Methods of prospecting and estimating ore bodies of the Wisconsin Zinc and Lead District

Guy Henry Cox

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METHODS OF PROSPECTING AND ESTIMATING CREE BODIES
OF THE WISCONSIN ZINC AND LEAD
DISTRICT

BY
GUY HENRY COX

A
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submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
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Approved by
Professor of Mining
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GEOLOGY

Stratigraphy

General.- The stratigraphy and structure of the Wisconsin Zinc and Lead District are remarkably simple; so simple in fact that one is liable to under estimate their importance in relation to the ore deposits. But four formations are of interest to one operating in this district, all of which are Ordovician in age and which in ascending order are,- the St. Peter sandstone, the Platteville limestone, the Galena dolomite, and the Maquoketa shale.

St. Peter sandstone, - This sandstone is of interest only as a possible source of water for the mills when the mine pumps do not furnish a sufficient supply. As the mines almost invariably bottom upon the oil rock at the base of the Galena dolomite, a drill hole 60 feet deeper would tap this water bearing horizon.

Platteville limestone, - This formation is about 60 feet thick and is usually separated from the sandstone below by a thin bed of clay. The lower half of this limestone is heavily banded and is known as the "quarry beds". The upper portion is inclined to be thinly banded and to contain layers of clay. (See Pl.I.,A,B).
About 10 feet from the top occurs a dense, fine grained pure limestone known as the "glass rock", which is an important ore-bearing horizon in the northern part of the district where it reaches a maximum thickness of 5 feet.

Galena dolomite.- The Galena Formation is a porous, flinty dolomite about 360 feet thick. Its base is marked by a layer of clay, known as the "clay bed", above which is an organic shale, known as the "oil rock". Each of these beds average about one foot thick but either or both may be absent or reach a maximum thickness of 5 feet. Within the dolomite are a number of chart and fossil horizons which can be recognized with a fair degree of accuracy at exposures, and which are of considerable assistance in working out the structure.

This is the chief ore-bearing formation of the district, the lead ore occurring largely within the upper and middle portions and the zinc ore within the lower 50 feet. The dolomite is porous, jointed, and fractured, the latter producing the "gosh veins" of Bain* which do not penetrate the underlying formation. Pores, fractures, and bedding planes have been enlarged by

solution forming openings of various types into some of which the roof has slumped. (See Pl.II., A, B and Pl.III., A). By far the greater portion of the ore has been deposited in such solution openings so that the various types of ore deposits are primarily due to the various types of openings.

**Maquoketa shale,**—This shale has been entirely eroded from the district except for a few small patches near the western and southern edges. Being soft and easily eroded it seldom outcrops. It is mentioned here because it is thought to have been the source from which most of the ore was derived and its presence in continuous masses marks the western edge of the mineralized district.
Structure

The location of most, if not all, of the ore deposits in this district has been controlled by rock structures. The base of the Galena is marked by impervious layers of oil rock and clay. Inasmuch as this horizon is easily recognized and all drill holes are sunk to this level, it is used to determine the dip of the rocks and the positions of the so-called "oil rock basins". These basins have been brought about by folding or initial dip, or by both, such that the oil rock surface simulates anticlines and synclines, the major depressions or troughs of which average between 2 and 4 miles in length and about 1 1/2 miles in width. (See Pl. V.). The longer axes of such troughs strike in general a little north of east. Many of the large fractures occur within and most of them are parallel to these basins and are therefore probably related in origin.

Water passing through the rock has enlarged the pores and on converging into the joints and fractures has widened these so that in many cases what were tight fractures have become open fissures the walls of which may be a number of feet apart. (See Pl. III.) Underground baves have also been formed in this manner, some of which are 30 or even 100 feet wide and 30 feet high. (See Pl. IV.)
Where openings have been formed by slump of the oil rock because of the decomposition of its organic matter, or by solution, or by both, the overlying beds which have thus been relieved of their support may settle, tending to break in the form of a 'natural arch' in vertical section* and an outwardly pitching crvice in a horizontal one**. These fractures and the bedding planes of the central portion which have been opened by the fall, would then be farther enlarged by solution.

Many of these openings have acted as receptacles for ore so that the shape and extend of resulting ore deposit have been conditioned mainly by those of the available openings.

* See Plate III , B and figures 4 and 5.
** See figure 6.
ORT DEPOSITS

Origin

But two theories of origin are considered to be of sufficient importance to be recorded here; the one by Bain* which states that the ore was probably derived from the Galena formation itself, being originally more abundant in the oil rock basins and further concentrated there by surface waters; and the one by myself** in which evidence is given to show that the ore has probably been derived largely from the overlying Maquoketa shale, and that during its erosion, surface waters dissolved the ore particles and carried them downward into openings in the Galena dolomite.

In each case the ore is believed to have been deposited from surface waters so that the location of the deposits has been controlled by the surface and underground water circulations. Prospecting is, therefore, primarily a study of underground water channels, both past and present.

** Cox, G.H., Econ. Geol. Vol. VI., No. 5, August, 1911.
Occurrence

Galena was the first ore to be worked. It was found almost entirely in those parts of the Galena formation which are near the surface so that it has been largely mined out. The zinc ore occurs mainly in the lower 50 feet of the Galena, rising higher in the formation as it thickens, although some zinc ore, especially smithsonite, is found at higher levels. Considerable zinc ore is also found with the glass rock beds of the Platteville in the northern portion of the district, especially near Highland and Linden where the impervious layers of oil rock and clay have been eroded, permitting the ore to be carried down below their level. No commercial deposit has been reported at this horizon in the southern half of the field.
Types and Nomenclature.

The shapes of the ore bodies have been conditioned by those of the previously existing openings. Vertical crevices enlarged by solution have often been filled with ore and are known as "verticals" and "cravice deposits". (Pl.III,A) These are often designated "four o'clocks", "ten o'clocks", "north and souths", "quarterings", etc. depending upon the time of day at which the sun is in its line of strike.

A parallel set of "verticals" is known as a "range" and may extend intermittently for a number of miles, although usually less than a mile in length and seldom mineralized for a considerable distance. (Fig.1) Such deposits may lead down to any of the following types.

In places caves have been formed by solution along such fractures or porous beds, some of which have been lined or filled with ore. These are known as "opening" deposits (Pl.IV.). Such deposits were formerly very common along the Mississippi River bluffs and many of them were directly connected with sink structures. Such deposits elsewhere in the district show no apparent relation to surface depressions. "Openings are commonly about 20 feet wide and 20 feet high and not mineralized for more than a quarter of a mile. However they have been known to have a width of 100 feet and a length of one or two miles. The longest ones have been found
in the vicinity of Dubuque, Iowa.

Sometimes, when these are small, there may be two or even three in a vertical section. They have therefore been given various names such as, "first opening", "second opening", "third opening", "flint opening", "pipe clay opening", etc., depending upon their sequence and stratigraphic positions. (Fig.?) The "verticals" and "opening" were the first to be worked and it is from these that most of the lead ore has been obtained.

Where the ore has been deposited in horizontal fractures or enlarged bedding planes the deposit is known as "sheet ground". Where pores have been enlarged and partly filled with ore in pieces 1/4 to 2 inches in size, it is said to be "honey combed" or "sprangled" ore. (See fig.?) "Disseminated" ore occurs to a slight extent in some of the more organic beds but is usually of but slight importance. When the crystal groups are 1/2 inch, or larger, in diameter, it is known as "strawberry" ore. Where one body of ore overlies another, they are spoken of as "upper" and "lower runs".

Where the rock in settling has broken in the form of a natural arch and the fractures have been mineralized, the inclined fractures are known as "pitches" and the deposits formed along enlarged bedding planes, "flats". The ideal "flats and pitches"
Deposit would have a central portion, "core ground", surrounded on all sides by an outwardly pitching crevice, a horizontal section of which would be an ellipse. (See figs. 4, 5, and 6) As would be expected, most of these deposits vary considerably from the ideal and much money has been lost, often needlessly, in looking for portions of a deposit called for by the ideal but which were not present.

Such deposits average between 150 and 300 feet wide, 50 and 75 feet high, and 400 and 600 feet long, and occur typically in the minor oil rock basins so that an attempt is always made to work out the structure before or during the drilling operations. The "core ground" may or may not be all mineralized.

Recently a new type of deposit has been noted by the writer*, a type which I have designated as the "single pitch" deposit. Water flowing along a crevice, or minor fracture in the oil rock, gradually escapes through the rock on the drainage side. Solution on this side may at length cause the rock above to slump forming openings which may become mineralized and so result in a deposit that is usually bounded by a "pitch" on one side and a rather tight vertical crevice on the other. These deposits average about 50 feet wide but vary between 30

and 100 feet. They have, however, great length, a number of them have been known to be mineralized for more
than a mile, and change their course quite abruptly.
(See figs. 7, 8, 9, & 10)

When a pitch is encountered in prospecting it can
often be determined whether it belongs to a "flats and
pitches" or a "single pitch" deposit by the fact that
in the former the pitches tend to dip in a direction
opposite to that of the beds while in the latter case
the direction of dip tends to be the same.

Other provincialisms commonly used are:
"Jack" for sphalerite,
"Mineral" for galena,
"Sulphur" for marcasite and pyrite,
"Bone" or "drybone" for smithsonite,
"Tiff" for calcite,
"Gray", "brown", and "blue" rock to indicate various
degrees of weathering of the dolomite,
etc.
Hazard of Locating

Prospecting is a hazard. The ratio of the hazard to the possible gain is a determining factor in profit and loss. If it is necessary for a company to drill 20 properties at a cost of $30,000 in order to locate one good mine, which then clears $60,000, the investment is profitable. A company has been known to strike a valuable ore body with its first drill hole, yet other companies may put down hundreds of holes without locating a commercial body of ore. No definite statement can then be made concerning the cost of discovering a mine in this district, as it varies greatly from mine to mine and depends much upon the ability of the one who directs the prospecting as well as upon what is ordinarily known as "luck".

The larger companies have been somewhat inclined to think that when the price of zinc is low the odds are against the prospector, and therefore limit their operations largely to the purchasing of properties discovered by others. When the price of zinc is high, the cost of prospecting remaining the same, the chances are much better for the prospector and these companies do considerably drilling.

The price of zinc goes up and down through periods of years. It therefore seems as if companies which have the capital might do better by reversing the operations; doing most of their prospecting when the price of zinc is low
and leases are easily obtained, and then retarding the
dev elopment of the properties until the price of ore is
satisfactory. The chance of finding ore decreases as
time goes on and more and more of the deposits have been
located.

The conclusion concerning the hazzard drawn from the
actions of some of the companies is indicitive rather than
conclusive. These companies are willing to spend much
money in salaries and experiments to improve their min-
ing and milling methods, and have found that it pays them
to do so, yet the most difficult thing in mining is to
secure new properties. The best mining man cannot make
money for his company without a mine. Yet there are many
companies that are inclined to think that the poorest man
on their force is able to direct this work. If a good man
can do no more than save his company one drill hole a
week, he is profitable to his company. Economy is the
last word in mining, but economy is not the saving of
every dollar possible, as most people seem to believe,
but rather the wise investment of it, for money is only
made by the use of money.
Indications

While it is intended that this article contain only a general statement of the conditions and methods to be taken into consideration in the drilling and estimation of ore bodies, a word concerning the conditions which lead one to believe that one place is more favorable for prospecting than another may be in order. Only some of the general conditions will be given as much as an actual study in the field of the occurrence and structural relations of the ore bodies is necessary if one is to be able to understand and apply details, a knowledge of which is essential to those who are to direct prospecting work in this district.

Some idea of the origin of the ore is necessary, for its occurrence, shape, and extent has been conditioned by this factor. Fortunately the two best theories of origin advanced for this district involve the same general processes, i.e., the solution, concentration, and deposition of the ore by surface waters. If these are true, the ores have been deposited in water courses; prospecting becomes in reality a study of the present and past underground water channels; and conditions indicative of favorable areas for prospecting are therefore such as indicate the presence of former drainage courses.
During past years prospecting has been guided largely by the presence of old lead workings. But even here much money has been wasted by drilling in a hap-hazard manner over the area until the ore was found or proven to be absent. If the ores have been deposited by surface waters, they have been carried downward. Lead sulphide is the first to be precipitated from acid solutions and the zinc ore if present will either lie directly below or on the drainage side of the lead ore, so that this side should be drilled first. Every drill hole misplaced is about $100.00 lost. At the present time these old lead workings have practically all been drilled so that prospecting must either stop or other methods must be used for locating favorable areas.

The underground drainage of this district is controlled largely by two factors, the fissures and the impervious oil rock basins or throughs. Many of the fissures occur in and strike parallel to these troughs so that they are considered to be somewhat more favorable to prospecting than elsewhere. Such troughs are located by drill records, dip and strike of the rocks at surface exposures, and to a less extent by the presence of springs and surface depressions. The major surface depressions tend to follow those which are structural. Valleys are therefore
considered to be more favorable than elevations in a general way for two reasons; the chance of finding ore is slightly better and the prospecting will be less expensive, the holes being more shallow.

The presence of fissures is indicated by actual outcrop, by discoloration of the soil, by float minerals, by springs, by surface depressions, and by abnormal drainage courses. A normal valley always makes an acute angle with the upper portion of a larger one which it enters. Thus the presence of the two fissures which off-set the ore body of the Empire mine at Platteville might have been predicted by the abnormal character of the two small ravines on the surface at these points.

The chances are best where the Galena has a thickness between 50 and 200 feet. Thick oil rock is desirable but not necessary. Abrupt changes in the dip and thickness of the oil rock are very favorable.

Before leaving this subject it is desired to point out a difference between the theory of origin proposed by Bain and that proposed by myself which has an important bearing upon prospecting and the future of the district. According to the former practically all of the ore will be found in the oil rock basins, while according to the latter most of the ore will probably
be found there but the sides and even the ridges become favorable places to prospect, especially for the single pitch type of ore body. I believe that this is the future type of the district, a statement which, if true, means that hundreds of square miles of land previously condemned may be good prospecting territory and that the district still has considerable life before it.
DRILLING.

Object.

The object of drilling is to obtain such a record of the underlying rocks as can be interpreted with the greatest ease and accuracy that is consistent with low cost. These factors acting together have limited the manner of procedure to one method, namely that of churn drilling. Diamond, calyx, and shot drills have been tried but with no success. The texture of the rock varies considerably and fractures and flints are abundant. Diamonds are torn from their settings and cores lost, calyx drills are dulled and turned to one side, and shot drills are unable to keep the shot at the working face. Cost therefore becomes a minor consideration and such variations in the contract price for drilling as occur are largely due to variations in the supply and demand of machines and the size of the contracts. Variations in the cost of the work to the drill owner are largely a matter of skill of the operator, but of course occur during short intervals because of unusual repair costs and lost time from accidents, rain, distance to be traveled, etc.

The operators therefore demand accurate samples the pieces of which are of the greatest size consistent with fair speed, while the drillman attempts to obtain the greatest speed consistent with the requirements of the operators.
Steam vs. Gasoline Drills.

Both steam and gasoline drills are used, but chiefly the former. While the gasoline machine is cheaper in first cost, lighter, and more easily transported and set up in difficult places, there seems to be a growing tendency for the drillmen to secure the heavier and more permanent steam drills. The three machines most commonly used in this district are, in order of their abundance, No. 3 Keystone special, No. 5 Keystone, and Sparta drill.

Attempts have been made to cut costs by using a gasoline drill and but one man to operate it, but this is not satisfactory and, in general, is not to be allowed. An assistant is necessary to help sharpen the drills and to sludge and should be on hand to look after the engine, etc., as otherwise the temptation for the drillman to allow the drill to run alone while he performs these tasks, becomes too great.

Both machines require fuel and water, the gasoline machine the less, and water is also required for the hole until it reaches the level of ground water. This water is usually obtained from the last hole or from a nearby well, spring, or creek.

The steam drill is the more reliable and flexible in the actual operation of drilling. It is evident that
the speed and size of the cuttings will depend upon the height of the drop of the drill bit, the number of drops per minute, and its weight and sharpness. The height of drop, the number of drops per minute, and the movement of the bit after the blow (this becomes important where there is a tendency for the drill to stick) are best regulated on the steam drill. However the speed and size of cuttings also depend so much upon the skill of the operator that it is difficult to obtain any accurate figures as to the relative efficiency of these two types of drills. It is generally assumed that the steam drill is to be preferred because it is more flexible, faster, and gives coarser cuttings. The coarse cuttings are very desirable to the operators and the increased speed, probably not over two feet a day, is worthy of consideration by the drillman.
Costs

At present the price of drilling varies from 60 to 75¢ a foot, the holes to be drilled to the oil rock, an average depth of about 150 feet. The lower price is obtained only by large contracts. One company reports an average cost of 30¢ for the last three years. This is unusual and is due to deep holes (averaging 175 feet) and the care taken by this company to secure accuracy, approximately every third hole in ore being made with a three inch bit and reamed out to six inches in order to secure large fragments.

The cost of running a gasoline drill has been estimated to be as follows: One man each at $3.00 and 2.25 per day, $5.25; 4 gallons of gasoline per 10 hours at 20¢, 80¢; moving drill, one-fifth of $5.00, $1.00; total $8.05. If a daily progress of 25 feet is made, at 60¢ a foot, this leaves $6.95 profit for the contractor. Without doubt this figure is too high as the drills do not average more than 20 feet a day and these figures do not allow sufficiently for breakage, loss of tools, and depreciation and interest during the months which most drills stand idle.

Mining companies which have operated their own

drills have reported a cost between 49 and 45¢ a foot. Assuming a cost of 40¢ and an average daily progress of 20 feet, the company would save but $4.00 a day as compared with $6.05 as given above. Without doubt the smaller figures are the more nearly correct and it is probable that they are still high. The cost of operating a steam will differ but little from that given above, but will be slightly higher due chiefly to the extra cost of hauling water. With the increased cost of gasoline which must soon come, steam drills may soon be the cheaper to operate.

**Cutting Recovery**

Cuttings are usually recovered by means of an ordinary sand bucket which consists of a tube of galvanized iron as large as will readily pass through the hole, between 4 and 8 feet in length, and fitted with a valve at the lower end. This is given an up-and-down motion similar to that of the plunger of a pump which causes the water and cuttings to pass through the valve into the bucket, which is then pulled to the surface and emptied. After ore has been encountered in a hole a vacuum bucket is sometimes used because of its greater ability to pick up the heavy ore particles.
The sludge is poured into a pail or trough, the excess water and some of the fine material flowing over the side and escaping. No particular effort is made to save the fine material, in fact the cuttings are sometimes washed that they may be the more readily inspected. The error due to this loss is small, is on the safe side, and well within the accuracy of the general computations. Where careful estimates are required the fines should be saved.

After a hole has been cleaned, the sludge is allowed to settle and is then poured in a pile on the grass or on a board reserved for that purpose, and a block of wood, upon which is written the depth from which the sample came, is placed upon the pile. In a short time the material is dry and ready for inspection.

If soft ground is encountered, the hole must be cased to prevent the material above from falling in and sating the cuttings. The casing may be recovered after the hole has been finished. The presence of water in the hole is absolutely essential. It not only tends to float the cuttings so that they can be recovered by the bucket; but also tends to prevent them accumulating in the bottom of the hole where they would retard the cutting and be powdered. A strong flow of water may be detri-
mental as the cuttings may be lost entirely or in part, especially the fines. Where porous ground, pitching crevices, or "openings" are encountered, the cuttings may roll into these and be lost, or it may be impossible to keep any water in the hole. The only recourse in such cases is to ream the hole or to "shoot" it at these points, in which cases the pieces tend to fall into the hole below and can then be recovered. The loss of a sample in this manner is bad enough, but a log which does not show a blank record for these points is worse and is not to be condoned.

Size.—Coarse cuttings are essential to the correct interpretation of the character of the ore and the type of ore body encountered. The operating companies therefore insist that the drillmen take precautions and that they do not sacrifice coarse cuttings for speed. However, size of cuttings and speed are opposed to each other in but a small way as both depend upon the same factors, namely; shape of the drill bit, the proper turning of the drill between strokes, the force and rapidity of the blows, depth drilled before sludging, presence of water, etc. Speed is opposed to coarse cuttings in so far as the latter require that the drill be sharpened a little more
often than would otherwise be the case, that the drill be not allowed to rise and fall without being turned, and that the hole be sludged often.

The drill bits usually have but one cutting edge, which is slightly concave and sharpened at an angle ranging between 90 and 100 degrees. The turning of the bit during operation is usually fairly well performed, even by men of slight experience; it is when no attempt is made to keep it turning that objection is raised.

The force of the blow depends upon the weight of the string of tools attached to the drill bit and the distance of the drop. The tendency seems to be to make the string of tools too light so that one company goes so far as to specify in its contracts that the string of tools shall not be less than 20 feet in length, on the assumption that the shorter the string of tools (weight) the greater the number of blows required for a foot of advance and the finer the cuttings.

The distance through which the drill drops is only roughly regulated by the machine as it really only determines what the maximum drop can be. The actual distance of drop depends upon the skill of the drillman. A slight amount of slack should always be present in the cable so that the drill may strike the bottom firmly,
but the proper adjustment of this slack is a matter of skill and increases both the rate of cutting and the size of the fragments.

The use of jars is therefore somewhat objectionable except when operated by a skilled drillman, as the weight of the upper part of the jars is always upon the cable keeping it taut and making it difficult to determine the proper amount of slack. Yet the use of jars cannot be prohibited because a stuck drill is a serious matter, but they should be used judiciously.

Most churn drills have a drop of 40 to 45 times a minute. While a faster drop might increase the rate of cutting, it would result in much trouble if the drill should stick and is considered detrimental to the life of the machine.

The driller is permitted to use his own judgment as to the distance to be drilled each time before sludging until ore has been encountered, ore is expected, or the hole is within about 50 feet of the oil rock. From here on the hole is usually slugged after each foot of progress.
Interpretation,- After drilling has once been started the advance work is planned almost entirely from information secured from cuttings and logs of the finished holes. From the size and shape of the ore particles and the associated material, one determines whether the ore is disseminated, sprangled, or in sheets; and if in sheets a tendency of the drill to be deflected to one side or to stick indicates a pitch rather than a flat, while a small amount of cuttings with much calcite indicates "open ground". If the drill drops thru an opening and enters ore below an "opening deposit" has been found.

If the cuttings have been lost or are too fine so that the record is doubtful, some companies resort to the practice of reaming the hole at the doubtful points, the sample obtained in this manner being sufficiently coarse for positive determinations. This method, however, is rather expensive and increases the cost of drilling materially. Sometimes a small charge of dynamite is exploded in the hole at the doubtful point in the hope that the fragments will be dislodged from the wall and fall into the hole below and thus be secured.

After a number of holes have been finished and their logs plotted, the relative positions of the ore horizons in the different holes indicate the character of the ore
body and the type of the deposit. The type of deposit most likely to be encountered can be often inferred from the surface and structural conditions.

An early recognition of the type of ore body encountered or likely to be encountered is of much importance and at least results in the saving of time and money, for each type has its peculiarities of shape and occurrence that should influence the placing of the rest of the drill holes, as otherwise the holes may be located in barren ground, ore bodies missed, and valuable leases given up. This is essentially true of "new single pitch" deposits. For instance, one small lease which was entirely crossed by a narrow ore body of this type was drilled successively by four companies and was abandoned by the first three, although some of the drill holes were within three feet and one within one foot of the ore. This was due to the holes being spaced too widely and the tendency to avoid difficult set-ups. Another company with a shaft in rich ore surrounded by four barren holes were glad to dispose of their property for $60,000 and thereby lost more than $200,000, simply because they did not recognize this type of deposit, even after the shaft had penetrated it. A third company operating on a deposit of this type, but still not recognizing its character,
concluded that the ore remaining in the mine was probably not worth more than $10,000, but succeeded in disposing of it to a company for $20,000. The mine later netted the purchasers some $700,000. How many other ore bodies have been missed in this way only the future can tell.

**Sampling and Assaying**—After material collected from the sludge becomes dry it is examined by both the drill-man and the company's inspector, each of whom record its nature. The method of determining the value of sample showing ore varies; some companies depend almost entirely upon the estimates made by their engineers, while others make a practice of assaying everything that shows traces of ore. Perhaps a "happy medium" between these two would be best. The company drilling its own ground desires to know mainly whether or not the ore is rich enough to mine and this can often be settled definitely by an ordinary examination of the cuttings. On the other hand, where a property is to be purchased accurate results may be necessary and assays of everything except traces should be made. Mining men become expert and their estimation of cuttings are often within the degree of accuracy by which the cuttings are a true sample of the hole. However, large companies seem to consider it advisable to remove the per-
sonal factor so much as possible and so make a large number of assays. Such assays are made for zinc, lead, and iron.

Formerly the companies attempted to keep samples of all their cuttings. This soon became a source of considerable expense and trouble. After a number of years' experience they found that the cuttings were referred to but seldom and then only in case they had been incompletely described in the log of the hole. Cuttings showing ore were sometimes reexamined where the metallic content had only been estimated. At the present time no attempt is made to keep samples of any sort, so that the records must be correct, and accurate assays become more important as there can be no chance to check a record.

The company's inspector collects his samples from the piles of sludge and either estimates their value or collects samples to be assayed. In case the cuttings for a number of consecutive feet are about the same, they are put together and one assay made for the lot. No great pains are taken in quartering down the sample for some of the fines have been lost and the sample itself is none too accurate. The results obtained in this manner are fairly satisfactory but the logic is wrong. One inaccuracy should not lead to another as errors may be accumulative.
Records,— In practice two logs are taken of each hole, one by the drillman and one by the company's inspector. Both record the same data and may or may not secure it individually. How much of his record the inspector obtains from the drillman depends upon his confidence in the latter. In all cases the inspector is responsible for everything in his records and these are the ones used in making all estimates.

While the blank log forms in use by the various companies differ in detail, the essential points are the same and include; the number of the hole, the name of the lease, the name of the drillman, the date of starting and that of finishing, the depth of water level, the depth of the clay bed, the elevation (either actual or assumed) of the top of the hole, the thickness and character of the rock passed through, and the assays. The character of the ore, (i.e., in flats, disseminated, etc.), the presence of fissures and openings, the presence of chert, missed samples, etc., should all be recorded opposite the proper depths on the log sheet. No samples are kept so the record must be complete and final. Logs showing pay ore are usually summarized to show the depth and thickness of the commercial ore and its average assay as computed by the "foot-percent" method.
As fast as the holes are completed they are located carefully, by transit and chain, with respect to some known point on the lease and the elevation of the top of each determined. These records are recorded on a map in the office, using a scale of about 30 feet to the inch.

The location and character of a hole is usually indicated on the map by the means of small circles; a blank hole is shown by a single circle, one showing a trace of ore by a small circle with a smaller one within it, and a good hole by a small circle with a smaller one within it, the center of which is solid black. The number of the hole is always placed upon the drawing and it is very handy to also have the elevation of the clay bed recorded here. From these locations and their logs cross section are made as needed and are of considerable aid in determining where the remaining drill holes should be "spotted".

After the drilling has been completed and the holes recorded, the engineer is then in a position to outline the ore body, to determine the best point for the location of the shaft, and to compute the general value of the deposit.
ESTIMATION OF MILL DIRT.

Volume.

After the drilling has been completed and the ore body outlined, the engineer is then in a position to determine its tonnage and value. Assuming that the drill holes have been properly placed (this distance varies with the type of deposit but should not be over 100 feet apart in any case) so that it is safe to assume that the ore is continuous between those holes which show values, the first step is to compute the volume of the mineralized rock, or "mill dirt", that is to be extracted. In this connection it should be noted that this district differs from most others in that it is rare indeed that it is necessary to deduct from the volume measurements an allowance for pillars that are to be left in the mine. The roof is good and deposits other than the "flats and pitches", which is the broadest type, practically never require pillars, and while the roof of the latter may need temporary support, the poorer rock is left for the pillars and even this is usually recovered before the mine is abandoned.

Fortunately the outer limits of the ore bodies are usually fairly sharp and regular; conditions which
aid greatly in the estimation of volume. If the "core ground" is all mineralized, the computation becomes simple. On the other hand where the "core ground" is irregularly mineralized, the computations become very complicated and are to be made, with even a fair degree of accuracy, only by the use of good judgment after much experience. It is true that exact computations are often not necessary, the main fact to be determined in many cases being whether or not the deposit will pay expenses and a fair profit. It is not intended to depreciate the importance of accurate computations for they are always to be desired, in fact with the present competition they are often absolutely essential. Yet there is such a thing as adapting one's methods to his needs.

Given cuttings which will make concentrates that will assay 50% Zn, and a market price of $50.00 a ton for zinc concentrates on a 60% basis (i.e., concentrates that assay 60% Zn), it will require an ore carrying 2.6% Zn, 7.75% of concentrates (i.e., 7.75% of the mill dirt will be concentrates), to pay expenses, assuming that it will cost $1.50 a ton to mine and mill. While this is a handy figure to use in a general way, it is not at all satisfactory when used to compute the
amount of ore that should be mined and that which should be left in the ground. A certain amount of the overhead charges and the cost of instillation are fixed and will be about the same whether a large or a small amount of ore is mined. Therefore the excavation of more material distributes this charge among a greater number of tons and lowers it proportionately. Also the low grade ore usually occurs mixed with the high grade so that any attempt to gouge it out would so increase the mining costs that it might require a 4 or even a 6% ore to pay expenses, while on the other hand the mining of all the material together would permit of the use of mining methods which might materially lower the mining costs. And while it may still cost all that the 7.75% material is worth to mine it, the lowered cost of mining the richer ore will pay a handsome profit for that which is poor. Again it is often necessary to break much of the low grade ore in order to get to that which is profitable. Most of the cost of mining comes in breaking the rock, so that after it is broken rock carrying more than about .7% Zn (1% of 50% concentrates) should be hoisted and milled.

With these figures in mind the engineer determines
how much of the ore is to be mined and computes the volume accordingly. Too much stress cannot be laid upon these facts, especially where mines are to be purchased on close margins. Not long ago a company purchased a mine at a price which the other companies would not consider. The engineer based his opinion upon his belief that by working on a large scale he could lower the costs and thus increase the workable ore body. Many were the predictions of failure, yet the mine has paid for itself, has yielded a good profit, and is still being operated.

Tonnage.

Having computed the volume of the ore body, the operation of changing it to tons must follow. To be exact the average assay must be considered as the number of cubic feet to the ton will vary with the amount and kinds of sulphides present. Using the average assay of the ore body, the number of cubic feet per ton may be determined as follows.

\[
\text{Percentage of Pb} \div 86.6 \text{ (percentage of Pb in PbS)} = \text{percentage of PbS in the ore.}
\]

\[
\text{Percentage of Zn} \div 67 = \text{percentage of ZnS in ore.}
\]
Percentage of Fe ± 46.6 = percentage of FeS₂ in ore.

100% less the sum of the percentages of PbS, ZnS, and FeS₂ = the percentage of dolomite in the ore.

---

Ore volume and weight of minerals.*

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Cu.ft. per ton</th>
<th>Lbs. per cu.ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphalerite</td>
<td>8.5</td>
<td>235.3</td>
</tr>
<tr>
<td>Pyrite (marcasite)</td>
<td>7.0</td>
<td>266.7</td>
</tr>
<tr>
<td>Galena</td>
<td>4.7</td>
<td>425.5</td>
</tr>
<tr>
<td>Dolomite</td>
<td>12.5</td>
<td>160.0</td>
</tr>
</tbody>
</table>

---

Percentage     | Wt. per ton |
---------------|-------------|
" ZnS \times 2000 lbs. = " \div 235.3 = No. cu.ft. |
" FeS₂ \times = " \div 266.7 = " " " |
" PbS \times = " \div 425.5 = " " " |
" dolomite \times = " \div 160.0 = " " " |

\text{Sum} = ?

The sum of the number of cubic feet of each is the number of cubic feet of mill dirt it will require to make a ton.

* Charleston, A. G., Trans. Inst. Min. and Met., Vol. IV., p. 208, 1901. (Note that this is not mineral volume)
For example let us assume that the computations have shown that the average assay of the ore to be extracted is 8% Zn, 10% Fe, and 2% Pb.

\[
\begin{align*}
8\% \text{ (Zn)} & \div 67. = 11.94\% \text{ ZnS} \\
10\% \text{ (Fe)} & \div 46.6 = 21.46\% \text{ FeS}_2 \\
2\% \text{ (Pb)} & \div 86.6 = 2.31\% \text{ PbS}
\end{align*}
\]

Total = 35.71% of sulphides.

100% of ore - 35.71% of sulphides = 64.29% of dolomite.

\[
\begin{align*}
\text{Lbs. per ton,} & \quad \text{Cu.ft. per ton,} \\
11.94\% \text{ ZnS} \times 2000 & = 238.8 \div 235.3 = 1.01 \\
21.46\% \text{ FeS}_2 \times " & = 429.2 \div 266.7 = 1.61 \\
2.31\% \text{ PbS} \times " & = 46.2 \div 425.5 = .11 \\
64.29\% \text{ dolomite} \times " & = 1285.8 \div 160. = 8.04
\end{align*}
\]

Total cubic feet per ton = 10.77

The leaner the ore the greater the volume required to make a ton. This ore is unusually rich in concentrates so that it is at once apparent that the use of 10 cu.ft. to the ton, which is quite common, while convenient, is neither correct nor on the safe side. For instance, an ore carrying 2% Zn and 1% Fe would run 12.24 cu.ft. to the ton, so that the use of 10 cu.ft. in that case would result in a volume 18% too large.
ESTIMATION OF CONCENTRATES.

Tonnage.

Having determined the amount of mill dirt to be extracted, the next step is to compute the amount and value of the concentrates that will be made. Starting with the logs of the drill holes, each of which shows the thickness of the ore body at that point and the percentage and essay of the concentrates as indicated by the cuttings, the general principle is to combine these by the foot-per cent methods to determine the average assay of the ore body. However this method is not to be adhered to too closely. The edges of the deposits may be poorer or richer than the central portions and almost invariably contain more iron sulphide. The foot-per cent method assumes that the holes are equally distributed, a condition which, if present, is more or less accidental. Also the distance between holes is never exactly the same. It therefore follows that where there is an apparent regularity in the differences of the assays, it may be best to not give them equal weight in making the average assay determination.

On a previous page it has been shown how the assay of the drill cuttings is changed to percentages of the various minerals and that to the percentage of concentrates the mill dirt will make if all is recovered. Unfortunately
a considerable portion of the ore minerals is not recovered so that a deduction must be made from the total amount of concentrates in the mill dirt. The proper estimation of this loss is a matter of experience. The loss tends to increase with the richness of the ore and the percentage of iron sulphide. The presence of "black jack" (sphalerite unusually high in iron) the fine mixtures of galena and sphalerite tend to reduce the purity of the concentrates, etc.

Owing to the facts that the mills are so arranged that accurate determinations are impossible and that the mine operators themselves show but little desire to know their losses, an insufficient number of mill tests have been made to give accurate figures. It is safe to assume that the best practice in the district does not save more than 73% of the zinc, 90% of the lead, and 50% of the iron.

Assuming then, for the sake of example, that we have an ore body consisting of 450,000 tons of mill dirt with an average assay of 8 per cent Zn, 10 per cent Fe, and 2 per cent Pb, and that these will be recovered in the above ratios, the amount of concentrates may be computed as follows:
73% of 8% = 5.84% = amount of Zn that will be recovered.
50% of 10% = 5.00% = " " Fe " " "
30% of 2% = 1.60% = " " Pb " " "

5.84% Zn (+ 67.0) is equivalent to 8.72% ZnS
5.00% Fe (+ 46.6) " " 10.73% FeS2
1.60% Pb (+ 86.6) " " 1.85% PbS
Total concentrates recoverable = 21.30%*
21.3% of 450,000 tons = 95,850 tons of concentrates.

The concentrates usually contain about 1 per cent of "lime" (dolomite). This is in part a self compensating error as it increases the tonnage and decreases the value, but results in a value about 1% too large. For the sake of simplicity we will omit this in our problem.

* Where a face of ore has been exposed in a mine of which it is desired to obtain the value, samples for assay are but seldom taken, the estimates of the engineer being considered as accurate as sampling, or at least sufficiently accurate for the work in hand. In all cases, except where assays have been made as in the case of drill cuttings, the value of the ore is spoken of in terms of the percentage and the zinc assay of the concentrates it will make, i.e., a "20 per cent ore", means that 20 per
It having been determined above that we shall have 95,350 tons of concentrates, it remains to be computed how much of this will be sold for its lead and how much for its zinc content. In many cases there is not sufficient lead in the ore to be worthy of separate consideration, but in this case it should be taken into account. A neglect to consider the galena by itself lowers the apparent value of the ore body by an amount equal to the value of the lead concentrates and by a variable amount due to the fact that it would lead one to underestimate the assay of the concentrates.

Iron sulphide has a specific gravity between those of galena and sphalerite, but nearer the latter, and goes in part into the lead concentrates but mostly into those of the zinc. Since the lead concentrates average but about 70 per cent lead, 30.83 per cent PbS, they will contain about 19.17 per cent of FeS₂.

As 8.685 (1.85 + 21.30) per cent, or 8,324.57 tons, of the total concentrates are PbS, and the lead concentrates consist of 80.83 per cent PbS, the total amount of lead concentrates will be (8,324.57 - 80.83) 10,298.75 tons.

20 per cent of the mill dirt will be concentrates; a "20 per cent of 45" means that the dirt will yield 20 per cent of its weight in concentrates which will assay 45 per cent zinc.
The total concentrates (95,850) less the lead concentrates 
(10,299.) leave 85,551 tons of zinc concentrates.
ZnS in total concentrates (8.72% of 450,000) = 39,240 tons.
FeS₂ " " (10.73% " " ) = 48,285 "
We have used (10,299 - 8,325) 1,974 tons of the iron sulphide in the lead concentrates, and the remaining (48,285 - 1,974) 46,311 tons should be added to the zinc sulphide 
(39,240 tons), giving a total of 85,551 tons of zinc concentra-
tes (note that this checks the figures obtained above).
In as much as the zinc concentrates contain 39,240 tons of ZnS or (39,240 x 67%) 2,629t tons of zinc, they will assay 
(2,629÷85,551) 30.73 per cent zinc.

We then have, 10,299. tons of 70% (assumed) lead concentrates; and 85,551. tons of 30.73% zinc concentrates.
Value.

The most difficult and serious part of the estimation of the value of ore bodies of the base metals is that of determining the price at which the concentrates or mine product will sell when put upon the market. In this district it may be six months, a year, or a number of years before the ore is all extracted, and during this time the price will have undergone various fluctuations. No general rule by which the price may be determined in advance can be given, but in general one should try to keep on the safe side. A knowledge of mining conditions and political events will of much assistance.

For the sake of example, let us assume the highest current prices for our concentrates,-

"Platteville, Wis.- Apr. 18, 1914.

"The base price paid this week for 60% zinc ore was $39 @ 40 per ton. Lead sold at the low base price of $46. @ 48 per ton for 80% ore." - F. & M. J.

It is thus seen that the prices of lead and zinc concentrates are based upon the assumption that they contain 30 and 60 per cent of lead and zinc respectively. In the problem which we are considering the percentages of these elements have intentionally been made low in
order that the concentrates will not come up to this standard and so illustrate the methods of computation to be used in such cases.

Given a base price, the value of a concentrate will depend upon both its content of the desired metal and the nature of the impurities. Unusual amounts of "lime" in any of the concentrates, too much lead with the zinc, too much iron with the lead, etc., are penalized. Just what these penalties will be can only be estimated as they depend upon the purpose to which the buyer wishes to put the ore and how much he desires it. The limit for "lime" varies from 1.5 to 3 per cent; the penalty being 50¢ a unit (per cent) above the limit. The limit for lead in the zinc concentrates varies from 0.5 to 1.5, while the penalty varies from 50¢ to $1.00 a unit in excess. We will assume that the ore of our example will not be penalized, it is very low grade.

The price of zinc concentrates which do not assay less than 50 per cent zinc is readily computed from the base price, but the price of ore containing less than this amount of zinc becomes more and more uncertain as the zinc content decreases. Below is given a general scheme for making deductions, exemplified by the ore we are considering.
Price scale for zinc concentrates.

<table>
<thead>
<tr>
<th>Between</th>
<th>Deduct per unit</th>
<th>Amount</th>
<th>Assay</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-50%</td>
<td>Zn - - -1.00 - - or, 81.00 for 50% ore.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-47%</td>
<td>&quot; - - -0.90 - - or, 12.70 &quot;47% &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47-45%</td>
<td>&quot; - - -0.85 (?) - or, 14.40 &quot;45% &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45-40%</td>
<td>&quot; - - -0.80 (?) - or, 18.40 &quot;40% &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-30.73%</td>
<td>&quot; - - -0.75 (?) - or, 25.35 &quot;30.73% ore.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Base price - - - - - - - - - - | $40.00 |
| To be deducted - - - - - - - - | 25.35 |
| Value of zinc concentrates -- | $14.65 a ton. |

85,551 tons zinc concentrates @ $14.65 = $1,253,322.15

The price of the lead concentrates is also somewhat uncertain, the amount to be subtracted or added for each unit of lead below or above 80 per cent varying from 40 to 85%. We will assume that it will be about 75¢ a unit. Hand cobbed lead usually runs about 80 per cent while the mill concentrates vary from that to as low as 60. In the latter case high penalties are inflicted because of the high percentage of iron.

We have assumed that our lead concentrates will assay 70 per cent lead. They will therefore be penalized (10 x 75¢) $7.50.
Base price - - - - - - - - - $48.00
Penalty - - - - - - - - - 7.50
Value of lead concentrates - - - $40.50 a ton.

Lead concentrates (10,299 tons @ $40.50) - $417,100.50
Zinc concentrates - - - - - - - - -1,253,322.15
Total value of ore - - - - $1,670,431.65
VALUOF THE ORE BODY.

The true value of a mine is the amount for which its products will sell less than which it will cost to produce them. A number of factors enter into the cost of production such as; cash payment, bonus, cost of installation and equipment, cost of prospecting, cost of mining and milling, and depreciation and interest.

When it is desired to prospect or secure a property on which ore has already been discovered, an option rather than a lease is usually obtained, i.e., the company may drill the ground at their own expense and may then, if they so desire, secure the mineral rights by purchase, by the payment of royalties, or by both. The cash payments in such cases are usually less than $75,000.

In former years when excitement was high, a cash payment or "bonus" was often required and obtained for a lease; such payments are no longer made.

Nearly all the mining of this district is done on leases, the land owner receiving 10% of the value of the gross output where no ore has been discovered before the lease is issued. If a good showing of ore has been found, 15 or even 20 per cent may be given.

The cost of equipment and installation usually lies between $12,000 and $20,000, but nearer the larger figure.
The value of the equipment after the mine has been worked out is usually thought to be too small to be considered. However, it does have some value as the boilers, engines, motors, hoist, pumps, etc. can be readily moved to another mine. A fair estimate of its value would be about $5,000.

The cost of drilling, while often included, really has no bearing upon the price that should be paid for a property if this money has already been expended. It does, of course, enter into considerations concerning net profits. Eight or ten drill holes may be sufficient to condemn a property, but it will require 20, 50, or even more holes ($2,250., 5,625., or more) to prove up an ore body.

The cost of mining and milling under the best conditions is close to $1.00 a ton of mill dirt, but in the general practice of the district is much higher. Unless conditions are very exceptional it should not exceed $1.50 a ton, and this is usually a safe figure to use. It does not follow that the "safe" figure is the right one; in accurate computations the cost must be estimated in each case.

Depreciation is accounted for in the costs of mining and milling. By interest is meant what one would have to pay (or could get for it) for sufficient money to equip
and run the mine until such a time that the profits are sufficient to repay the money invested with interest. If no cash payment, or only a small one, is made, this would be between 6 and 9 months under rapid development. Naturally the time increases with the amount of money invested.

---

Assuming values for the costs, the continuation of our problem would be as follows:

Cash payment $50,000.
Cost of prospecting 4,500.
Cost of equipment and installation 15,000.
Interest ($74,500 for 9 mo. @ 8%) 4,470.
Mining & milling (450,000 tons @ 1.50) 675,000.
Royalties (1,670,431,65 @ 15%) 250,564.75

Total Estimated profit $670,896.90

Value of concentrates $1,670,531.65
Total costs 999,534.75
The importance of accuracy in computations might be better shown if the problem were worded in this manner: "Given the location and logs of the drill holes, what is the maximum amount that you would recommend that your company pay for the ore body?" There is probably no engineer in the district who would not hesitate to give an answer to this question and to show how he arrived at his conclusions. In fact the answer would vary with the company, depending upon how much they are in need of another mine in order to keep all the help they have trained, how much it would aid them by crippling a competitive company, the effect the payment of a large price would have upon the price of other properties they would wish to buy in the future, etc, etc.

In this case the cost of drilling (assuming that it has been finished) is not to be considered.

The cost of equipment, installation, mining, and milling will be the same as before.

The safety factor for tonnage is a variable depending upon the type of ore body, the number and location of drill holes, the method of computation, etc., etc. With proper care under favorable circumstances it should probably be less than 10 per cent.

The greatest difficulty comes in determining a mini-
A decrease of $10.00 a ton for concentrates would lower the value of the product by nearly 72 per cent; a decrease of $1.00 a ton would lower the value by more than 7 per cent. At the present time this safety factor might be quite low for the price of ore is so low now that it does not seem at all probable that it will go much lower. But as the price of ore and the life of the mine increase, the greater becomes the possible variations. This factor is not constant but varies from time to time. It must always be a matter of personal opinion.

An additional charge must be made to take care of the interest on the investment for such a period that the profit will have paid back the money invested together with proper interest. When figured as interest on the investment, the problem becomes quite complicated. It is therefore more convenient to cover this by discounting the value of the mine after other expenses have been deducted. The consideration of time introduces new problems, such as the most economic methods of working, i.e., whether to plan to extract 100 or 500 tons a day. Figuring an average of about 125 tons a day for 6 days a week, this deposit would last about 13 years. It might be better to work on a larger scale, yet this may not be so for the price of ore
may be very much higher a few years hence.

In figuring profit it should be remembered that the safety factors will probably be profit and that there should be as much chance of these being in your favor as against you. This is why the minimum profit is placed at $50,000, a sum which no company would consider for an undertaking of this size.

---

Estimated value of concentrates $1,670,531.65

Equipment and installation $15,000

Mining and milling 675,000

Safety factor for tonnage (10%) 167,532

" " " market value (10%) 167,532 1,025,064

Minimum value of concentrates $675,468.

Discounted value (17 years @ 3%) $243,168.

Minimum profit 50,000

Maximum purchase price $193,168

Minimum profit 50,000

Probable profit $385,064

Maximum profit $820,128
CONCLUSION.

In conclusion it should be said that methods can be adapted to conditions, but one cannot err by being too accurate. Errors are accumulative. If one accuracy must enter into the work the rest of the computations should be made the more accurately. It is much better to have a low known error and a low safety factor than an unknown error and a large safety factor. Without doubt the most successful companies of the future will be those whose engineers can best figure the value of ore bodies and which can underbid their competitors, for as the district grows older the companies will rely more and more upon the competitive purchase of mines which have been discovered by others.
Fig. 1.—Map of Hazel Green mine, July, 1903. Contour interval, 10 feet. Circles represent test pits; heavy black dots and lines represent old workings.
Fig. 2. Hypothetical section showing general occurrence and nomenclature of the "opening" deposits.

Maquoketa shale

First opening

Second opening

Third or nipa-clay opening

Upper flint opening

Lower flint opening

Oil rock and shale
Platteville limestone

Fig. 3

Note: Honeymomb ore from the Hazel Green mine.
Hazel Green, Wis. m. Marcasite; b. Bande; g. galena.
Fig. 4. Hypothetical vertical section of "flats and pitches" deposit.

Fig. 5. Hypothetical vertical section of a "single pitch" deposit.

Fig. 6—Plan and four cross sections of the Empress mine.
Stippled areas represent refuse-filled parts of the mine. Vertical crevices are shown by heavy black lines. Arrows indicate direction of dip of pitches.
Figs. 7 & 8. Vertical section showing outline of "single pitch" ore body.

Fig. 9.- Ground plan and cross section of the "Empire mine, Platteville, Wis. "Single pitch" type.

Figs. 10 & 11.- Plan showing irregularity of "single pitch" deposits along strike. Each of these mines is about a mile in length.
PLATE I.

A. THIN BEDS FORMING NO. 4 OF GENERAL SECTION OF THE PLATTEVILLE, AS EXPOSED IN THE CITY QUARRIES AT TYPE LOCALITY.

B. QUARRY ROCK OF THE PLATTEVILLE, COVERED BY WAVY BEDS AT MINERAL POINT, WISCONSIN.
PLATE II.

A. FIRST OPENING AT DUBUQUE, IOWA.
   (From Iowa Geol. Survey.)

B. CREVICES AND OPENINGS AT EAST DUBUQUE, ILL.
   (Photo by U. S. Grant.)
A. View showing enlarged cravices along Mississippi River bluff near Old California mines, north of Blanding, Ill. Many of these cravices contained ore.

B. View illustrating the formation of flats and pitches.
Pipe-clay Opening, Hoosier mine, 2 miles SW. of Millbrig, Ill. The opening as seen above was filled within about one foot of the top with ore, rock, and mud. About 12 feet of low grade ore below the opening was worked in connection with the richer portions.
MAP SHOWING GEOLOGY AND TOPOGRAPHY OF THE HIGHLAND DISTRICT, WISCONSIN

Reduced from the Highland sheet of the Wisconsin Geological and Natural History Survey

Scale

0 1/4 1/2 3/4 1 mile

1900

Galeadolomite
Plateville Limestone
St. Peter Sandstone
Prairie du Chien Formation

Elevations of ground in feet above sea level
Shafts
Small shafts and test pits
Old workings

Central line contours of dolomite, showing position of ground-water level, where line is absent the dolomite has been removed by erosion. Arrows indicate direction of dip.