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 × 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 × 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

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

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.

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 from 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 octahedrous, 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 piece of magnetite, broken from its parent bed, and suspended

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

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 or 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.

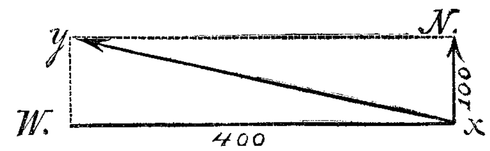
The *direction* which a magnetic needle takes (allowing it to have universal motion), under the circumstances supposed above, and the *power* with which it holds to that direction, must be the mechanical resultant of all the forces acting on it. It cannot point in two directions at the same time, hence 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

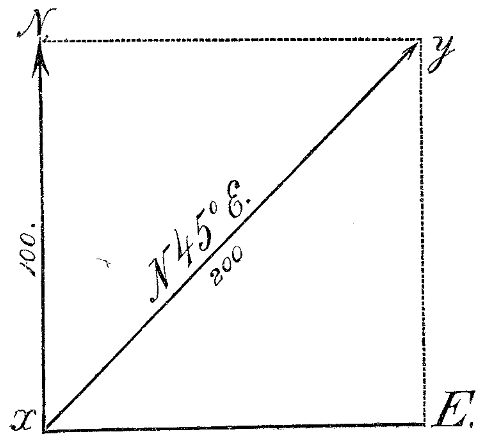
Fig. 16.



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.

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

Fig. 17.



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 may be, 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

* 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.

minute. The vibrations varied from 0 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.

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."

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

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."

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.

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

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

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

* See Appendix H., Vol. II.

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.

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 more 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

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

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.

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 Moun-

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

tain 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.

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 1 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.

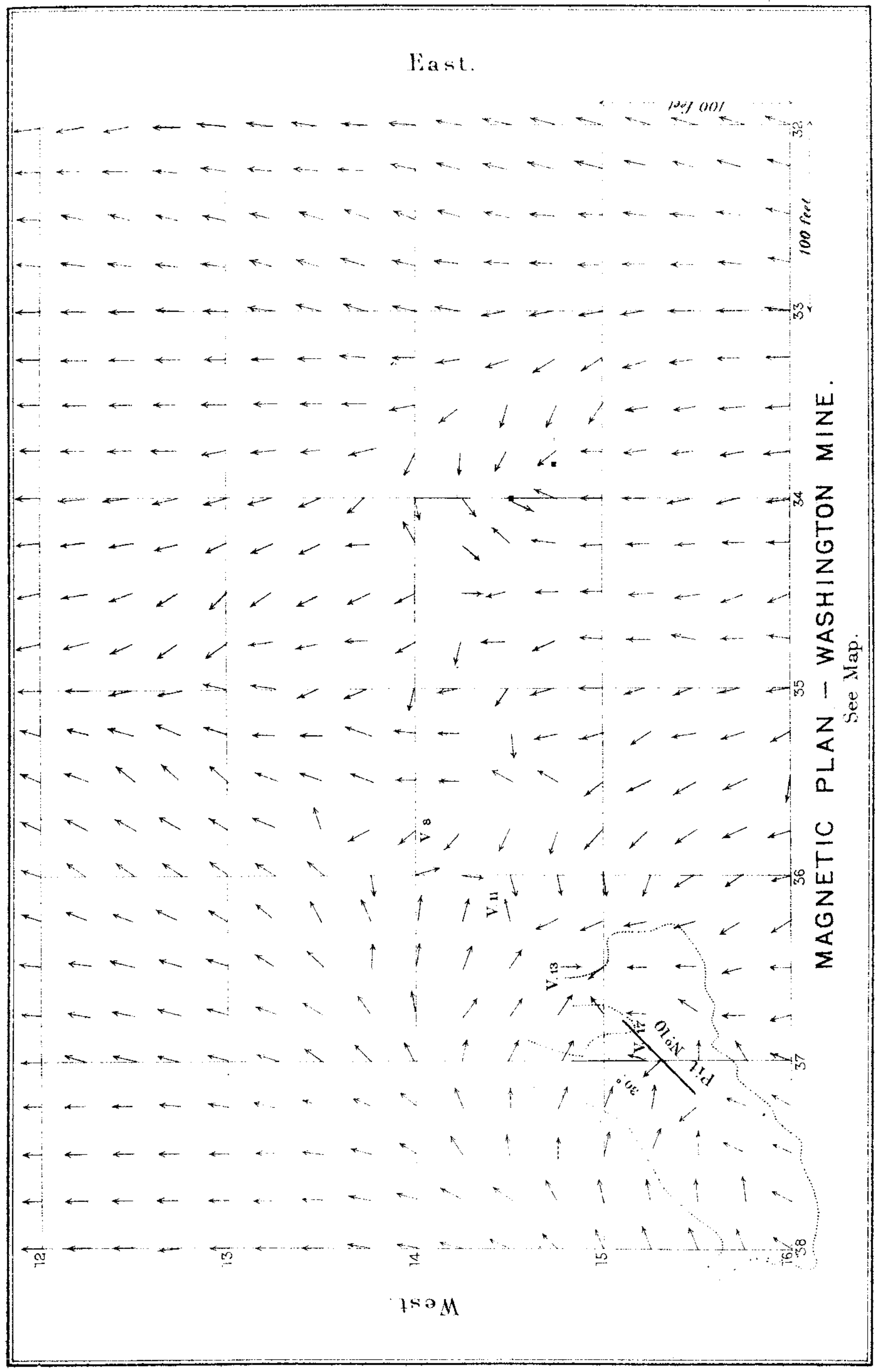
Magnetic observations were made across the entire Huronian series lapping on the Laurentian on each side, along survey lines 26 and 30, which run N. 53° E.; the observations being taken for a considerable part of the distance every 25 feet. The arrows in Fig. 1 indicate the directions which the needle 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.

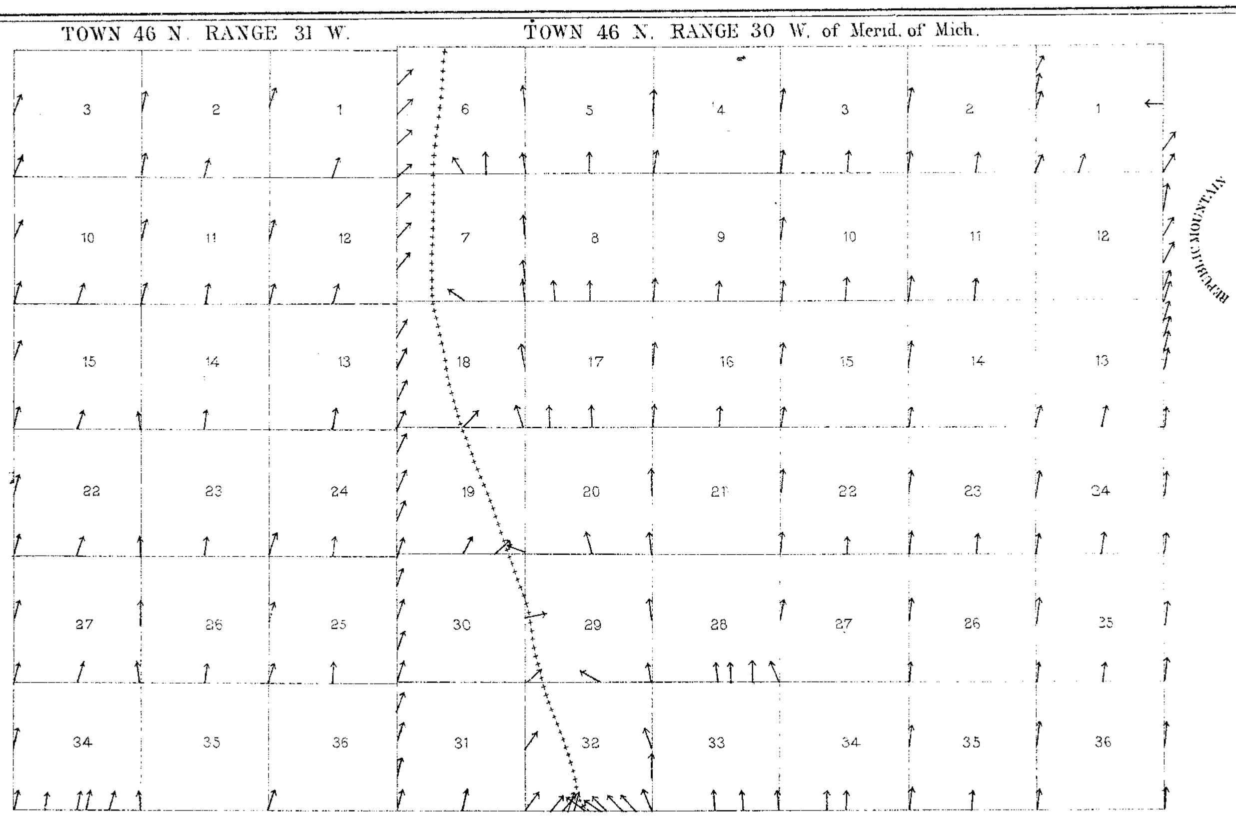
The full significance and value of the common compass in locating magnetic rocks and ores is better shown in Plate V., which represents variations observed at the west end of the Washington mine, embracing the West Cut or Pit No. 10. The stations indicated on the Plate refer to survey lines shown on 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. 1, 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.

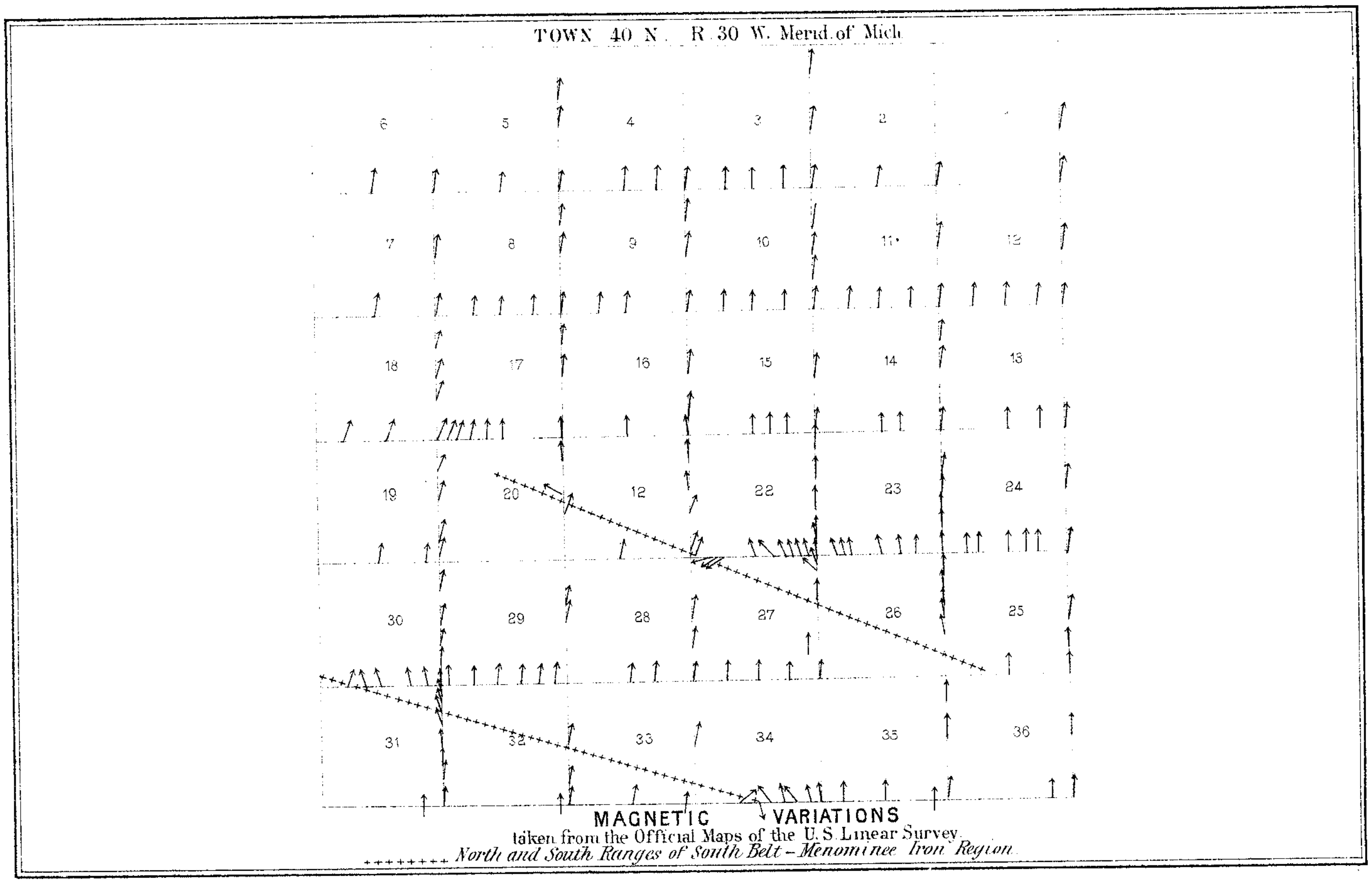
Pl. V.





MAGNETIC VARIATIONS
taken from the Official Maps of the U. S. Linear Survey.
++++++++++++++ *Line of Maximum Attraction as determined with Dip Compass by Geo. P. Cummings, C. E.*

Pl. VII.


TOWN 40 N. R 30 W. Merid. of Mich.
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MAGNETIC VARIATIONS
taken from the Official Maps of the U.S. Linear Survey.
++++++++ North and South Ranges of South Belt - Menominee Iron Region

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. 1, 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.

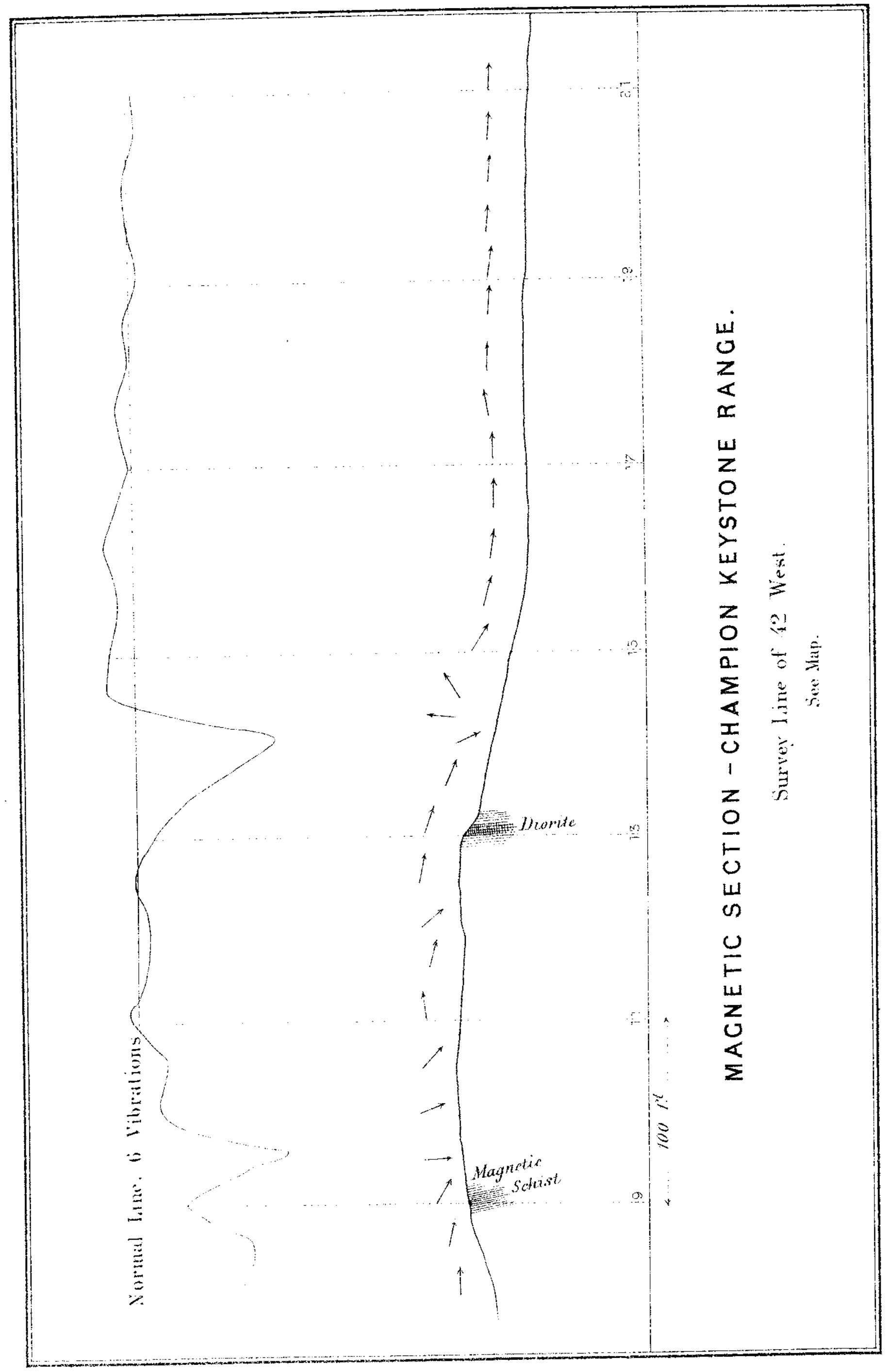
Passing to the south-west side of the Huronian basin we find the influence exerted by the magnetic rocks to gradually diminish as we recede from their edge, which is believed to be under the Michigamme river. See Fig. 1. Here we find the needle varying 15° at a distance of at least 800 feet from the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

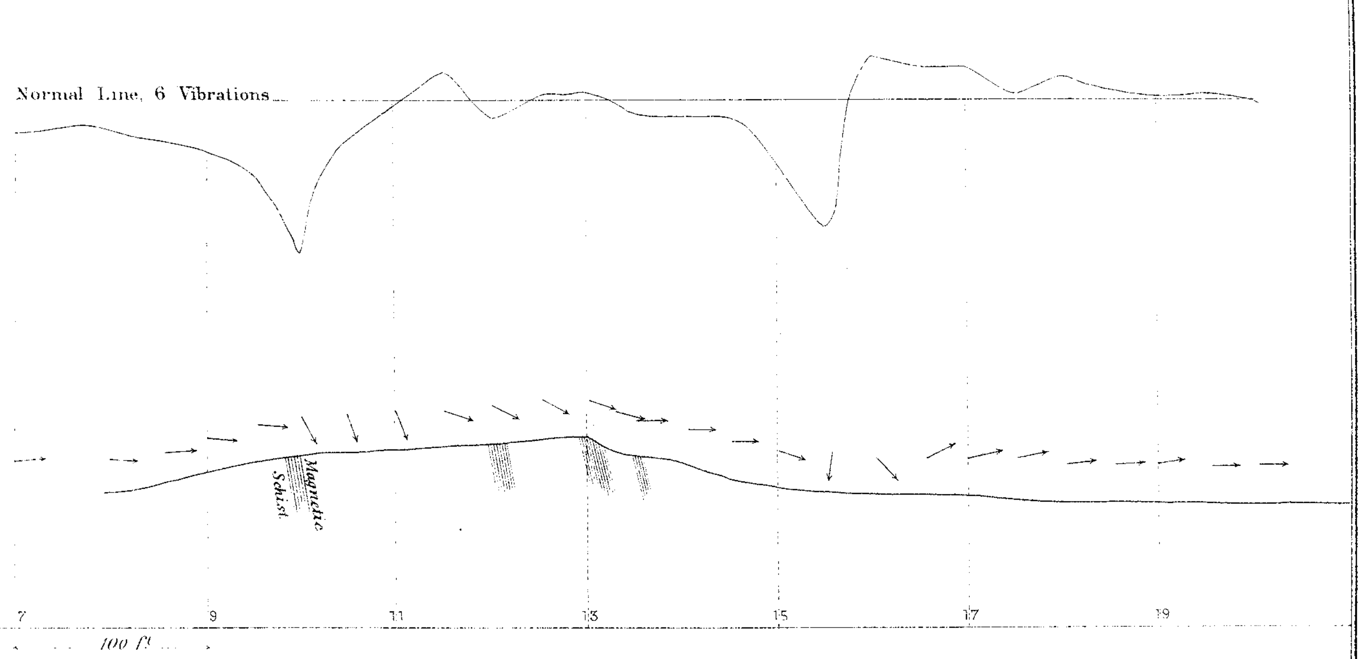
An inspection of Fig. 1 shows that the variations of the needle are much greater on the north-east than on the south-west side of the mountain, which should evidently be the case from the fact that to the south-west the terrestrial and local forces are more nearly in the same line than on the north-east 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.

Pl. VIII.



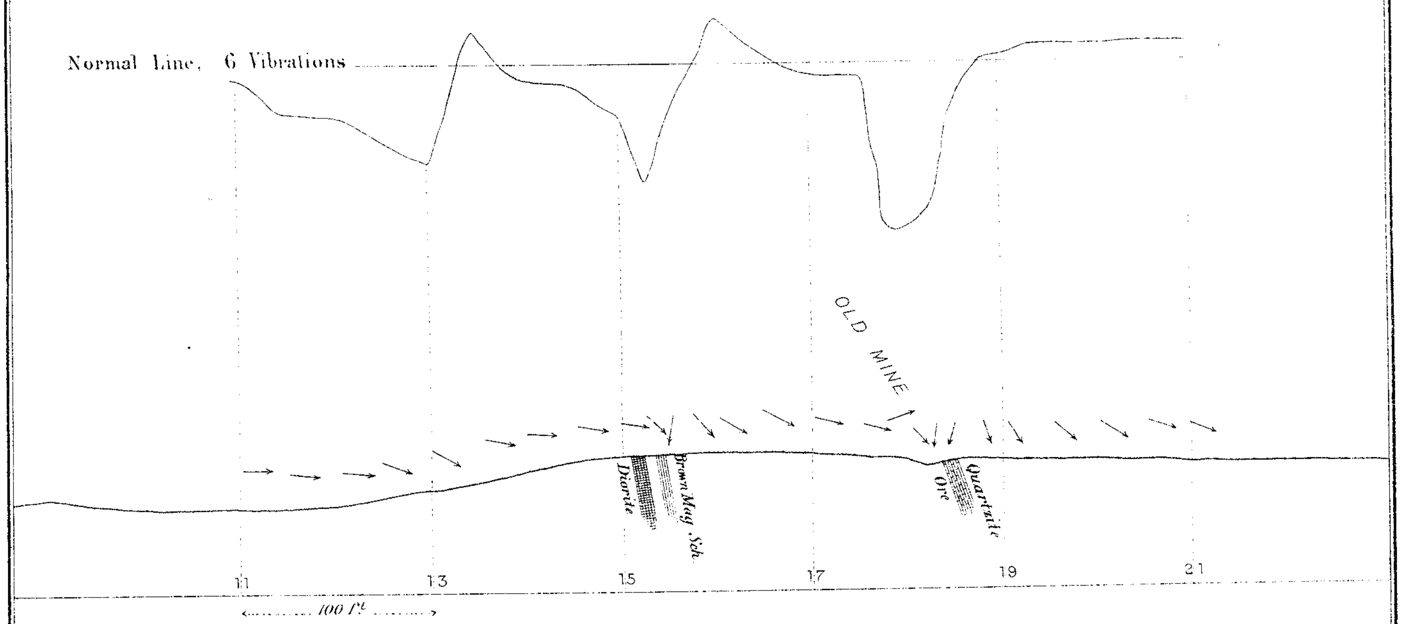


MAGNETIC SECTION - CHAMPION KEYSTONE RANGE.

Survey Line of 50 West

See Map.

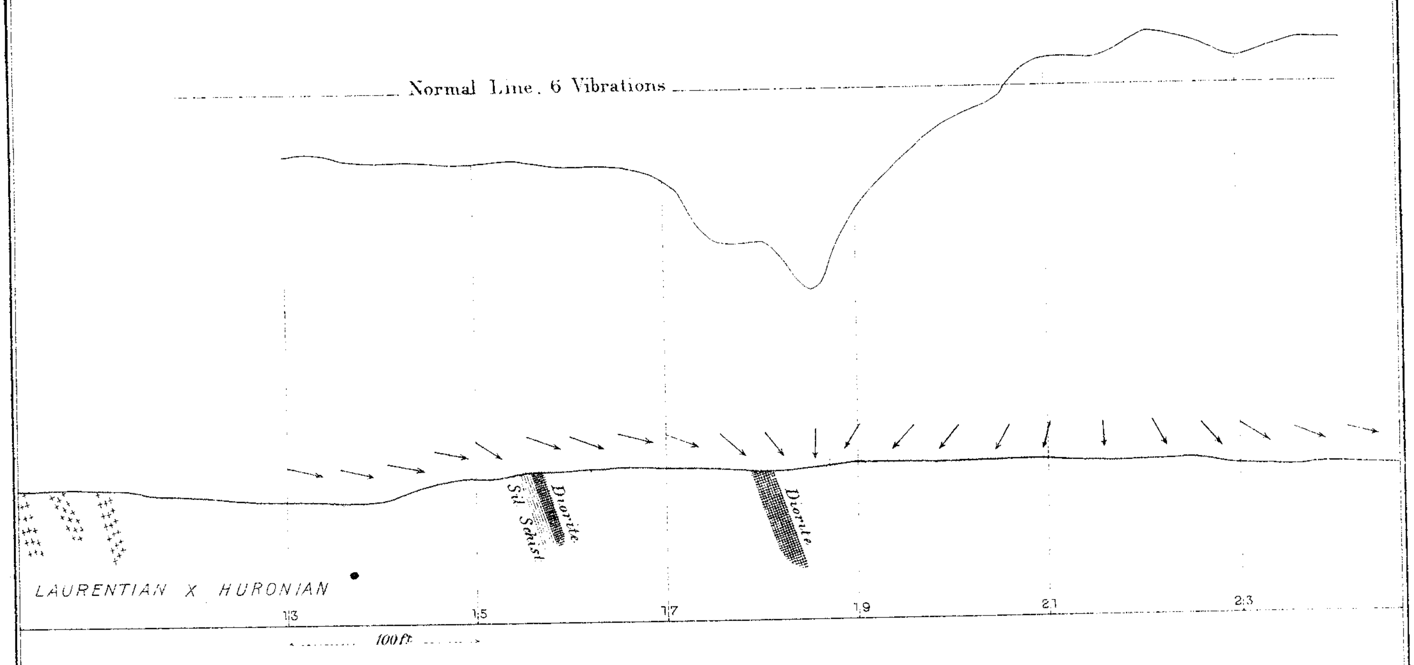
Pl. X.



MAGNETIC SECTION – CHAMPION KEYSTONE RANGE.

Survey Line of 54 West.

See Map.

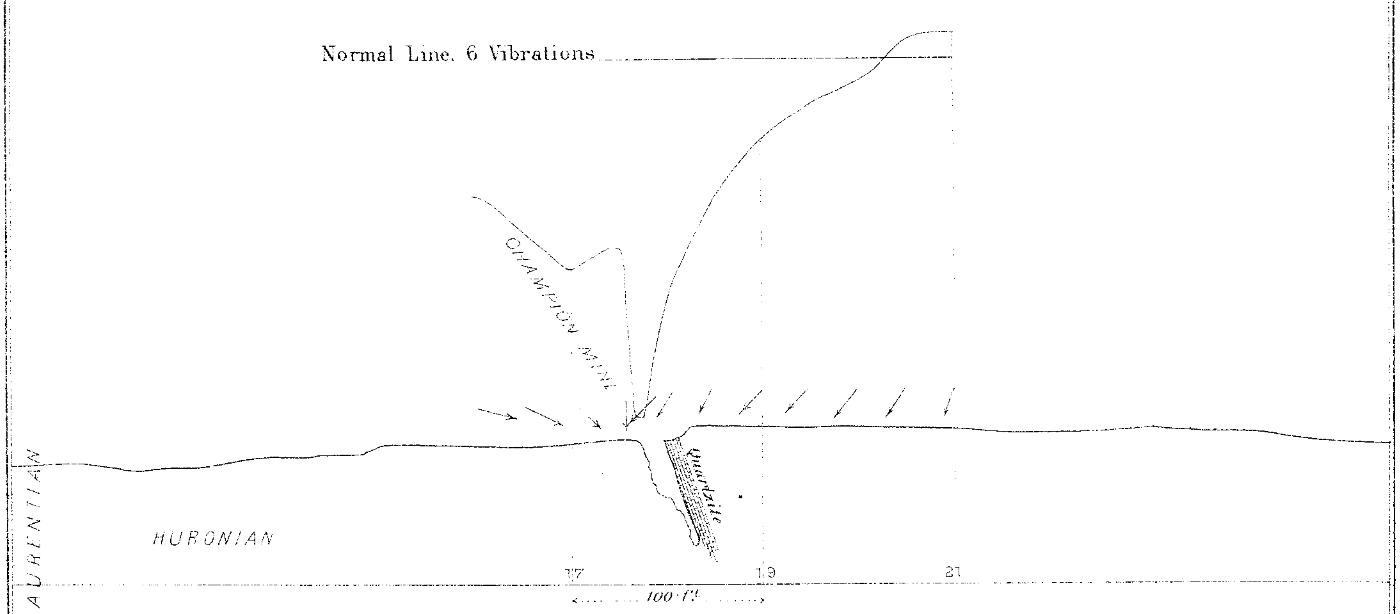


MAGNETIC SECTION - CHAMPION KEYSTONE RANGE.

Survey Line of 74 West.

See Map.

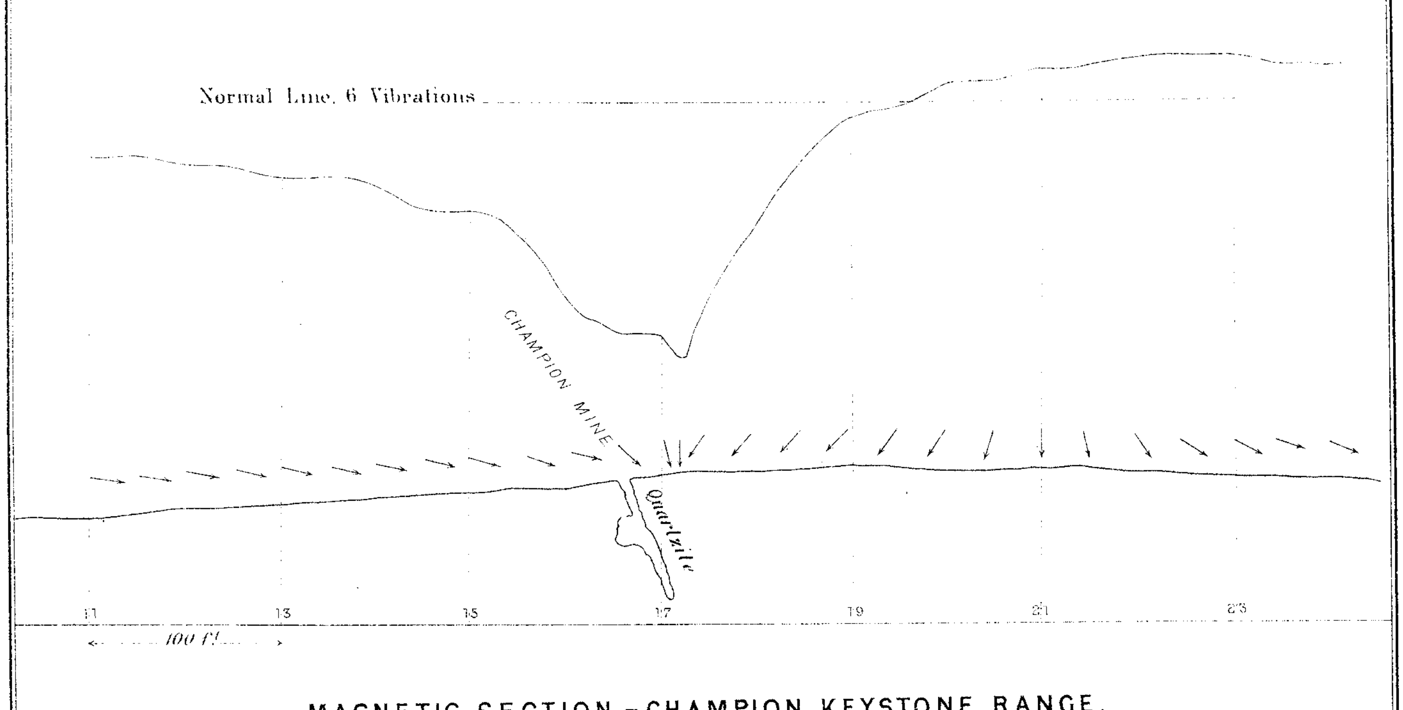
Pl. XII



MAGNETIC SECTION – CHAMPION KEYSTONE RANGE.

Survey Line of 76 West.

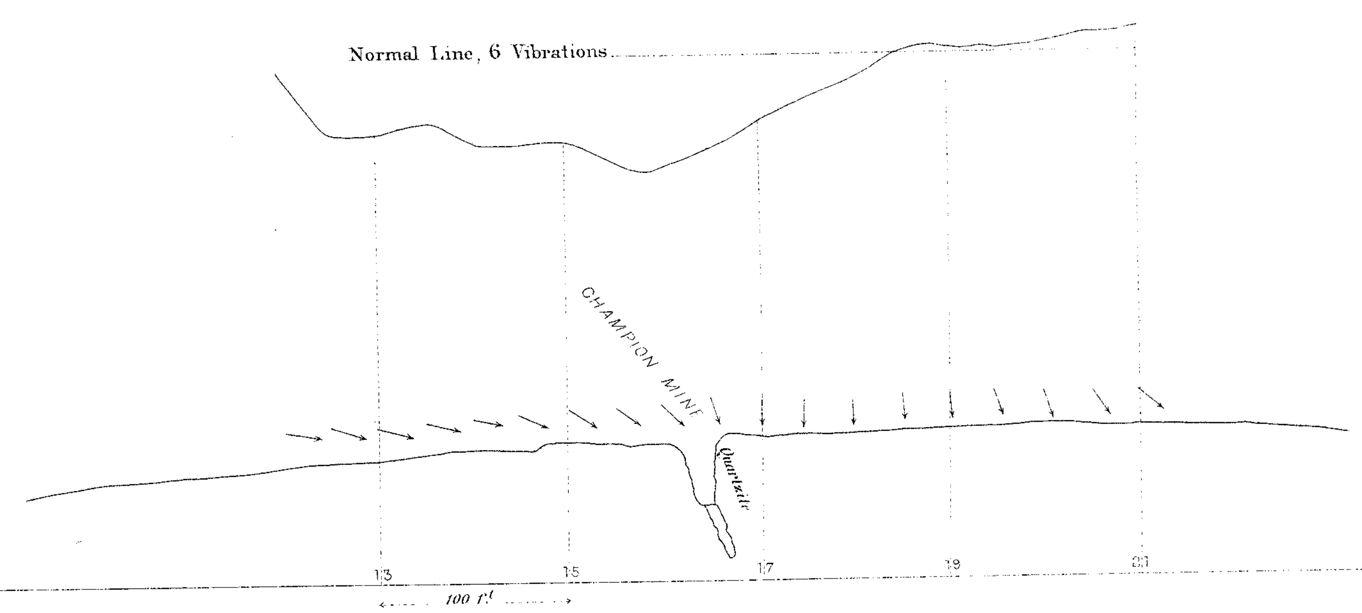
See Map.



MAGNETIC SECTION – CHAMPION KEYSTONE RANGE.

Survey Line of 78 West.

See Map.



MAGNETIC SECTION - CHAMPION KEYSTONE RANGE.

Survey Line of 82 West.

See Map.

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.

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 north-east 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.

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.

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

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 subect 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 com-

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

pass 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.

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 wind-fall, by means of which eight equi-distant 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.

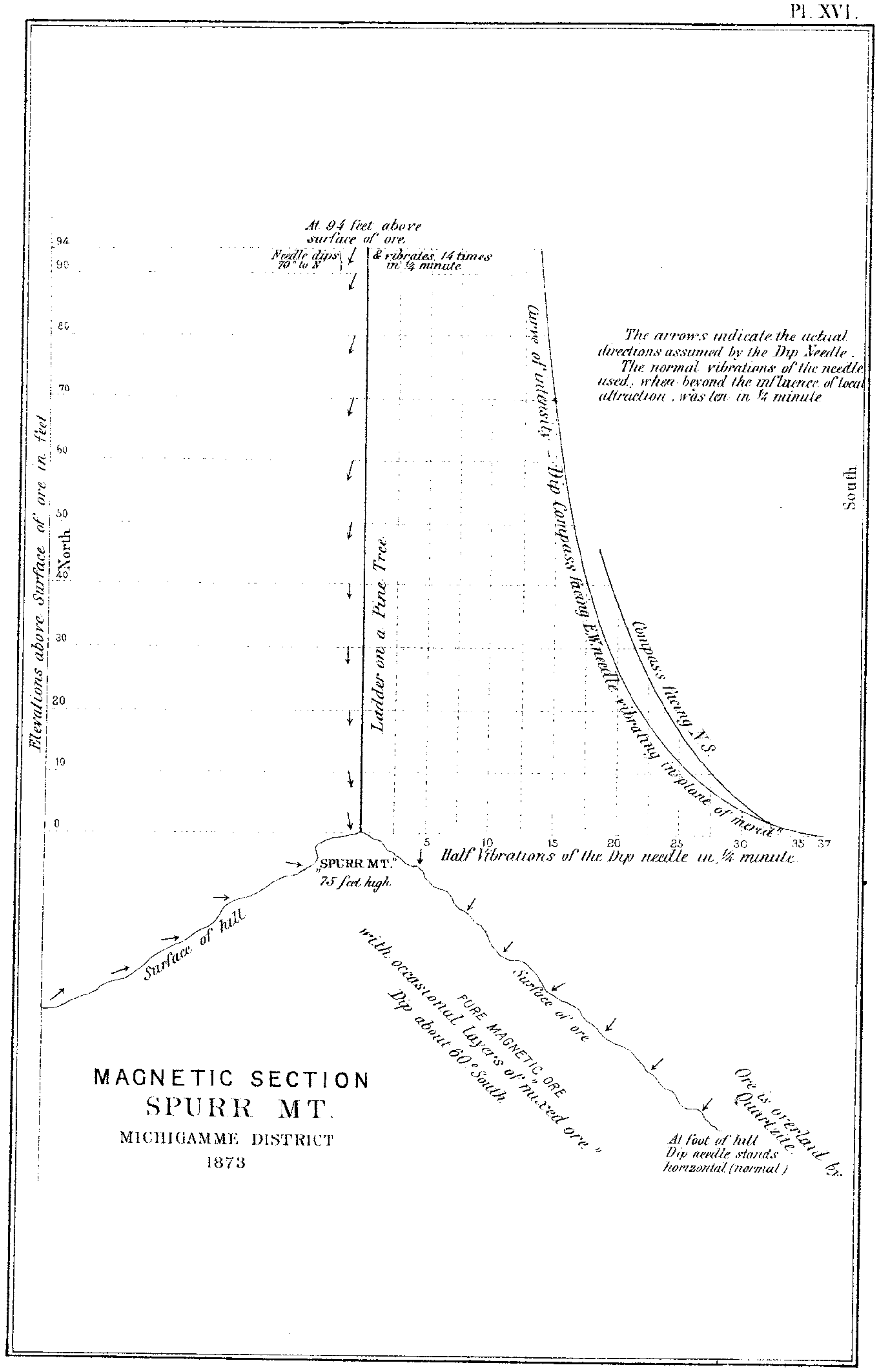
The difference between the rate of diminution at the two localities is very marked; at Republic Mountain an elevation of 12 feet in one instance reduced the vibrations from 60 to 18½, in another 14 feet elevation reduced the number from 56 to 12. At the Champion 44 feet elevation made an average of less 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 per cent. 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 0 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

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

Pl. XVI.



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.

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.

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°	19¼	
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 in 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.

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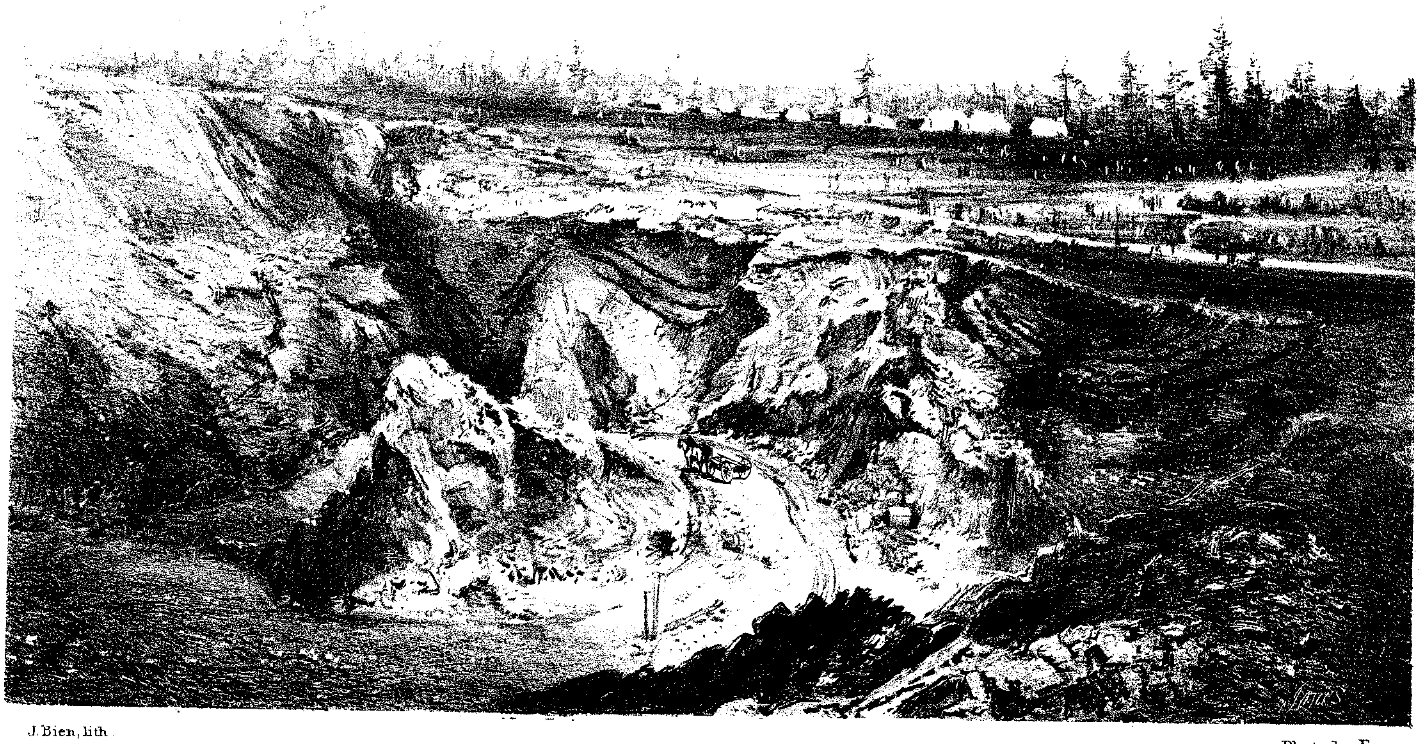
* Two papers on this subject read before the American Institute of Mining Engineers and the American Society of Civil Engineers, and published, are embodied in this chapter.



J. Bien, lith.

Photo. by Emery

LAKE SUPERIOR MINE

Looking West-towards "Big W."

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.

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

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

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.

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 footwalls 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, the 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 0 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 pay-