite this item embraces all the blacksmiths' work done in and about the mine, for whatever purpose. Therefore strictly, it should have been divided, part going to dead work.

IV. Handling Ore from Miners' Hands to Cars, and Pumping.

Pumping, which has heretofore been a small item in the Marquette region, cannot well be separated from hoisting ore, as the same machinery does both. This item, in the case of some New Jersey magnetic mines, costs 75 cents per ton of ore: at the Persberg mines, Sweden, it costs but 7 cents. The entire cost under this head, in the Marquette region, including hoisting and pumping, is 41 cents per ton of ore produced, which equals 15½ per cent. of the whole. This work is done in part by horses, part by men, and part by steam.

1, 2, 3. **The Work of Horses in Handling Ore.**—The team work employed at the Marquette mines, apart from the stripping, amounts, according to my inquiries, which have been quite full on this point, to 10 per cent. of the whole cost of mining, or say 27 cents per ton of ore, the drivers' wages being the largest item. This cost is obtained by dividing the total expenditure for teaming, by the total number of tons of ore produced. If it was figured only on the ore actually handled by the horses, it would be much greater. If to this were added the cost of the team-work employed in stripping, the total would not be less than 30 cents per ton of ore, or, say $250,000 on the product of 1870, a sum sufficient in itself to supply all the mines in the region with all the additional steam-hoisting and pumping machinery and small locomotives required to do the work now done by horses, and at a very much less yearly cost. We may verify this almost incredible estimate in another way. The total number of horses employed at all the mines in 1870, including hired teams, was about 364, or an average of 30 to each mine, varying from 9 to 74. The best data I can get indicate that to work a lot of horses for one year, including wages of drivers, stable-men, smiths' work, forage, repairs of vehicles, and depreciation, in the years 1869 and 1870, cost an average of $650 per horse. The wages of hired teams, including drivers, for the same period, was $6 per day. At this rate, 364 horses would have cost nearly $240,000, a sum sufficiently near the other to confirm the general truth of the estimate.

These figures surely justify the prediction, that if there ever comes a period when our mines do not pay, it may be due largely to horses. In this age of steam, has a business any just right to prosper which employs horses to do work that can be more cheaply done by machinery? The average number of tons of ore handled per horse employed in and about the mines for all work in 1870 was 2,350, ranging from 1,150 to 5,300 tons. In considering these facts it must be borne in mind that the mines in question are not by any means without steam power. Twelve engines, varying in power from say 10 to 50 horse, were at work. To prove that this item of cost is unusually large in the Marquette region, I will give a few facts regarding the employment of live stock at mines, which have come under my notice elsewhere. While the cases cited do not present all circumstances like the Marquette mines, they are sufficiently near to afford interesting comparisons.

The Cornwall Ore Bank Co., Penn., shipped from their one immense deposit, in 1870, over 174,000 tons, employing no horses in the work. The ore was all handled by one locomotive, the cars being loaded by wheelbarrows. No pumping is required in this mine, and the facilities for reaching the ore with cars are unusually good. The ore is quite soft, so that the blasting does not endanger the tracks.

The Iron mountain mine, Missouri, shipped in 1870 more ore than any one mine in the Marquette region. It employed during the winter 68, and during the summer a somewhat less number of horses, mules, and oxen. One animal moved about twelve tons per day, or 3,600 tons per year; but more than three-fourths of this stock was employed in getting "surface ore," a feature which does not exist in Marquette mining. The bluff (quarried) ore moved per horse employed was more than five times the above amount. No steam-engine or locomotive was in use at the mine.

At the Caledonia and Keene mines, St. Lawrence County, New York, in 1869, three horses handled 27,500 tons of ore and waste, the average haul being over 700 feet, all up grade, in places steep. This gives over 9,000 tons per head; steam was not employed for handling material at either mine.

The Sterling mine, Orange County, New York, shipped in 1869 40,000 tons of ore, which was handled under circumstances quite similar to those encountered in the Marquette region, by two horses and one small stationary engine, which gives 20,000 tons per animal employed. The system of tramways and sidings at this mine is very complete.

Passing from American to Swedish mines, which are far deeper, and in which there is a larger percentage of rock mixed with ore, we find that in the Persberg mines, in 1870 (see table), the total cost for handling ore and water drawing was 14^2 per cent. of the whole cost, or 33 cents per ton of ore; and this amount included the handling of all the rock and other waste material which in our table is embraced under *Dead-work.* If we take out of dead-work 10 cents for handling this waste and add it to the amount found above, we have 51 cents as total cost of handling Lake Superior ores, equal to twenty per cent. of the whole cost, or about fifty per cent. greater than in the Swedish mines, but there water was exclusively used.

It is not difficult to understand how *horses** have come to play so important a part at our mines.

*It should be noted that oxen have been in use for some time at the Lake Superior mine, but, so far as I am informed, at no other.

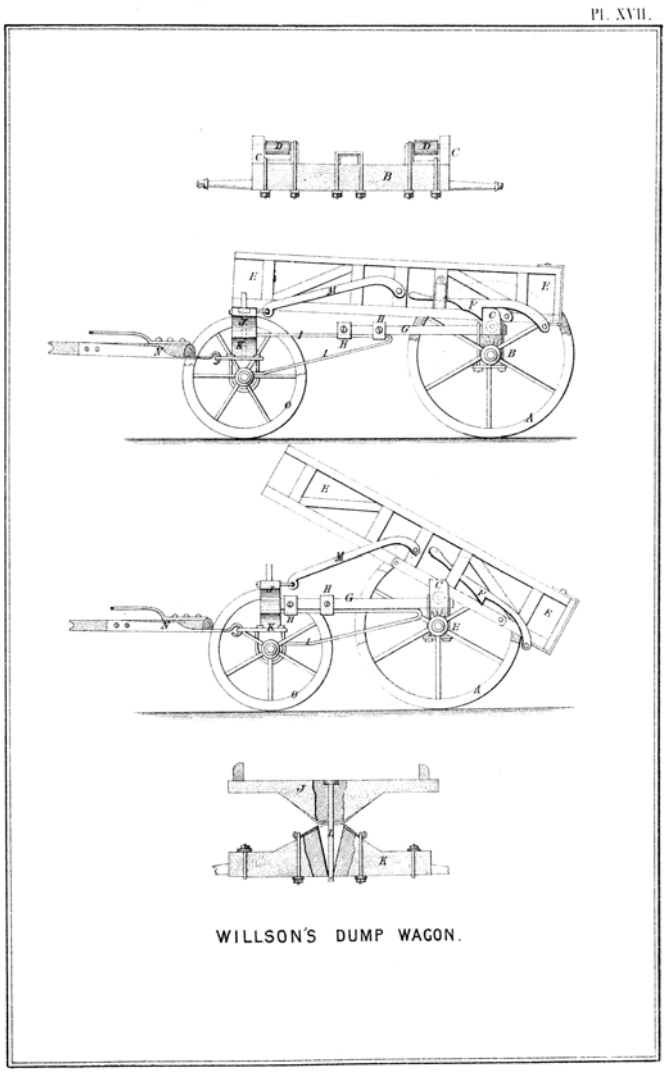
The first operation in opening a new mine is, usually, to strip off the earth and rock covering, which can be best accomplished with the horse and cart. On the ore face thus exposed, mining is begun, the ore being hauled to the cars (often not brought very near to the pit), and

such rock as is mixed with the ore is sorted out and hauled in another direction. It is very convenient and economical to back a cart directly to the miners' hands, and this was done until it came to be regarded as *the way* to get out ore. There was certainly no better way at the start in many cases; but when horses come to be used on hauls of over 500 feet and up grades, in places as steep as 1 in 10, the operation costing 25 to 30 cents per ton, it may be worth while to ask if such ore had not better be left in the ground until machinery propelled by steam can be brought to bear on it. Another cause which conspired to prolong this expensive mode, was the great demand for ore during the war and the consequent high prices. Mine superintendents were given no time to plan nor make improvements looking to future economy. Mine owners did not then want surveys, nor machinery, nor tunnels, nor anything that had reference to the future; they only wanted ore, nor did they care much what it cost, nor what the quality was (so consumers say): it was ore, ore, ore! Wherever three men could be set at work, a cart was backed up to them and shipments began from a new pit.

On short hauls, smooth roads, and light grades, horses can be used to advantage, and will continue to be so used, especially where there is more or less uncertainty as to the quantity of ore in the pit worked, which is often the case. But where there is a large mass of ore, rock, or earth to be moved under any other circumstances, it will usually pay to bring steam-power to bear upon it. Portable, or easily-to-be-moved railroads, and small locomotives for long hauls are in much favor at this time, and would have the advantage of utilizing existing wagon-roads. But the first step in many cases is undoubtedly to lay horse railways on the present roads. As is shown above in the remarks on the use of horses in certain New York iron mines, one animal can move from ten to twenty thousand tons on such roads in one year. If the horses at our Marquette mines can be made to perform one third this amount of work, the present cost of hauling will be reduced fifty per cent.

Portable hoisting-engines are extensively used in New Jersey and Pennsylvania; they can be set up quickly just where wanted, and handle material rapidly and with great economy. A thorough system of under-ground communications which would bring all or most of the material to the main hoisting-shaft is always to be aimed at, as in this way the dead lift may be made by steam. At present, owing to the continued pressure for ore, it is not uncommon to see ore and rock carted up-hill, over abominable roads, from pits which in a few months, perhaps, will or could be reached by drifts along which the ore could be cheaply trammed to a steam hoisting-shaft.

As may be supposed, this extensive use of draught animals has led to great perfection in the carts, wagons, and sleds. A dump-sled for winter use, contrived by Captain Merry, of the Jackson mine, is a perfect vehicle of its kind. I am unable to give drawings of but one, known as Daniel Willson's Patent Dump Wagon, of which over 50 are in use in the region. See Plate XVII.



[XVII. Willson's Dump Wagon]

While harnessed to the cart or wagon is the favorite mode of using the horse, it is by no means the only way. Some pits in the course of mining became too deep for cart roads; these were in many instances worked by *swing derricks*, horses being the power employed; the long booms of these derricks made it possible to drop the bucket in different parts of a wide pit. This method is, however, very expensive, as the following figures will show. The total lift from bottom of pit to bottom of cart was in one case 79 feet ; the cost being as follows:—

2 men filling	$4 00
1 man to land	2 00
2 derrick horses and driver	5 25
	$11 25

This sum paid for hoisting 45 tons in 10 hours, is equal to 25 cents per ton. In one case, where the hoist was 55 feet, the cost was 16 cents per ton.

In another case, with the ordinary two-bucket horse-whim, the cost of hoisting 65 feet, and landing, was 6 cents per ton; this did not include filling the buckets. In another case the ore was hoisted 40 feet, and landed for 5 cents per ton, not including the filling. Estimating the filling at 10 cents, these facts show that it costs in the cases cited an average of 1 cent to lift one ton of ore 7 feet, including the landing or dumping, which employs one man.

Without attempting to fully solve the important problem of the best mode of handling the material at Marquette mines, for that is beyond the scope of this report, I would suggest the following general policy as being safe for the mines to pursue:—

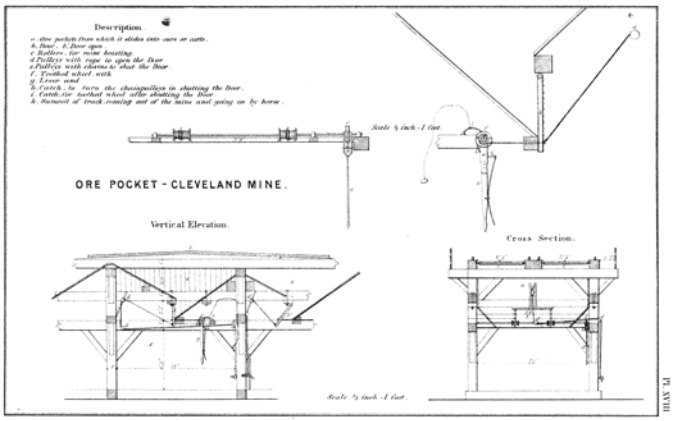
Let all large pits now worked, where a considerable amount of horse labor is required, be suspended until some form of steam machinery can be brought to bear on them. There are, of course, exceptions to this rule: for instance, where the other costs are unusually light, more money may be expended in handling the ore, as is often the case with the soft hematites; but the principle is, I think, correct. It would not be difficult to find many instances of this kind; for example, a given pit is worked, the ore being moved by horses, at a profit say of 50 cents per ton, which if left for one year could be reached by some tunnel or other improvement which would permit the same ore to be taken out at a profit of $1.00 per ton; it would certainly pay to wait in such instances. In these cases it will usually be found that the superintendent has been persuaded into promising that his mine can be made to produce a certain amount of ore which may have been already sold, his attention being thereby fixed on a large product, rather than cheap mining. This subject will be considered more fully below. I will here only ask, if it is not better policy for a mine to net say $50,000 on 50,000 tons of ore, than to make the same sum on 100,000 tons. If the mines were inexhaustible it might not make much difference, but as it is, it may make all the difference there is between a profitable business and an unprofitable one in the end. It must be borne in mind, that while the ore business has been on the whole profitable, there are large mines that have been producing ore for years that have never returned a dollar to their stockholders.

Among the mining appliances which have been brought to great perfection in the Marquette region, are the various forms of pockets and shoots for transferring the ore, first, from the mine cars, buckets, and carts to the railroad cars, and second, from these to the vessel.

The magnificent ore docks at Marquette, Escanaba, and L'Anse belong to the latter class, and are undoubtedly the best of the kind In the United States If not in the world. They are described and Illustrated in Chapter I., and in Appendix F. of Vol. II.

Of the first class there are numerous varieties, from the simple log crib built up alongside and above the track, into which the ore is dumped from elevated railways, and from the sloping bottom of which it is "shot" through holes closed by rods into cars at a cost of not over 3½ cents per ton, to the more expensive and perfect contrivance employed at the Cleveland mine, which is shown in Plate XVIII.

The mine car in this case passes over the centre of the pocket, which dumps its ore in turn into a car or cart below, by an ingeniously arranged door which is shown on an enlarged scale.



[XVIII. Ore Pocket, Cleveland Mine]

4. **Loading Ore from Stock Pile.**—During the winter no shipments are made from the mines, hence the product has to be piled up. It is the policy of some mines, and I think it is the best, to do most of their dead work in the winter, hence to stock but little ore; others maintain nearly the same rate of production in proportion to the force employed, winter and summer. Stocked ore has to be loaded In cars by hand, which is always contract work and costs from 9 to 12 cents per ton, the mean being, say II cents, including all costs connected with it. This amount, distributed over the whole product for the year, was found to average for the cases inquired into, $3^5/_{10}$ cents per ton.

5. **Machinery for Pumping and Hoisting.**—Notwithstanding the great cost of the work of horses, a large amount of machinery, as has already been remarked, is now in use, as the following statements will prove:—

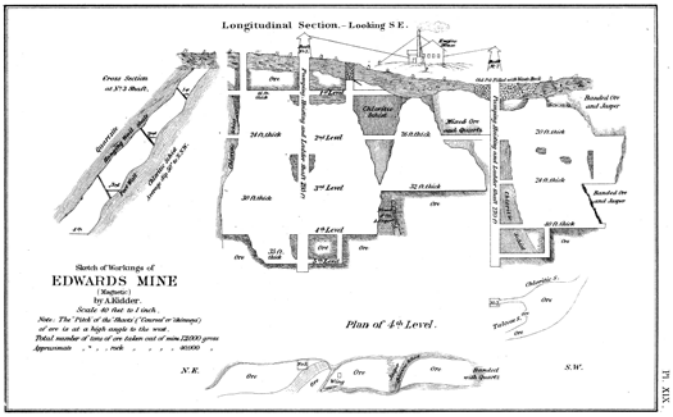
The introduction of machinery has so far seemed to make but little relative diminution in the number of horses employed, because of the greater amount of waste material which has to be moved in the later years. The amount given in the table, opposite this item, $11^2/_{10}$ cents, is designed to be an approximation to the cost of running the machinery of such mines as have plants distributed over the entire product of those mines. I estimate that less than one-half of the product of such mines was handled by machinery in 1870. The actual cost of moving the ore so handled, including the *pumping*, varied from 14 to 21 cents, the mean, as shown by my data, being about 18 cents. This cost is made up of wages of engineers and firemen, say fifteen per cent.; fillers, landers, and surface tramming, sixty per cent.; fuel, repairs of machinery and supplies, say

twenty-five per cent. This covers the cost from miners' hands to cars or stock pile.

While this sum is materially less than the cost of the same work by horses, it is much greater than in the Copper region of Lake Superior, where this work is brought to great perfection. Some of the appliances employed in the Copper region cannot be used at iron mines on account of the greater irregularity of the deposits. But time will introduce many economies which will reduce this item below the figures given. It must be borne in mind, in comparing the cost of steam machinery with horses, that in the case of the engines all the pumping is included, while the horses handle only the ore and rock. Making this correction, it is safe to say that it costs at least four times as much to handle the same material by horses as by machinery.

The following description of recently erected plants will give a good idea of the machinery now in use at iron mines, it being essentially such as is employed at the copper mines.

The *Macomber mine machinery* consists of one steam-engine with cylinder 18 X 24 inches, with bed cast solid in one piece. Valve is of the kind known as the H valve, and is worked by link motion; steam pipe 4 inches in diameter; exhaust pipe 6 inches in diameter; engine supplied with the Judson governor. Pump for feeding boiler is worked from cross-head; also an auxiliary for fire protection, etc. Main shaft is 5 inches in diameter, of hammered iron, and 16 feet long. One boiler 48 inch shell, 26 feet long, with two 18-inch flues. Smoke-stack is 40 feet high and 24 inches in diameter. The winding drums are 4 feet in diameter, and of sufficient capacity to contain 525 feet of 1¼ inch wire rope. They are worked by a friction movement, thrown in and out of gear by means of eccentrics with lever attachments. The brakes are known as band-brakes, which clamp the entire surface of the drum, 5 inches in width, and are of sufficient power to hold a loaded skip at any point in case of accident. They are worked by levers with hand or foot, as may be desired. The drums make about 13½ revolutions per minute, the engine making 80, which gives the skip a speed of a trifle less than 3 feet per second. The skips are of heavy boiler iron, each having four 12-inch wheels. The capacity of each is 35 cubic feet, equal to about 2½ tons of ore. The pump is 10 inches in diameter by 6 feet stroke, capable of discharging 660 gallons of water per minute. It is worked from a slotted crank arm, on end of main drum shaft, which admits of lengthening or shortening the stroke at pleasure. The pump is double acting, with single valve on a new plan. It is furnished with rods, travellers, connections, balance bobs, etc. This machinery was furnished complete in all its parts, and set up at the mine in working order for pumping and hoisting by the Iron Bay Foundry, Marquette, Mich., 1872.



[XIX. Workings of Edwards Mine]

The *Barnum mine plant* consists of one horizontal high pressure steam-engine of 20 inches diameter of cylinder and 30 inches stroke; steam furnished by two tubular boilers, each 48 inches in diameter and 14 feet long, and each containing 50 tubes, three inches in diameter. Maximum power of this engine is 120 horse, but is working at present at one-third its capacity. There are two winding drums, each 5 feet in diameter; speed of engine about 60 revolutions per minute, and of drums about 12. Drums are attached to main shaft by cone-gears, which are operated by steam cylinders and levers; screw-levers control the brakes and drums during the descent of the skip.

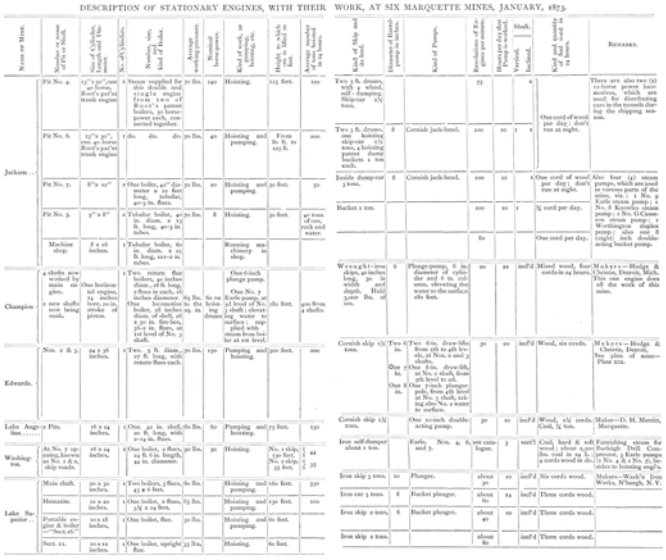
Engine is connected to the drum-shaft by spur-gearing in the proportion of one to five; speed of skip in shaft, about 3 feet per second; load of ore, 5,ooo pounds; weight of skip, which is self-dumping, is 2,400 pounds, making the total load 7,400 pounds. Actual power employed, about 47 horse; engine also draws water with a 6-inch Cornish pump. Total weight of this machinery about 42 tons, and total cost about $10,000. Built at the Michigan Iron Foundry, Detroit, in 1869.

The foregoing described plants, together with those given in the subjoined tabular statement (pages 280 and 281), embrace over three-fourths of all the machinery employed in hoisting and pumping in the entire region.

V. Management and General Expenses.

This covers only such expenses as are incurred in the mining region, and not salaries of officers above the superintendent, nor the cost of selling the ore.

1, 2.—**Salaries, Office Expenses, and Taxes.**—This element of cost constitutes less than 5 per cent. of the whole cost of the ore, amounting to about 12 cents per ton. I am happy to note here a much better showing than In the Persberg mines, Sweden, where this item, in 1870, cost 16½ per cent of the whole, or 36 cents per ton of ore; nearly three times its cost with us. I presume the excess of this item in Sweden may be largely due to heavier taxes, and smaller production.



DESCRIPTION OF STATIONARY ENGINES, WITH THEIR WORK, AT SIX MARQUETTE MINES, JANUARY, 1873.

CHAPTER X.
CHEMICAL COMPOSITION OF ORES.—ANALYSES.

THIS chapter contains the results of over one hundred and fifty analyses, more or less complete, of iron ores from the Upper Peninsula of Michigan, mostly from the Marquette region, together with five analyses of pig-iron produced from these ores; and several analyses of ores from other parts of the U. S., which are largely used with Lake Superior ores as mixtures. In order to bring out the variations in quality of the ores, and to obtain *reliable practical averages*, seldom less than two and in one instance eight samples were analyzed from the same mine.

By far the largest portion of the samples, the analyses of which appear in this Report, were selected by myself with a view to obtaining a fair and *safe average* of the ore sampled, one that would be borne out and confirmed by practically working the same ore in the furnace. I am well aware, from extended observation and practical experience, that a large majority of the published analyses of iron ores, not only have no practical value, but are positively detrimental to the best interests of the iron trade, representing as they so often do the ores to be richer in iron than they actually are, simply because the samples analyzed were not honestly or skilfully collected. Even the most skilful and conscientious men, if they err at all in collecting a sample from a new iron location, are almost sure to err on the side of finding too much, rather than too little iron. The chemist is often wrongly blamed for these false results. My experience with many analysts leads me to believe that they are, as a rule, thoroughly honest and painstaking men, who return correct results for the *samples sent them;* the trouble is with the samplers. This point receives further consideration under Explorations, Chapter VII.

In earnestly endeavoring to avoid this rock on which so many mining engineers and geologists have wrecked their reputations, I may in some instances have gone to the opposite extreme and collected samples which were below the average richness—at least I am quite persuaded that I shall be charged with this—hence venture this explanation in advance of the charge. If such mistakes are found, I can only say myself and not the analysts are to blame, and I stand ready to make such corrections as lie in my power.

My *method of sampling* is as follows:—1st. To obtain an average of a producing mine; I found that the immense stock piles accumulated at Cleveland, Ohio, at the end of the shipping season, afforded excellent opportunities for sampling. The stock piles at the mines or a large number of loaded cars were often resorted to, and in many instances it was thought best to go into the mine and take the samples from the solid ledge or the loose ore as it was being taken out. In either case an ordinary shot bag, holding 4 *or* 5 *pounds of ore, was filled with small fragments, varying from the size of a pea to that of a walnut, of all kinds of ore, from all parts of the pile, together with the rock, if any, which was found mixed with the ore.* Some of these fragments were picked up and some were broken from larger pieces; the dust and mud over the ore made it often impossible to distinguish whether the pieces taken were ore or rock. These samples were all pulverized and thoroughly mixed, and from this the specimens were taken for the chemist, the same being forwarded by mail in small numbered tin tubes; and in each instance a pound or more of the pulverized ore was retained for future reference. The reserved portions are now in my safe in Marquette, from which samples will be furnished to any who may desire. 2d. To obtain an average sample from a new locality or from exploration pits is more difficult and unsatisfactory. This subject is fully treated under Explorations, Chapter VII.

With all this care my results varied, in extreme cases, from 10 per cent. below to 5 per cent. above the true average, but the common variation was not more than three per cent. Two or three of the extreme results, known to be wrong, are omitted from the tables. The name of the sampler is in every case given when known, and the circumstances of its collection are briefly stated in the notes. The samples collected by E. R. Taylor, of Cleveland, were, at my request, taken in accordance with the rules above given.

The surname of the chemists and date at which analysis was made, as near as could be ascertained, are given under the result in every instance except one. The number of analyses made, with names in full and address of these gentlemen, are as follows:—

	No. Made.
Professor Oscar D. Allen, New Haven, Conn.	17
Professor Geo. J. Brush, New Haven, Conn.	1
J. Blodgett Britton, Philadelphia, Pa.	56
A. A. Blair, St. Louis, Mo.	2
Dr. C. F. Chandler, School of Mines, N. Y.	8
Dr. C. F. Chandler and F. A. Cairns, School of Mines, N. Y.	12
Chandler and Schweitzer.	1
F. H. Emmerton, Chicago, Ill.	1
F. B. Jenney, Marquette, Mich.	8
Prof. Geo. W. Maynard, New York.	5
Maynard and Wendel.	3
Ed. R. Taylor, Cleveland, Ohio.	14
Dr. A. Wendel, Troy, N. Y.	20
Dr. Otto Wuth, Pittsburgh, Pa.	30
Samuel Peters.	1
T. G. Wormley.	4

The metallic iron was usually determined by but one chemist, as the chances of difference on this element are small. Phosphorus determinations are more difficult, and considerable differences in the amount of this element found in the same sample by different chemists, will be observed. For this reason duplicates were often sent to two and sometimes to three; the results being given as returned by them. If any one supposes the differences to be due to errors in samples, which is improbable, I will gladly furnish duplicates for re-examination. The specific gravities of powder were mostly determined by Mr. Jenney, and not by the chemists over whose names they are sometimes placed.

The subjoined table contains an approximate general summary of the results, exhibiting the average composition of the four classes of ore now produced by the following mines:—

I. Red Specular Ores. Barnum, Cleveland, Jackson, Lake Superior, New York, Republic, and Kloman.

II. Black Magnetic and Slate Ores. Champion, Edwards, Michigan, Spurr, and Washington.

III. *Soft Hematites*. Foster, Lake Superior, Lake Angeline, Taylor, Macomber, New England, Shenango, S. C. Smith, and Winthrop.

IV. *Flag Ore*. Cascade.

Table No. XIII. of Atlas contains a somewhat similar summary so far as metallic iron and phosphorus are concerned. More facts are incorporated in this table, which has slightly changed the averages.

	I.	II.	III.	IV.
Protoxide of Iron		19.639		
Sesqui- or Peroxide of Iron.	90.52	67.761	75.75	70.98
Oxide of Manganese.	Trace.	0.13	0.80	Trace.
Alumina	1.39	2.13	1.536	2.01
Lime	0.70	0.68	0.36	0.45
Magnesia.	0.42	0.69	0.294	0.20
Sulphur.	0.05	0.132	0.110	0.03
Phosphoric Acid	0.258	0.199	0.185	0.13
Silicic Acid, Silica, or Insoluble Silicious Matter	5.892	7.828	14.035	25.12
Water, Combined.			3.94	
" Uncombined.			1.18	
" Total.	0.77	0.811		1.08
Volatile Matter.			1.81	
	100.000	100.000	100.000	100.00
Metallic Iron.	62.915	62.930	52.649	49.332
Phosphorus.	0.111	0.085	0.078	0.053
Sulphur.	0.05	0.132	0.110	0.03
Metallic Manganese	Trace.	0.091	0.56	Trace.
Specific Gravity.	4.74	4.59	3.88	4.09

A glance at this table shows us that, except the soft hematite III which contains about 5 per cent. of water, all the ores are essentially and chiefly composed of oxide of iron and silica or insoluble silicious matter. The other elements, viz., oxide of manganese alumina, lime, magnesia, sulphur, phosphoric acid, and water amount in the aggregate to only about 5 per cent. in the I., II., and IV classes. So constant is this ratio that a valuable determination of iron in a hard ore, and one sufficiently accurate for practical purposes, can be made by ascertaining the percentage of insoluble silicious matter, adding 5 to it and subtracting the sum from 100. The result is the iron oxide, which, multiplied by .70 for red, and .72 for black oxides, gives the metallic iron.

Regarding the percentage of metallic iron, consumers of Lake Superior ores will at once note that their furnace books very often show a higher yield than 62.9 per cent., which is given in the table as the average percentage for first-class ores. This may not have been the case in exceptional years, like 1872, when the consumption so crowded the production that mines had not the time nor skilled labor to make such selection as they usually make. But that furnaces running on first-class ores usually make a better yield than that given, is shown by "Table of Metallurgical Qualities of certain Lake Superior Ores by Consumers," Plate No. XIII. of Atlas, where various consumers credited these ores, in 1870, with an average of *over sixty-four per cent. of iron*, as shown by their furnace-books. This discrepancy is easily accounted for; the chemist's result is in pure metallic iron, the furnace man's is in *pig iron*, which contains several per cent. of carbon and silicon, and other substances,—see subjoined analyses. Therefore the chemist should always find *less* iron than is shown by the furnace accounts if he has an *average* sample of the ore. Just what this difference is depends on the grade of iron made, on the waste in the slag, and other things: good authorities have placed it at 2½ per cent.

Passing to a more detailed examination of the facts recorded in the table, we find, in descending order,—oxide of *manganese* has a maximum of nearly one per cent. in the hematite, and is nothing in the specular and flag ores. If the hematite was subdivided into

manganiferous and non-manganiferous varieties, as suggested under Lithology, Chapter III., then one variety would contain only a minute quantity of manganese, while the other would reach an average of, say 3 per cent. of the oxide. The presence of manganese adds to the value of an ore, especially for making steel. *Alumina* reaches a maximum of over 2 per cent. in the magnetite ores, and is least in the specular ores. The earthy character of the hematites would lead one to expect more of this element in that class. *Lime* and *magnesia* aggregate a trifle over one per cent. in the high grade ore, and less than this amount in those of low grade. *Sulphur* is relatively most abundant in the magnetites; but, so far as I know, the minute quantity found has never been objected to by consumers of the ore. The quantity of *phosphoric acid* and phosphorus is of such moment in connection with the wants of the Bessemer steel manufacture, now rapidly developing in the West, that this subject will receive especial attention hereafter.

The distribution and relations of the *silicious matter* have been mentioned;—it has its maximum in the flag ores where it reaches one-fourth of the whole weight, and is least in the rich speculars, which contain only about 6 per cent. on the average.

The total *water* in the hard ores is only about 1 per cent. In the soft hematites it rises to an average of over 5 per cent., and, as will be seen in the subjoined analyses, increases in a few instances to about twice this amount, the greater part of which is combined with the limonite, which largely makes up the soft ore. An appreciable amount of *volatile* matter, supposed to be mostly carbonaceous, occurs only in the hematite ores. The specific gravities given will be observed to have a very significant relation to the amount of iron, which subject is considered fully in Chapter III.

Phosphorus in Lake Superior Ores.

Pig-iron intended for the use of *steel* makers must be remarkably free from phosphorus, *one-tenth of one per cent*., according to some authorities, being the maximum amount allowable for many purposes. As it has been found impossible, up to this time, to eliminate this element from the metal either in the blast furnace or in any of the various processes for making steel, it is indispensable, in steel manufacture, that we start with an ore comparatively free from it; and for the best bar iron, only a very small amount of phosphorus is admissible,—its effect being to produce cold shortness.

It is a safe practical maxim of iron metallurgy that all the phosphorus contained in the coal, limestone, and ore charged into a blast furnace will be found in the resulting pig-iron, and that the conversion of such pig-iron into steel will increase the phosphorus just in the ratio in which the metal is wasted in the process. It is therefore very evident, if say one-tenth of one per cent. only is admissible in steel, not only our ores but fuel and flux must be very free from phosphorus at the start. In considering the facts regarding this element here given, it must be constantly borne in mind that a rich ore may contain more phosphorus than a lean ore, and yet produce a pig-iron containing less phosphorus than the other, because *less of the rich ore is required* to make a ton of iron.

To illustrate: an ore yielding 66⅔ per cent. in the furnace, and containing .06 of phosphorus, will produce a pig containing .09 of phosphorus; while an ore containing but 50 per cent. of iron and .05 of phosphorus will produce a pig containing .10 of phosphorus; therefore the amount of iron in the ore must be always considered in comparing the amounts of phosphorus. Applying this rule to the facts given in the foregoing table, we shall find that the apparent greater freedom of the hematite and flag ores from phosphorus is nearly balanced by their comparative poverty in iron.

The distribution of phosphorus among the Lake Superior ores, so far as my facts go, follows no obvious law; it seems to have little, if any, relation to the kind of ore. Some of the hematite ores are among the lowest and others among the richest in this element, and so of the specular and magnetic ores.

A rule, to which there are, however, several exceptions, seems to be that the ores poor in iron and rich in silica, contain least phosphorus; but the analyses of the Republic mountain ore show more iron and less silica than in any other, and that it is also very low in phosphorus. The table of analyses, in Plate No. XIII. of Atlas, presents most of the facts in a compact form; but as this subject is of peculiar interest at this time in connection with the Bessemer steel manufacture, I venture to incorporate a second tabular statement here, in which the mines are arranged in order of the quantity of phosphorus, beginning with the lowest. No mine is included from which less than two samples have been analyzed. The deposits and mines marked with a * are new, and not sufficiently developed to enable me to say that an average sample of the ore was obtained.

Mine.	Kind of Ore.	Phosphorus.	Iron.
Lake Angeline	Jaspery Specular	0.031	53.83
Winthrop	Soft Hematite	0.037	54.63
Republic*	Specular and Magnetic	0.040	66.51
Michigamme*	Magnetic	0.041	64.388
Silas C. Smith	Hematite	0.047	49.70
Cascade	Flag	0.053	49.332
Menominee Iron reg'n*	Specular & Hematite	0.054	48.209
Edwards	2d Class Magnetic	0.055	49.190
Macomber	Hematite	0.058	54.92
Cascade	Flag and Specular	0.061	51.253

Mine.	Kind of Ore.	Phosphorus.	Iron.
Jackson	Specular	0.066	63.715
Magnetic*	Magnetic	0.067	54.72
Edwards	Do.	0.067	61.60
Shenango	Hematite	0 070	56.315
Champion	Magnetic and Slate	0.072	63.55
Negaunee*	Manganifs. Soft Hem'e	0.074	44.29
Lake Angeline	Hematite	0.079	50.70
New England	Soft Hematite	0.080	48.24
Kloman*	Specular	0.089	63.55
Foster	Hematite	0.094	52.27
Spurr Mountain*	Magnetic	0.104	63.81
Lake Superior	Specular	0.104	62.11
Taylor (L'Anse)*	Hematite	0.107	52.88
Jackson	Hematite and Jaspery.	0.124	57.155
Cleveland	Specular	0.126	61.092
Lake Superior	Hematite	0.130	54.19
Saginaw*	Specular and Hematite	0.132	52.40
Barnum	Specular	0.134	61.69
Washington	Magnetic	0.141	61.305
New York	Specular	0.224	61.74

It has been stated that an inspection of the first table did not warrant us in asserting that either of the four classes of ore represented could be easily recognized as being comparatively free from phosphorus; so an examination of the above presentation of the facts forces us to the conclusion that the distribution is not geographical; for we here see widely-separated mines containing the same amount of phosphorus, whilst contiguous mines vary widely. In fact, in different parts of the same mine there is found a wide difference in the quantity of this noxious element; *e. g.:* The New York mine results show more than twice as much phosphorus in the ore from pit No. 1 as from pit No. 2; and the Lake Superior ore appears to contain less phosphorus than the Barnum, although they belong to one deposit. A part of this difference is undoubtedly due to errors in sampling and errors in the analysis; but the number of samples analyzed, the care taken in collecting them, and the reputation of the chemists, leave but little doubt that the relative and absolute average amounts of phosphorus in the ores from the developed mines are nearly expressed in the foregoing table.

At the suggestion of Mr. A. L. Holley, I selected, with much care, an average sample of the rock which occurs in the hard ores, more or less of which goes into the furnace, and had it analyzed ; the result was less than the average amount of phosphorus. This fact, in connection with the low amount found in the second class and flag ores, leads me to believe that no care in selecting and sorting ore will diminish the quantity of phosphorus.

By way of verifying the amount of phosphorus in Lake Superior ores, here given, there are presented in the following table five analyses of pig-iron made from them with charcoal, and a flux containing no appreciable amount of phosphorus. They may, therefore, be said to indicate very accurately the amount of phosphorus in the ores, which, as will be seen, averages about the maximum amount given above as admissible in steel.

	1	2	3	4	5	Average.
Magnesia			0.47			
Silicic Acid, or Silica		1.16	1.83	3.21	2.91	2.28
Silicon	2.245					
Graphitic Carbon	2.88	3.72	3.35		3.61	3.39
Combined "	.80	0.30	0.00		.05	.38
Metallic Iron	93.201		93.49			93.34
Phosphorus	.138	0.104	0.082	0.126	.092	0.108
Sulphur	.011	0.045	trace.		.04	0.032
Metallic Manganese	.174					.174

No. 1 was chipped from many pigs of No. 1 gray foundry iron made at the Pioneer furnace Negaunee, of Jackson ore. Analysis by Dr. C. F. Chandler. No. 2 is a pig-iron made from assorted Lake Superior ores at the Appleton Furnace, Wisconsin. Analysis by Mr. Morrell. No. 3 is also a specimen of Appleton iron. Analysis by Dr. Wuth. No. 4 is No. 1 gray foundry iron made by the Jackson Iron Co. at Fayette, Michigan, of Jackson ore with charcoal, and is extensively used in the manufacture of Bessemer steel Analysis by Mr. Morrell. No. 5 is a specimen of pig made by the Michigan Iron Co. in Marquette County, of a mixture of specular, magnetic, and hematite ores. Analysis by Mr. Morrell. The analysis of Pioneer pig was at the expense of the Survey; the others were furnished by Mr. Holley. It was proposed to carry this work much further, but the limited means would not permit.

For contributions in money, and valuable suggestions and encouragement in obtaining the results set forth in this chapter, I am under especial obligation to John Fritz, of Bethlehem, Pa., and S. P. Ely, of Marquette; A. Pardee, Daniel J. Morrell, A. B. Meeker, and W. H. Barnum also contributed liberally towards paying for the chemical work, which cost nearly $2,000.

The physical and mineralogical character of the following ores is given under Lithology, in Chapter III. For commercial statistics, and, incompletely, the metallurgical qualities, see Plates XII. and XIII. of Atlas.

Analyses of Ores.

(The mines are arranged alphabetically. The upper line gives the number of the sample.)

BARNUM MINE—*Specular Ore.*

	58.	14.*	14.*	262.*	262.*	277.*	277.*	Averages.
Sesqui- or Peroxide of Iron	93.40	86.71						
Oxide of Manganese	.....	trace						
Alumina	0.33	1.92						
Lime	0.30	0.64						
Magnesia	0.15	0.53						
Sulphur	min'te trace.	0.04						
Phosphoric Acid	0.23	0.25	0.189	0.31	0.288	.....	0.649	
Silicic Acid, or Silica	4.80	9.43						
Water, Total	0.29	0.46						
	99.50	99.98						
Metallic Iron	65.38	60.79	.....	64.30	.....	56.31	.....	61.69
Phosphorus	0.10	0.11	0.083	.133	0.123	0.149	0.278	.134
Sulphur	.....	0.04						
Specific Gravity	.....	4.58						
	Chemist, Allen. Sept. 2, 1871. *Sampler*, Brooks.	*Chemists*, Chandler & Cairns. Mar. 4, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Taylor. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Britton. Dec. 31, 1872. *Sampler*, Brooks.	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*,	

Notes.—58. From three stock piles at mine. 14. Large stock pile at Cleveland. 262. Stock pile at Cleveland. 277. All parts of mine.

CLEVELAND MINE—*Specular Ore.*

	36.	36.	36.	260.	260.	271.	271.	272.	272.	273.	Averages.
Sesqui- or Peroxide of Iron	88.50										
Oxide of Manganese	trace.										
Alumina	1.84										
Lime	0.89										
Magnesia	0.75										
Sulphur	0.01										
Phosphoric Acid	0.46	0.229	.....	0.178	0.14	0.343	.....	0.218			
Silicic Acid, or Silica	6.40										
Water, Total	1.23										
	100.08										
Metallic Iron	61.95	.....	.....	.....	62.10	.....	56.590	.....	.....	63.730	61.092
Phosphorus	0.20	0.100	0.187	0.076	.061	0.147	0.168	0.093	0.154	0.111	0.119
Sulphur	0.01										
Metallic Manganese	trace.										
Specific Gravity	4.64	.....	.....	.....	.....	4.42	.....	4.37	.....	4.93	
	Chemists, Chandler & Cairns. Mar. 9, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. *Sampler*,	*Chemist*, Wendel. *Sampler*, Taylor.	*Chemist*, Taylor. *Sampler*,	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*, Brooks.	*Chemist*, Britton. Dec. 31, 1872. *Sampler*,	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*, Brooks.	*Chemist*, Britton. Dec. 31, 1872. *Sampler*,	*Chemist*, Britton. Dec. 31, 1872. *Sampler*,	

Notes.—36. Large stock pile in Cleveland. 260. Stock pile in Cleveland. 271. Laurie Genth's Pit, No. 3. 272. Swede's pit. 273. School House opening. The last three were from mine.

* The occurrence of the same number more than once in this line, signifies that duplicates of the same sample were sent to different chemists.

CHAMPION MINE—*Magnetic and Slate Ore.*

	38.	38.	38.	227.	227.	228.	228.	Averages.
Protoxide of Iron	17.87							
Sesqui- or Peroxide of Iron	74.93							
Oxide of Manganese	0.05							
Alumina	1.15							
Lime	0.52							
Magnesia	0.92							
Sulphur	0.12							
Phosphoric Acid	0.28	0.116	.....	0.021	0.337	0.161	0.316	
Silicic Acid, or Silica	3.70							
Water, Total	0.52							
	100.06							
Metallic Iron	66.04	.....	.....	.....	57.97	.....	66.65	63.55
Phosphorus	0.12	0.051	0.048	0.009	0.143	0.070	0.136	.084
Sulphur	0.12							
Metallic Manganese	0.03							
Specific Gravity	4.75	.....	4.43	.....	.....	4.87		
	Chemists, Chandler & Cairns. Mar. 9, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. *Sampler*,	*Chemist*, Wuth. *Sampler*, Brooks.	*Chemist*, Wendel, Feb. 6, 1873. *Sampler*,	*Chemist*, Wuth. *Sampler*, Brooks.	*Chemist*, Wendel, Feb. 6, 1873. *Sampler*,	

Notes.—38. Large stock pile in Cleveland, all varieties. 227. "Slate ore," Shaft No. 4. 228. "Black ore," Shafts Nos. 1, 2, and 3. The two last from mine.

CASCADE MINES—*Flag Ore.*

	17.	22.	22.	257.	257.	258.	258.	15.	Averages.
Sesqui- or Peroxide of Iron	71.98	83.70	.....	.....	.....	.....	.....	66.20	
Protoxide of Manganese	0.01	trace.							
Alumina	0.68	3.34							
Lime	0.16	0.75							
Magnesia	0.06	0.34							
Sulphur	0.04	0.03							
Phosphoric Acid	0.07	0.24	0.248	.....	.....	.....	.....	.14	
Silicic Acid, or Silica	.....	10.67							
Insoluble Silicious Matter	25.26	.....	.....	.....	.....	.....	.....	31.02	
Water, Total	1.03	0.87	.....	.....	.....	.....	.....	1.29	
Alkalies, undetermined and lost	0.73								
	100.00	99.94							
Metallic Iron	50.49	58.59	.....	46.120	.....	45.010	.....	46.450	49.332
Phosphorus	0.03	0.10	0.108	.042	0.043	0.027	0.036	0.060	.053
Sulphur	0.04	0.03							
Specific Gravity	.....	4.43	.....	3.95	.....	4.01			
	Chemist, Britton, Aug. 18, 1870. *Sampler*, Brooks.	*Chemists*, Chandler & Cairns, Mar. 4, 1872. *Sampler*, Brooks, J'y, 72	*Chemist*, Wuth, 1872. *Sampler*,	*Chemist*, Britton, 1872. *Sampler*, Brooks.	*Chemist*, Allen, 1872. *Sampler*,	*Chemist*, Britton. *Sampler*, Brooks.	*Chemist*, Allen. *Sampler*,	*Chemist*, Britton, Aug., 1870. *Sampler*, Brooks.	

Notes.—17. Selected bird's-eye slate ore. Exploration pit. 22. The richest pieces from a small stock pile in Cleveland. 257. Emma mine. 258. Bagley mine; bird's-eye slate ore. The two last were obtained from the mine workings. 15. Old opening, north face ridge, S.W. corner. Sect. 29.

CASCADE MINES—*Flag and Specular Ore.*

	259.	259.	266.	266.	256.	256.	Averages.
Phosphoric Acid	.....	.....	0.16	0.096			
Metallic Iron	50.820	.....	44.00	.....	58.940	.....	51.253
Phosphorus	0.078	0.073	0.069	0.041	0.055	0.055	0.061
Specific Gravity	4.13	.....	.....	.....	4.44		
	Chemist, Britton, 1872. *Sampler*, Brooks.	*Chemist*, Allen. 1872. *Sampler*,	*Chemist*, Taylor. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Britton, 1872. *Samplers*, J. Fritz & A. Pardee.	*Chemist*, Allen. 1872. *Sampler*,	

Notes.—259. Saw-Mill opening, west of stream. 256. West End Mine (specular ore). Stock pile at Mine. 266. Stock pile at Cleveland.

CANADIAN ORES—*Magnetic.*

	222.	217.	216.	220, *b.*	220, *a.*	Averages.
Bisulphide of Iron	.....	.....	.....	.....	2.19	
Sesqui- or Peroxide of Iron	.....	.....	.....	78.03		
Proto-sesquioxide of Iron	92.10	.....	.....	.....	84.38	
Alumina	.68	.....	.....	1.17	2.86	
Lime	.28	.....	.....	.....	0.74	
Magnesia	.83	.....	.....	.....	5.61	
Sulphur	.78					
Phosphoric Acid	.14	0.21	.....	0.077	0.087	
Silicic Acid, or Silica	3.55	.....	.....	6.10	4.13	
Water, Total (moisture)	.48					
Carbonate of Lime	.....	.....	.....	13.71	.....	
Carbonate of Magnesia	.....	.....	.....	0.91	.....	
Oxygen with the Sulphur and loss	1.07					
	100.00			99.997	99.997	
Metallic Iron	66.86	51.40	45.20	54.00	60.00	55.49
Phosphorus	.06	0.092	.037	.033	0.037	0.052
	Chemist, Britton. Nov. 17, 1870. *Sampler*, Brooks.	*Chemist*, E.R. Tay. lor. Jan. 2, 1873. *Sampler*, Taylor.	*Chemist*, Taylor. Jan. 2, 1873. *Sampler*, Taylor.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Wuth. *Sampler*,	

Notes.—222. Analysis furnished by Redington and Adams, Cleveland. 217. Stock pile at Cleveland. 216. Stock pile at Cleveland. 220. Analyses furnished by Dr. Wuth. *a.* Magnetic ore after roasting: *b.* Red hematite. 222 and 217 are Forsyth ore. 216 and 220 are Marmora ore.

EDWARDS MINE—*Magnetic Ore.*

	41.	41.	41.	199.	*Averages.*
Protoxide of Iron	21.60	.....	.....	9.98	
Sesqui- or Peroxide of Iron	55.80	.....	.....	85.41	
Oxide of Manganese	0.10				
Alumina	4.34				
Lime	0.77				
Magnesia	0.84				
Sulphur	0.16				
Sulphuric Acid	.....	.....	.....	.03	
Phosphoric Acid	0.12	0.288	.....	.07	
Silicic Acid, or Silica	15.41				
Insoluble Silicious Matter	.....	.....	.....	2.43	
Water, Total	0.81				
	99.95				
Metallic Iron	55.75	.....	.....	67.45	61.60
Phosphorus	0.05	0.125	0.137	.030	.067
Sulphur	0.16				
Metallic Manganese	0.06				
Specific Gravity	4.24				
	Chemists, Chandler & Cairns. March 9, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. *Sampler*,	*Chemist*, Taylor. Jan., 1873. *Sampler*, Unknown.	

NOTE.—41. Large stock pile in Cleveland.

EDWARDS MINE—*Second-class Magnetic Ore.*

	265.	265.	286.	*Averages.*
Phosphoric Acid	0.10	0.136		
Metallic Iron	48.80	.....	49.580	49.190
Phosphorus	0.043	0.058	0.061	.055
	Chemist, Taylor. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Britton. Jan. 9, 1873. *Sampler*, Brooks.	

NOTES.—265. Stock pile at Cleveland. 286. From mine.

FOSTER MINE—*Hematite Ore.*

	49.	87.	270.	270.	26.	*Averages.*
Sesqui- or Peroxide of Iron	74.69	.....	.....	.....	79.49	
Oxide of Manganese	.42	.....	.....	.....	0.25	
Alumina	.50	.....	.....	.....	1.19	
Lime	.37	.....	.....	.....	0.27	
Magnesia	.63	.....	.....	.....	0.33	
Sulphuric Acid	.....	.....	.....	.....	0.17	
Phosphoric Acid	.18	.....	0.33	0.226	0.19	
Silicic Acid, or Silica	16.44	.....	.....	.....	9.28	
Insoluble Silicious Matter	.....	20.68				
Water, Combined	.....	6.12				
Water, Total	7.16	.....	.....	.....	8.74	
	100.39	.....	.....	.....	99.91	
Metallic Iron	52.28	49.78	51.40	.....	55.64	52.27
Phosphorus	.080	.....	0.144	0.097	0.083	.094
Sulphur	.....	.....	.....	.....	0.068	
	Chemist, Brush. July 5, 1871. *Sampler*, Brooks.	*Chemist*, Britton. Nov. 4, 1871. *Sampler*, Brooks.	*Chemist*, Taylor. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Chandler. May 14, 1866. *Sampler*, Brooks.	

NOTES.—49. Stock pile at Pioneer Furnace, Negaunee, Mich. 87. From mine, numerous fragments. 270. Stock pile at Cleveland. 26. From mine when first opened.

JACKSON MINE—*Specular Ore.*

	24.	24.	24.	51.	230.	230.	230.	*Averages.*
Sesqui- or Peroxide of Iron	93.75							
Oxide of Manganese	trace.	.....	.....	0.60				
Alumina	0.73							
Lime	0.61							
Magnesia	0.23							
Sulphur	0.03	.....	.....	0.18				
Phosphoric Acid	0.32	0.127	.....	0.10	0.144			
Silicic Acid, or Silica	3.27	.....	.....	1.45				
Water, Total	1.09							
Alumina, Lime, Magnesia, Water, etc	.....	.....	.....	1.67				
	100.03							
Metallic Iron	65.62	.....	.....	.....	.....	61.810	.....	63.715
Phosphorus	0.14	0.055	0.069	0.04	0.063	0.078	0.073	.066
Sulphur	0.03	.....	.....	0.18				
Specific Gravity	.....	.....	.....	.....	4.95			
	Chemists, Chandler & Cairns. Mar. 9, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*, Brooks.	*Chemist*, Britton. Dec. 20, 1872. *Sampler*, Brooks.	*Chemist*, Chandler. July 13, 1871. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*, Brooks.	*Chemist*, Britton. Feb. 18, 1873. *Sampler*,	*Chemist*, Allen. *Sampler*,	

NOTES.—24. Large stock pile in Cleveland. 51. Stock pile at Pioneer Furnace, Negaunee, Mich. 230. Slate ore. West end of mine.

JACKSON MINE—*Hematite and Jaspery Ores.*

	231.	231.	231.	229.	229.	229.	*Averages.*
Phosphoric Acid	0.316	0.523	.....	.....	0.338	0.054	
Metallic Iron	.....	59.30	54.530	56.590	58.20	.....	57.155
Phosphorus	0.138	0.224	0.154	0.061	0.144	0.023	.124
Specific Gravity	4.20	.....	.....	4.59			
	Chemist, Wuth. 1872. *Sampler*, Brooks.	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*,	*Chemist*, Britton. Feb. 18, 1873. *Sampler*,	*Chemist*, Britton. Feb. 18, 1873. *Sampler*, Brooks.	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*,	*Chemist*, Wuth. *Sampler*,	

NOTES.—231. Hematite ore—west part of mine. 229. Old Pioneer opening—Jaspery ore. The Hematite and Specular ores occur together in this mine.

KLOMAN MINE—*Specular Ore.*

	235.	225.	*Averages.*
Metallic Iron	63.55	.....	63.55
Phosphorus	0.097	0.081	.089
Specific Gravity	4 90		
	Chemist, Britton. *Sampler*, Brooks.	*Chemist*, Allen. *Sampler*,	

NOTE.—235. Fragments broken from outcrop, before work began.

LAKE SUPERIOR MINE—*Specular Ore.*

	37.	37.	37.	261.	261.	44.	274.	*Averages.*
Sesqui- or Peroxide of Iron	86.70							
Oxide of Manganese	trace.							
Alumina	1.64							
Lime	0.57							
Magnesia	0.24							
Sulphur	0.02							
Phosphoric Acid	0.14	0.075	.....	0.24	0.239			
Silicic Acid, or Silica	9.82							
Water Total	0.61							
	99.74							
Metallic Iron	60.69	.....	.....	63.50	.....	64.37	59.89	62.11
Phosphorus	0.06	0.033	0.046	0.103	0.102	0.10	.065	.078
Sulphur	0.02						4.69	
Specific Gravity	4.55							
	Chemists, Chandler & Cairns, Mar. 9, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. *Sampler*,	*Chemist*, Taylor. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Britton. *Sampler*, John Fritz.	*Chemist*, Britton, Dec., 1872. *Sampler*, Brooks.	

NOTES.—37. Large Stock pile in Cleveland. 261. Stock pile at Cleveland. 44. Stock pile at Bethlehem Furnace. 274. Lower bed. Pit No. 1. Pennsylvania mine.

LAKE SUPERIOR MINE—*Hematite.*

	10.	10.	10.	269.	269.	276.	276.	87.	*Averages.*
Sesqui- or Peroxide of Iron	79.80								
Oxide of Manganese	0.10								
Alumina	2.05								
Lime	0.45								
Magnesia	0.53								
Sulphur	0.03								
Phosphoric Acid	0.30	0.104	.....	0.24	0.237	.....	0.668		
Insoluble Silicious Matter	.....	.....	.....	.....	.....	.....	.....	15.42	
Silicic Acid, or Silica	12.52	.....	.....	.....	.....	.....	.....	.....	
Water, Combined	4.11	.....	.....	.....	.....	.....	.....	4.66	
" Uncombined	0.14								
	100.03								
Metallic Iron	55.86	.....	.....	52.00	.....	.....	.....	55.00	54.28
Phosphorus	0.13	0.045	0.066	0.103	0.101	0.131	0.286	.....	.130
Sulphur	0.03								
Metallic Manganese	0.07								
Specific Gravity	4.12								
	Chemists, Chandler & Cairns, March 4, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. *Sampler*,	*Chemist*, Taylor. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Britton. Dec. 31, 1872. *Sampler*, Brooks.	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*,	*Chemist*, Britton. Nov. 4, 1871. *Sampler*, Brooks.	

NOTES.—10. Large Stock pile at Cleveland. 269. Stock pile at Cleveland. 276. Hematite workings of mine.

LAKE ANGELINE—*Specular Ore (Jaspery).*

	21.	21.	267.	267.	34.	*Averages.*
Sesqui- or Peroxide of Iron	72.00	.....	.....	.....	85.43	
Oxide of Manganese	trace.					
Alumina	0.92	.....	.....	.....	1.89	
Lime	0.33	.....	.....	.....	0.24	
Magnesia	0.34	.....	.....	.....	0.23	
Sulphur	0.02	.....	.....	.....	none.	
Phosphoric Acid	0.08	0.101	0.04	0.083	none.	
Silicic Acid, or Silica	25.09	.....	.....	.....	12.31	
Water, Combined	1.09					
" Uncombined	0.12					
	99.99	.....	.....	.....	100.00	
Metallic Iron	50.40	.....	52.00	.....	59.08	53.83
Phosphorus	0.03	0.044	0.017	0.036	none.	.031
Sulphur	0.02					
Specific Gravity	3.97					
	Chemists, Chandler & Cairns, March 4, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. 1872. *Sampler*,	*Chemist*, Taylor. 1872. *Sampler*, Taylor.	*Chemist*, Wendel. 1872. *Sampler*,	*Chemist*, Wuth. Dec. 29, 1865. *Sampler*, Unknown.	

NOTES.—21. Stock pile in Cleveland. 267. Stock pile in Cleveland.

LAKE ANGELINE MINE—*Hematite.*

	268.	268.	280.	*Averages.*
Phosphoric Acid	0.09	0.160		
Metallic Iron	51.40	.....	50.000	50.70
Phosphorus	.038	0.070	0.104	.079
	Chemist, Taylor. 1872. *Sampler*, Taylor.	*Chemist*, Wendel. *Sampler*,	*Chemist*, Britton. Dec. 31, 1872. *Sampler*, Brooks.	

NOTES.—268. Stock pile at Cleveland. 280. Stock pile at mine.

MICHIGAMME MINE—*Magnetic Ore.*

	1.	197.	225.	225.	225.	*Averages.*
Protoxide of Iron	.....	29.109				
Sesqui- or Peroxide of Iron	.....	61.631				
Protoxide of Manganese	.....	traces.				
Alumina	2.12	2.120				
Lime	.12	1.070				
Sulphur	.....	0.002				
Sulphuric Acid	.....	0.008				
Phosphoric Acid	.05	0.057	0.067	.....	0.352	
Silicic Acid, or Silica	3.06	3.280				
Water, Total	.57	1.497				
Organic or Carbonaceous Matter	.....	0.340				
Titanic Acid	.....	0.032				
Copper and Carbonic Acid	.....	none.				
		99.146				
Metallic Iron	.....	65.767	.....	.....	63.01	64.388
Phosphorus	0.027	0.024	0.029	0.019	0.168	.041
Sulphur	.....	0.005				
Specific Gravity	.....	.....	4.61			
	Chemist, Britton. Sept. 21, 1870. *Sampler*, Brooks.	*Chemist*, Ralph Crooker, Boston. *Sampler*, Ralph Crooker.	*Chemist*, Wuth. 1872. *Sampler*, Brooks.	*Chemist*, Britton. 1872. *Sampler*, Brooks.	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*, Brooks.	

NOTES.—1. Drill mud from 3 holes. 197. Numerous fragments from Exploration pits. 225. Taken at mine, fragments after blasting. All were taken before mine was opened.

MACOMBER MINE—*Hematite.*

	35.	35.	87.	*Averages.*
Sesqui- or Peroxide of Iron	76.80			
Oxide of Manganese	2.06			
Alkalies (by difference)	3.47			
Sulphur	0.14			
Phosphoric Acid	0.15	0.130		
Silicic Acid, or Silica	14.64			
Insoluble Silicious Matter	.....	.....	14.51	
Water, Combined	.....	.....	2.23	
Water, Total	2.74			
	100.00			
Metallic Iron	53.76	.....	56.08	54.92
Phosphorus	0.06	0.057	.....	0.058
Sulphur	0.14			
Metallic Manganese	1.51			
	Chemist, Chandler. Oct. 6, 1871. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. Nov. 4, 1871. *Sampler*, Brooks.	

NOTES.—35. From two trains of 16 cars each, one month apart. 87. From Mine. Numerous fragments. This mine belongs to the Negaunee hematite group, and contains considerable manganese.

MAGNETIC MINE—*Magnetic Flag Ore.*

	69.	54.	232.	232.	*Averages.*
Proto-sesquioxide of Iron	78.35	78.42			
Oxide of Manganese	0.10	trace.			
Alumina	trace.	.43			
Lime	0.69	.19			
Magnesia	0.21	.17			
Sulphur	0.58	none.			
Phosphoric Acid	0.151	.13			
Insoluble Silicious Matter	19.64	19.44			
Soluble Silica	.....	.41			
Water, Total	.....	0.42			
Undetermined and Loss	0.279	0.39			
	100.000	100.00			
Metallic Iron	55.16	56.78	52.22	.....	54.72
Phosphorus	0.066	0.057	0.087	0.071	.067
Sulphur	.....	none.			
Specific Gravity	.....	.....	4.30		
	Chemist, Jenney. 1872. *Sampler*, Brooks.	*Chemist*, Britton. Nov. 21, 1870. *Sampler*, Brooks.	*Chemist*, Britton. 1872. *Sampler*, Brooks.	*Chemist*, Allen. Jan. 1, 1873. *Sampler*,	

NOTES.—69. From small stock pile at mine. 54. From layers of rich ore banded with rock. From outcrop. 232. Small stock pile at mine.

MENOMINEE IRON REGION—*Specular Ores and Hematites.*

	95.	98.	102.	246.	74.	254.	68.	68.
Sesqui- or Peroxide of Iron	47.27	78.30	.....	.....	80.63	.....	81.35	
Oxide of Manganese	.....	.....	.....	.....	3.075	.....	1.32	
Alumina	.....	.....	.....	.....	.....	.....	trace.	
Lime	.....	0.53	.....	.....	.....	.....	0.41	
Magnesia	.....	0.17	.....	.....	.....	.....	0.237	
Sulphur	.....	.....	.....	.....	.....	.....	0.14	
Phosphoric Acid	.....	0.044	.....	.....	.....	.....	.....	0.260
Silicic Acid, or Silica	.....	19.52	.....	.....	.....	.....	12.043	
Insoluble Silicious Matter	50.22	.....	.....	.....	15.54			
Water, Total	.....	.....	.....	.....	.....	.....	3.498	
		98.564			99.245			
Metallic Iron	33.09	54.81	53.742	37 720	56.44	44.720	56.944	
Phosphorus	.....	0.019	.....	0.053	.....	0.033	.....	0.113
Metallic Manganese	.....	.....	.....	.....	0.735	.....	0.313	
Specific Gravity	.....	.....	.....	3.45	.....	3.83		
	Chemist, Jenney, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. Sept. 19, 1871. *Sampler*, Brooks.	*Chemist*, Chandler. *Sampler*, R. Pumpelly.	*Chemist*, Britton. *Sampler*, Brooks.	*Chemist*, Jenney, 1872. *Sampler*, Brooks.	*Chemist*, Britton. *Sampler*, Brooks.	*Chemist*, Jenney, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,

NOTES.—95. Average of prevailing variety of lean ore, Sect. 31, T. 42, R. 29. 98. Average of five of the richest pieces found, S. 31, T. 42, R. 29. 102. Average of 10 analyses for P. S. and L. S. Ship Canal Co., Sect. 31, T. 42, R. 29. 246. Same as 95. 74. Boulders at west ¼ post, Sect. 10. T. 39, R. 29. 68. From outcrop in swamp, Sect. 13, T. 42, R. 23. 254. Slate ore south ¼ post, Sect. 30, T. 40, R. 30.

MISSOURI—IRON MOUNTAIN MINE—*Specular Ore.*

	127.	127.	127.	128.	128.	128.	*Averages.*
Sesqui- or Peroxide of Iron	93.57	.....	.....	95.42			
Proto-sesquioxide of Iron	0.76	.....	.....	0.86			
Alumina	0.08	.....	.....	0.06			
Lime	0.46	.....	.....	0.32			
Magnesia	0.23	.....	.....	0.21			
Sulphur	.....	.....	0.008	.....	.....	.012	
Phosphoric Acid	0.035	.....	0.112	0.036	.....	0.067	
Silicic Acid, or Silica	4.75	.....	.....	3.02			
Metallic Manganese	0.12	.....	.....	0.07			
	100.005	.....	.....	99.996			
Metallic Iron	66.049	.....	.....	67.416	.....	.....	66.732
Phosphorus	0.016	0.043	0.049	0.016	0.025	.029	.029
Sulphur	.....	.....	0.008	.....	.....	.012	.010
Metallic Manganese	0.12	.....	.....	0.07	.....	.....	.095
Specific Gravity	4.944	.....	.....	5.002			
	Chemist, Wuth. April, 1872. *Sampler*, Brooks.	*Chemist*, Allen. May, 1872. *Sampler*, Brooks.	*Chemist*, A. A. Blair. 1872. *Sampler*, Brooks.	*Chemist*, Wuth. April, 1872. *Sampler*, Brooks.	*Chemist*, Allen. *Sampler*,	*Chemist*, A. A. Blair. *Sampler*,	

NOTES.—127. "Quarry Ore." Chippings from all parts of the pit and Stock piles. 128. "Surface Ore" (Boulders). Chippings and pebbles from all the diggings and Stock piles.

NEW YORK MINE—*Specular Ore.*

	20.	20.	20.	237.	237.	238.	238.	*Averages.*
Sesqui- or Peroxide of Iron	90.00							
Oxide of Manganese	trace.							
Alumina	1.87							
Lime	1.20							
Magnesia	0.60							
Sulphur	0.03							
Phosphoric Acid	0.57	0.428						
Silicic Acid, or Silica	4.72							
Water, Total	0.98							
	99.97							
Metallic Iron	63.00	.....	.....	62.13	.....	60.10	.....	61.74
Phosphorus	0.22	0.187	0.204	.1385	0.151	0.326	0.326	.225
Sulphur	0.03							
Specific Gravity	4.64	.....	.....	4.88	.....	4.63		
	Chemists, Chandler & Cairns. March 4, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. *Sampler*,	*Chemist*, Briton. September, 1872. *Sampler*, Brooks.	*Chemist*, Allen. *Sampler*,	*Chemist*, Britton. March, 1873. *Sampler*, Brooks.	*Chemist*, Allen. *Sampler*,	

NOTES.—20. Large Stock pile at Cleveland—all varieties. 237. Great South Opening—Pit No. 1. 238. Beardsley's Pit—No. 2. The two last from mine.

NEW ENGLAND MINE—*Soft Hematite.*

	87.	239.	*Averages.*
Sulphur	.....	None.	
Insoluble Silicious Matter	25.66	23.30	
Water Combined	1.42		
Volatile Matter (a little organic and water)	.....	2.69	
Metallic Iron	49.64	46.84	48.24
Phosphorus	.....	0.08	.08
Sulphur	.....	none.	
Metallic Manganese	.....	0.18	
Specific Gravity	.....	3.79	
	Chemist, Britton. Nov. 4, 1871. *Sampler*, Brooks.	*Chemist*, Britton. December 27, 1872. *Sampler*, Brooks.	

NOTES.—87. From mine, numerous fragments. 239. From cars and stock pile at mine. First-class specular ore was formerly mined here, but is not at present.

NEGAUNEE HEMATITES—*Manganiferous Soft Hematite.*

	243.	243.	243.	11.	11.	108.	116.	*Averages.*
Sesqui- or Peroxide of Iron	.....	.....	.....	65.40	.....	65.48		
Oxide of Manganese	.....	.....	.....	6.71	.....	1.54		
Alumina	.....	.....	.....	1.46				
Lime	.....	.....	.....	0.45				
Magnesia	.....	.....	.....	0.66				
Sulphur	.....	.....	.....	0.04				
Phosphoric Acid	.....	.....	.....	0.16	0.171			
Silicic Acid, or Silica	.....	.....	.....	22.67	.....	29.25		
Water Combined	.....	.....	.....	1.88				
" Uncombined	.....	.....	.....	0.58				
				100.01				
Metallic Iron	.....	35.00	.....	45.78	.....	45.83	50.58	44.29
Phosphorus	0.067	0.065	0.099	0.07	0.074	.....	.....	.074
Sulphur	.....	.....	.....	0.04				
Metallic Manganese	0.42	.....	.....	4.67	.....	1.03	.....	2.04
Specific Gravity	3.47	.....	.....	3.83				
	Chemist, Jenney. 1872. *Sampler*, Brooks.	*Chemist*, Britton. 1872. *Sampler*,	*Chemist*, Allen. 1872. *Sampler*,	*Chemists*, Chandler & Cairns. Mar. 4, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. 1872. *Sampler*,	*Chemist*, Chandler. June 29, 1872. *Sampler*, Brooks.	*Chemist*, Jenney. July 13, 1872. *Sampler*, Brooks.	

NOTES.—243. From exploration pits. 11. Small stock pile at Cleveland. 108. Average of three analyses of ore from exploration pits. 116. Dark brown chalky ore. All from Sects. 6, 7, and 8, T. 47, R. 26.

NEW YORK STATE ORES (ST. LAWRENCE & WAYNE CO.)—*Hematites.*

	203.	206.	205.	204.	215.	209.
Protoxide of Iron	.....	.....	12.49	12.72		
Sesqui- or Peroxide of Iron	75.30	77.24	56.54	57.93	63.31	
Protoxide of Manganese	0.15	.....	trace.	0.07		
Alumina	1.69	0.45	0.69	4.54		
Lime	7.04	1.60	8.23	2.32	6.03	
Magnesia	0.38	0.23	2.13	0.85		
Sulphur	0.03	0.05	none.	0.07		
Phosphoric Acid	trace.	trace.	0.36	0.16	.....	1.49
Silicic Acid, or Silica	10.12	.....	4.28	10.97		
Insoluble Silicious Matter	.....	12.93				
Water, Total	.....	2.107	.....	0.62		
Carbonic Acid	5.41	.....	15.01	9.75		
	100.12	94.607	99.73	100.00		
Metallic Iron	52.71	54.07	49.30	50.23	44.31	41.80
Phosphorus	.....	.....	0.16	0.07	0.43	0.64
	Chemists, Maynard & Wendel. Mar., 1871. W. Geo. *Sampler*, Maynard.	*Chemist*, Jenney. 1872. *Sampler*, Brooks. Jan. 1871.	*Chemists*, Maynard & Wendel. W. Geo. *Sampler*, Maynard.	*Chemists*, Maynard & Wendel. W. Geo. *Sampler*, Maynard.	*Chemist*, Chandler. *Sampler*, Unknown.	*Chemist*, Taylor. Jan. 2, 1873. *Sampler*, Geo. R. Tuttle.

NOTES.—203. Sampled for John A. Griswold & Co., at mine. 204. Do. do. 205. Do. do. 206. From small stock pile at Cleveland. 215. Analysis furnished by H. B. Tuttle. 203 and 206 are from Keene Mine. 204 and 205 are from the Caledonia Mine, both owned by Rossie Iron Works. 209 and 215 are Wayne Co. ore.

NEW YORK (LAKE CHAMPLAIN REGION)—*Magnetic.*

	288.	289.	290.	291.	292.
Protoxide of Iron	26.69	25.35	23.29	8.87	19.05
Sesqui- or Peroxide of Iron	59.84	56.19	50.13	69.99	42.97
Protoxide of Manganese	.55	0.12	0.38	0.38	
Alumina	1.87	3.56	4.22	3.67	3.47
Lime		0.82	1.28	1.90	1.19
Magnesia			0.85	traces.	0.09
Sulphur	.20			0.24	
Phosphoric Acid	1.94	trace.	trace.	0.07	trace.
Silicic Acid, or Silica	3.45	12.34	20.02	14.60	32.94
Water, Total		0.47			
Carbonate of Lime	6.02				
	100.56	98.85	100.17	99.72	99.71
Metallic Iron	62.61	59.02	53.21	55.91	44.98
	Chemist, Geo. W. Maynard. *Sampler*, Geo. W. Maynard.	*Chemist*, Geo. W. Maynard. *Sampler*, Geo. W. Maynard.	*Chemist*, Geo. W. Maynard. *Sampler*, Geo. W. Maynard.	*Chemist*, Geo. W. Maynard. *Sampler*, Geo. W. Maynard.	*Chemist*, Geo. W. Maynard. *Sampler*, Geo. W. Maynard.

NOTES.—288. Wetherby, Sherman & Co., and Port Huron Iron Ore Co., No. 21. 289. New Bed; Wetherby, Sherman & Co. 290. Hammond, Crown Point. 291. Indian; Ferrona ore; Hassey, Wells & Co. 292. Fisher; Port Henry Iron Ore Co.

OHIO IRON ORES—*Black Band and Kidney.*

	293.	294.	295.	296.	297.	298.	*Averages.*
Protoxide of Iron	26.82	23.02					
Sesqui- or Peroxide of Iron	8.94	8.79	75.00	7.60	75.00	12.34	
Oxide of Manganese	1.00	1.70	1.65	1.35	1.85	1.70	
Alumina	trace.	0.70	0.60	2.60	0.60	0.50	
Lime	1.05	1.70	2.80		5.94		
Magnesia	0.97	0.88	1.48	carbo. 6.50	3.64	carbo. 5.33	
Sulphur	0.18	0.11	trace.	0.18	0.12	trace.	
Phosphoric Acid	trace.	0.492	0.773	0.863	1.26		
Silicic Acid, or Silica	11.84	26.22	17.02	8.96	8.46	11.94	
Water, Combined					2.28	.78	
Water, Total			0.25				
Volatile Matter	30.50	21.10					
Carbonic Acid	18.30	15.00					
Lime Phosphate						1.74	
Lime Carbonate				7.35		8.59	
Iron Carbonate				64.17		56.23	
	99.60	99.712	99.573	99.573	99.15	99.15	
Metallic Iron	27.12	24.06	52.50	36.31	52.50	35.88	
Phosphorus		0.216	0.34	0.379	0.554	0.797	
Specific Gravity	2.494	2.321	3.411	3.434	4.076	2.539	
	Chemist, T. G. Wormley. *Sampler*.	*Chemist*, T. G. Wormley. *Sampler*,	*Chemist*, T. G. Wormley. *Sampler*,	*Chemist*, T. G. Wormley. *Sampler*,	*Chemist*. *Sampler*.	*Chemist*. *Sampler*.	

NOTES.—293. Black Band, Mineral Ridge, Mahoning Co., O. 294. Black Band, Tuscarawas Coal and Iron Co., Tuscarawas Co., O. Raw. 295. Black Band, Tuscarawas Coal and Iron Co., Tuscarawas Co., O. Calcined. 296. "Shell" or "Kidney Ore," Tuscarawas Coal and Iron Co., Tuscarawas Co., O. Raw. 297. "Shell" or "Kidney Ore," Tuscarawas Coal and Iron Co., Tuscarawas Co., O. Calcined. 298. Nodular Ore, Washingtonville Co., Columbiana Co., O.

For further analyses of Ohio Iron Ores, consult *Geological Survey of Ohio*, 1870, pp. 47, 48, 49, 219, 223.

REPUBLIC MINE—*Specular and Magnetic.*

	233.	233.	234.	234.	*Averages.*
Metallic Iron	67.21		65.81		66.51
Phosphorus	0.03	0.025	0.061	0.045	.040
Specific Gravity	5.19		5.07		
	Chemist, Britton. 1872. *Sampler*, Brooks.	*Chemist*, Allen. 1872. *Sampler*,	*Chemist*, Britton. 1872. *Sampler*, Brooks.	*Chemist*, Allen. 1872. *Sampler*,	

NOTES.—233. Specular ore. First stock pile at opening of mine. 234. Magnetic ore. First stock pile at opening of mine.

SAGINAW MINE—*Specular and Hematite.*

	281.	282.	*Averages.*
Metallic Iron	50.820	53.980	52.40
Phosphorus	0.184	0.080	.132
	Chemist, Britton. Jan. 9, 1873. *Sampler*, Brooks.	*Chemist*, Britton. Jan. 9, 1873. *Sampler*, Brooks.	

NOTES.—281. Small stock pile (first mined) at mine. 282. Ditto. Both samples are soft hematite. By oversight no sample of the specular ore, which is first-class, was collected.

SHENANGO MINE—*Hematite.*

	242.	242.	78.	*Averages.*
Sesqui- or Peroxide of Iron			82.13	
Oxide of Manganese			.15	
Alumina			2.32	
Lime			.41	
Magnesia			.08	
Phosphoric Acid			.186	
Silicic Acid, or Silica			14.46	
Water, Combined			.26	
			99.996	
Metallic Iron	55.140		57.49	56.315
Phosphorus	.049	0.071	0.081	.070
Specific Gravity	3.60			
	Chemist, Britton. 1872. *Sampler*, Brooks.	*Chemist*, Allen. 1872. *Sampler*,	*Chemist*, Wuth. 1872. *Samplers*, Davock, Glidden & Co.	

NOTES.—242. From small stock pile at mine. 78. "Taken from under snow, with no possible selection."—Letter from Davock, Glidden & Co.

SILAS C. SMITH MINE—*Hematite.*

	70.	70.	87.	*Averages.*
Sesqui- or Peroxide of Iron	71.70			
Oxide of Manganese	0.10			
Alkalies	2.03			
Sulphur	0.27			
Phosphoric Acid	0.09	0.127		
Silicic Acid, or Silica	23.38			
Insoluble Silicious Matter			23.79	
Water, Total	2.43		2.43	
	100.00			
Metallic Iron	50.19		49.21	49.70
Phosphorus	0.04	0.055		.047
Sulphur	0.27			
	Chemist, Chandler. Sept. 7, 1871. *Sampler*, Brooks.	*Chemist*, Wuth. *Sampler*,	*Chemist*, Britton. Nov. 4, 1871. *Sampler*, Brooks.	

NOTES.—70. From small stock pile at mine when first opened. 87. From mine when first opened, numerous fragments.

SPURR MOUNTAIN MINE—*Magnetic Ore.*

	2.	226.	226.	226.	97.	*Averages.*
Proto-sesquioxide of Iron	89.21				92.36	
Oxide of Manganese	traces.				0.15	
Alumina	2.67				1.66	
Lime	.67				0.73	
Magnesia	0.19				0.75	
Sulphur	0.35					
Phosphoric Acid	trace.	0.259			0.221	
Silicic Acid, or Silica	6.28				4.31	
	99.37				100.181	
Metallic Iron	64.60			59.96	66.87	63.81
Phosphorus		0.113	0.112		0.096	.104
Sulphur	0.35					
Specific Gravity		4.62				
	Chemist, Chandler. Nov. 1868. *Sampler*, Brooks.	*Chemist*, Wuth. 1872. *Sampler*, Brooks.	*Chemist*, Britton. 1872. *Sampler*,	*Chemist*, Wendel. Feb. 6, 1873. *Sampler*,	*Chemist*, Wuth. Sept. 14, 1872. *Samplers*, Morgan & Herne.	

NOTES.—2. Numerous fragments broken from outcrops of ore. 226. Fragments broken from outcrop 97 Numerous fragments broken from outcrop. All before mine was opened.

TAYLOR MINE—L'ANSE RANGE—*Hematite.*

	88.	81.	89.	89.	87.	*Averages.*
Sesqui- or Peroxide of Iron	82.664	.....	62.25			
Oxide of Manganese	0.894	.....	1.87			
Alumina	.....	.....	3.028			
Lime	0.312	.....	0.31			
Magnesia	0.226	.....	0.26			
Sulphur	0.099	.....	trace.			
Phosphoric Acid	0.236	.....	0.31			
Silicic Acid, or Silica	6.180					
Insoluble Silicious Matter	.....	10.75	21.30	.....	5.29	
Water, Combined	.....	.....	.....	.....	8.70	
" Total	9.438	9.41	8.10			
	100.049		97.428			
Metallic Iron	57.86	52.00	43.576	44.78	57.51	52.88
Phosphorus	0.102	.....	0.13	0.097	.....	.107
Sulphur	0.099					
Metallic Manganese	0.62	.....	0.45	.....	.....	.53
	Chemists, Chandler & Schweitzer. *Sampler*, Brooks.	*Chemist*, Britton, 1871. *Sampler*, Brooks.	*Chemist*, Jenney, 1872. *Sampler*, Brooks.	*Chemist*, Britton, Feb. 18, 1873. *Sampler*,	*Chemist*, Britton. *Sampler*, Brooks.	

NOTES.—88. From shaft 20 feet in ore. 81. From three trenches across ore deposit. 89. From all pits, shafts and trenches showing ore. 87. From mine, numerous fragments. All before mine was opened.

WASHINGTON MINE—*Magnetic Ore.*

	39.	39.	39.	264.	264.	284.	285.	*Averages.*
Proto-sesquioxide of Iron	91.06							
Oxide of Manganese	0.23							
Alumina	0.85							
Lime	0.92							
Magnesia	0.77							
Sulphur	0.03							
Phosphoric Acid	0.25	0.406	.....	0.21	0.170			
Silicic Acid, or Silica	5.13							
Water, Total	0.66							
	99.90							
Metallic Iron	65.94	.....	.....	67.20	.....	57.280	54.800	61.305
Phosphorus	0.11	0.177	0.149	0.09	0.073	0.195	0.146	.141
Sulphur	0.03							
Metallic Manganese	0.14							
Specific Gravity	4.66							
	Chemists, Chandler & Cairns. March, 1872. *Sampler*, Brooks.	*Chemist*, Wuth. 1872. *Sampler*,	*Chemist*, Britton. 1872. *Sampler*,	*Chemist*, Taylor. 1872. *Sampler*, Taylor.	*Chemist*, 1872. Wendel. *Sampler*,	*Chemist*, Britton. Jan. 9, 1873. *Sampler*, Brooks.	*Chemist*, Britton. Jan. 9, 1873. *Sampler*, Brooks.	

NOTES.—39. Large stock pile in Cleveland. 264. Stock pile at Cleveland. 284. Shafts Nos. 1 and 4 at mine. 285. Shafts Nos. 2 and 6 at mine.

WINTHROP MINE—*Soft Hematite.*

	240.	240.	287.	*Averages.*
Sesqui- or Peroxide of Iron	.....	.....	84.66	
Protoxide of Manganese	.....	.....	1.41	
Alumina	.....	.....	0.13	
Lime	.....	.....	0.40	
Magnesia	.....	.....	0.007	
Sulphur	.....	.....	0.02	
Phosphoric Acid	.....	.....	0.084	
Silicic Acid, or Silica	.....	.....	12.70	
Insoluble Silicious Matter	24.34			
Water, Total	.....	.....	0.71	
Volatile Matter	0.93			
			100.121	
Metallic Iron	50.00	.....	59.26	54.63
Phosphorus	0.03	0.045	0.037	.037
Sulphur	none.			
Metallic Manganese	0.53			
Specific Gravity	4.03			
	Chemist, Britton. Dec. 26, 1872. *Sampler*, Brooks.	*Chemist*, Allen. *Sampler*,	*Chemist*, Fred. H. Emmerton. Feb. 13, 1873. *Sampler*, J. T. Torrence.	

NOTES.—240. From all parts of mine. 287. Stock pile at a Chicago furnace.

WISCONSIN IRON ORES—*Iron Ridge (Hematite).*

	298.	*Averages.*
Pure Metallic Iron	56.44	
Oxygen with the Iron	24.91	
Protoxide of Manganese	.47	
Alumina	2.30	
Lime	2.28	
Magnesia	.99	
Sulphuric Acid	.15	
Phosphoric Acid	1.10	
Insoluble Silicious Matter	3.57	
Soluble Silica	.75	
Water and Carb. Acid	6.30	
	99.26	
Metallic Iron	56.44	
Phosphorus	.48	
Sulphur	.06	
	Chemist, J. B. Britton. *Sampler*, J. J. Hagerman.	

NOTE.—298. The ore is a fossil ore, in grains about the size and shape of flax-seed; Dr. Topham calls it Oolitic ore. There are several old analyses showing no phosphorus, but they are not reliable.