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THESIS

FOR THE

Degree of Bachelor of Science

IN

MINE ENGINEERING.

SUBJECT:

"Notes on Phelps County Ores."

J. M. PRICE, E. E. PRICE.

JUNE, 1904.

This county is situated in the central plateau region of the State between the head waters of the Meramec and Gasconade rivers, comprising the townships between range five and ten west and townships thirty and forty north. The drainage of this county is by the branch streams of the before mentioned rivers, as well as by these rivers. The surface of the county presents a very broken appearance, the ridges seemingly not having a general trend in any direction while all the higher hills seem to be on the same general level topographically.

The streams have changeable and irregular water courses, the fall being comparatively rapid. They have in many places cut deeply into the underlying strata exposing fine sections of the country rock.

The ground is, generally speaking, rough, the hills being covered with chert and having only a thin covering of soil, consisting chiefly of the residual clays resulting from the decomposition of the various overlying strata of limestone and sanddstone.

The formation of the county consists entirely of sedimentary wrork and their derivatives . These sedimentary rocks consist of limestone, shales and sandstones. The cheif derivatives of these are clay, chert, beds of quartzite, etc. The strata of the region is every where distrubed having no general inclination in any direction but changing often in short distances. These disstrubance of the strata are due to several causes the most important of which are the following: The dissolving away of the underlying strata, and the erosion of the softer strata on the hill sides thereby leaving the overlying strata unsupported which would bend downward and would present an anticlinal appearance. The ercsion of the overlying strata resulting in the release of pressure would also result in an upheaving of the surface.

The limestones of this field are usually massive, fine grained and of magnesian character, sometimes highly crystalline approach - ing a marble, other times occurring as silicious limestone or cotton rock, so called.

These limestones are as a rule,very lean in fossils,making the corrugation of the strata in many sections very difficult as well as uncertain. These limestone strata present a very great variety of thicknesses even the same stratum will in short distances have a great change in this respect. In some instances the limestone beds seem to assume more the character of the lenses than true beds however,this may be due to the general errosion and being dissolved by the percolating water. In fact some sections are entirely dissolved away,leaving only a bed of residual clay and chert,the insoluble part of the limestone behind.

The sandstones are generally of a fine grained,compact nature varying in color from nearly white to dark brown. These sandstones very in thickness from a few inches to several feet.

The sandstonestrata which occur in the high elevations are usually thin,aggregating but a few feet in thickness while those in the southeastern part of the county,which is the lowest geologically,is from one hundred to two hundred feet in thickness.

These sandstones have in many places been changed to a compact quartzite by the infiltration of secondary silica thereby cementing the grains together.

The fossils of the region are as before noted,rather scarce. This is due no doubt,not to the dearth of life during this period, but rather to the general decay and also the metamorphism of the rocks containing them.

Two fossil horizons,however,were found. One a bed of silicious oolite which in places was nearly pure limestone,but still the fossils contained in it were most of silicious cast. The other a heavy bed of limestone,occurring about fifty feet above the first. These fossils were not positively identified. While these beds are not sufficient to definitely correlate the group they serve the purpose of correlating widely occuring outcrops. The fossils before alluded to and also the lithologically characteristics noted would indicate that the rocks of this region were of the same series that are known in other parts of the state to be of the Cambro-Silurian age.

Character of the Ore Deposits.

The ore deposits of this county may be classified into three general divisions based on the manner of formation.

(a) Vein or deposits occupying joints in the sandstone which may have been caused by the movement that has resulted in the Ozark uplift. The reason for these joints is rather obscure,but the mas master joints were most probably formed as indicated.

(b) Deposits filling sinks found by the caving in of overlying strata into subterannean water ways.

(c) Deposits that are replacements of the rock mass. These may be either in limestone or sandstone.

The ores of these deposits are essentially hematite/more or less hydrated/although under division (c) when occurring in limestone are pyrite.

Source of the Ores.

The ores are probably derived from the overlying strata which covered the region,and which have been eroded,leaving only small areas of chert and a few fossils as evidence.

The amount of this eroded strata is yet to be determined but in many localities fossils occur which belong to the carboniferous age.

In other parts of the Ozark region when the carboniferous series occur they have bedded deposits of ferrugeneous material. Considering this and the vast thickness of rock that has eroded and also the fact that the present strata of limestones and sandstones are highly ferrugeneous,giving a bountiful source for the iron found in the residual clays,deposits,etc. that occur in the region.

Manner of Ore Concentration.

Since the above is a reasonable hypothesis for the original source of the iron,it remains for us to provide a manner of concentration of the ore into the deposits and conditions as they now occur.

The overlying strata decomposing by the ordinary processes of erosion the iron contents would be subjected to the action of metoric waters containg CO_2 and since the iron occurs as sulphide in the limestones these waters would be an acid character. These acids would take the iron into solution and percolating through the porous underlying strata,would precipitate them as oxides. The conditions of the favorable precipitation of the iron would be an oxidizing influence as illustrated by the following equation:

$$2\ FeCO_3 + O + H_2O = Fe_2O_3 + 2CO_2 + H_2O$$

$$2\ FeSO_4 = Fe_2O_3 + 2SO_2$$

The best equation would undoubtedly be the most general since much greater amounts of iron would be in solution as $FeSO_3$

The degree of hydration depends wholly upon the conditions producing precipitation,the temperature and movement of the waters playing a very important part. By this process only hydrated oxides would occur,although varying in degrees of hydration. Since the ores are chiefly hematite,we must account for the dehydration of these partly hydrated oxides. As the region has undergone but slight movement,the heat from this source would not be sufficient to produce such general dehydration. Furthermore as the ores occur in unmetamorphosed sandstone,it forms conclusive evidence that the dehydration was not the result of high temperature.

Since the iron was precipitated with varying amounts of water it would have a tendency to change to a more stable compound. In other words if partially hydrated,it would absorb water until it reached its hydrated state completely.

Considering the ore bodies,as before stated,as partially hydrated oxides they would absorb the water required for hydration from the circulating solution or from the water containing the mass. This would hydrate the ore adjacent to the water passages to limonite which would form an impervious envelope,thus tending to exclude the water from the mass within.

The affinity of the partially hydrated oxides would have a tendency to dehydrate those of lower hydration,which would form speculat hematite,giving ~~the~~ a core of specular hematite enveloped in limonite.

This nodular form of the specular hematite,covered with limonite occurs throughout all the deposits of the region. Also near the surface we find the largest quantity of specular ore,while in the deeper parts of the deposits it does not occur so plentifully. The occurrence of the bulk of the specular ore near the surface may be accounted for by the varying temperature causing a more vigerous chemical action,or since the ore at the surface would not be in contact with water continuously the changes would be caused to extract its needed water from the mass within.

Form of Ore Bodies.

The general form of the ore deposits is widely circular or eliptical,occupying so called "sinks" or "eaves". A few assume the character of veins,or have one lateral dimensionmuch greater than the other,but closely observing the conditions surrounding the various deposits it is noticable that the larger,more circular or eliptical deposits are advanced conditions of the vein like deposits,or having their origin from the same general agencies.

When the sandstone in which the ore occurs,was exposed to surface conditions,meteroic waters began to enter the stratum. This circulation was largely concentrated by bedding planes and joint cracks along which it followed until coming to a more pervious stratum through which it escaped laterally. Along these joint cracks at certain places would be conditions favorable to extensive water or drainage ways. As soon as solution would begin it would henceforward be more rapid along that zone caused by the increased

circulation. As the water would follow the lines of least resistance this would tend to localize and concentrate the ground drainage to a common point, as these waters mechanically and by solution carried away the sandstones we would have the general sinking of the stratum acted upon. That this would result in a conical form can be explained by the greater amount of water passing the central portion toward the outlet, receeding from the center, the influence of the drainage would be less and less, until the sandstones would assume their normal state, or again this action may have been started by the caving of underground water ways and after the circulation would start the action would be more rapid, owing to the increased amount of water pouring upon it. These sinks may have been formed by either of these actions or by both, now one now the other taking a prominent part.

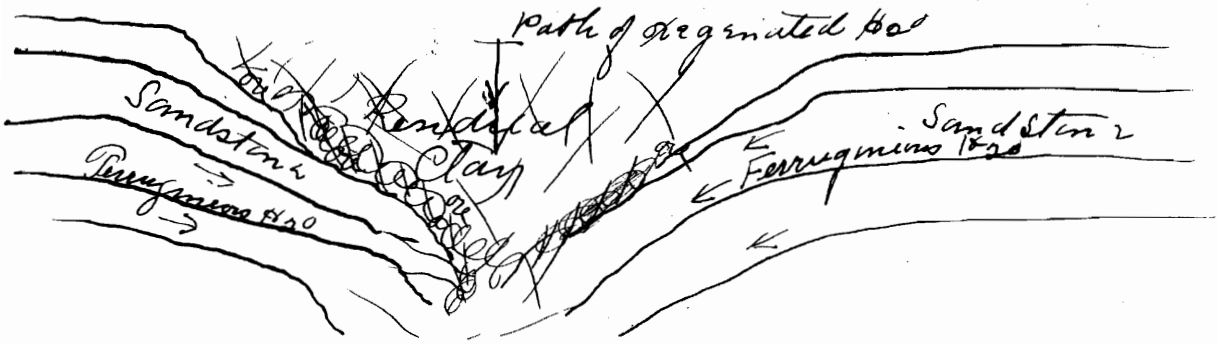
It is a noticable fact that the central portion of these "sinks" or depressions do not contain stratified rock but are filled by ~~cl~~ chert and clay, the derivatives from the now existing surface rock. This phenomenon is very good evidence that the sink was not formed before the stratum in which it now occupies, was acted upon by the dissolving powers of the surface waters.

The fact that the "sinks" now occupy depressions, indicated that the "sinking" is going on at present, faster indeed than the surface erosion, otherwise they would be soon filled.

The cherts that occur in the residual clays and mixed with the ore in the sinks throughout the district, apparently indicate that they are the residium of the decomposed limestone strata above but upon closer observation these cherts are found to be concentrations or deposits formed by the dehydration of colloidal silica.

The clays mentioned above represents the aluminous portions of the sandstones that were disintegrated by solution and other eroding agencies. The occurrence of the ore near the central parts of the sinks or along the sides may have been formed by the contact of the inward flowing ferruginous waters and the more quickly flowing oxygenated water than it flowing directly through the broken area, which would be near the central portion of the sink, which would result in the oxidation and precipitation of the

the central portion of the sink, which would result in the oxidation and precipitation of the iron in these particular locations, as per cut.



Formation of the Second Division of

Iron Deposits.

The original source of the iron occupying these deposits would be the same as the first class, but the manner of concentration and precipitation is quite different.

The limestones of this series contain much organic matter. This fact, as will be seen, plays a very important part in the formation of these sulphide deposits. These deposits occur throughout the country most frequently as bedded deposits. The iron having been taken into solution by the surface waters, and percolating through the surface material would encounter these limestone strata, through which it would percolate, being acted on by the water formed by the oxidation of the organic matter which the limestone contains. This action of the H_2O would cause the iron held in solution to be precipitated as iron sulphide (FeS_2). The water then would be free to take the limestone into solution thus gradually replacing the strata of limestone by iron sulphide.

At the outcropping of these beds, the iron is mostly limonite, caused by the oxidation and hydration of the pyrite. Although occurring throughout the district they are of very little commercial importance, excepting the deposits south of St. James which have been profitably mined.

Commercial Value.

The iron ores of the county are in most part hydrated hematite and limonite, although some siderite and pyrite occur. The hematites are of hydrated character, having a varying percentage of water, until

true limonites are formed. Throughout the deposits and most commonly near the surface quantities of specular hematite occur. It is a very bright crystalline variety. The limonites occur as brown hematite and yellow ochre, mostly occurring near the bottom of the iron deposits and the outcropping of the pyrite beds. The pyrite beds, as before stated, are not of commercial value. In the deposits, occurring with the ore are highly ferrugeneous clays, filling cracks and seams throughout the whole ore body, much kaolin, quartz and chert, all occurring in such a manner that they are all easily separated and not shipped with the ore.

The ores vary in their contents from 55% to 61% iron. The amount of sulphur and phosphorous, as will be seen from the following analyses is very low, making them very desirable ores for making pig iron.

Copper Ores.

In the workings of nearly all the iron mines of the county it is a noticable fact, that they encounter copper bearing ore near the bottom of the workings or near the sides of the deposits. The properties of most importance in this respect are the Lenox, Reide and Kelley properties.

The ores are chiefly malachite and azurite while some calcocite, bournite and chalcopyrite also occur. The ore as will be seen from the following analyses is of high grade but as yet no large bodies of it have been discovered. Since the development of the iron mines have been in the greater part only surface workings and that no development has been done in this direction it is impossible to give any definite conclusion as regards the extent of the deposits although it is probable that larger bodies will be encountered when the limit of surface oxidation has been reached

Analyses of Copper Ore.

	(1)	(2)	(3)
Cu	11.21	3.64	3.64
Fe	20.85	26.6	25.61
SIO_2	19.68	21.04	14.23
Al_2O_3	3.5	2.78	2.61
CaO	1.07	.92	1.23

These samples were specimens that were thought suitable for use but do not represent the bulk of the copper stained material at the mines.

Analyses.

	(1)	(2)	(3)
Ferric oxide	97.23	49.25	87.92
Ferrous oxide	—	1.20	
Lime		.37	
Silica	2.06	44.33	11.32
Phos. Acid	.09	.11	.89
Sulphur	trace	trace	.00
Total Metallic Iron	68.06	35.40	61.54
" Phosphorous	.04	.05	.39

Analysis No. 1 was a sample of decomposed specular ore from Meramec Bank

" No. 2 was a sample of hard silicious specular ore from the Meramec Bank

" No. 3 was a sample of fine granular ore from the Hames Bank.

" No. 4 was of hard specular ore from the Lenox Bank.

Commercial Value of Iron Ores.

The value of iron deposits does not depend upon any one characteristic but upon a combination of circumstances, the principal factors of which are the following:

(a) The amount of metallic iron in the ore

(b) The freedom from deleterious substances.

(c) The proximity to market

(d) Accessibility and extent of the deposit.

The ores of iron as to their iron contents are as follows:

Magnetite	72.4%	Iron	or	1448	#	per 2000#
Hematite	70.0"	"	"	1400	"	" "
Limonite	59.9"	"	"	1198	"	" "
Carbonate	48.3"	"	"	966	"	" "

This is the order of succession of pure ores but impurities are often present so that in a given locality an ore of normally inferior grade contains more iron than those ranking before it in the above list.

The deleterious substances are chiefly phosporous, sulphur, titanic acid and silica. Of these phosphorous and sulphur are the most detrimental. The phosphorous causing the pig iron to be cold short and brittle, while the sulphur causes it to be red short and destroys its welding properties also lowers the saturation point for carbon. From these reasons the limit of phosphorous is 2% above which it is valueless, while for most metallurgical processes .05% is the limit. The limit of the sulphur is one percent above which it must be roasted which greatly increases the cost of reduction. It will be noticed that the analyses of these ores show them to contain very little of these impurities, thus making them very desirable ores.

The market for these ores is good, being within easy shipping distances of St. Louis, and also local furnaces at Sligo.

The character of the deposits is one great hinderance to their development,being mostly sink deposits. Their extent cannot be determined without much expense. While it is true that most of the properties in the past have been small producers,it cannot be laid all to the extent of the ore bodies but to the lack of systematic development and mining. Of the many deposits that have been successful producers the most important are the Meramec,Winkler,Lenox,James and Beaver banks.

Of these the Meramec bank has been the largest producer,having up to the year 1893 produced 375,000 tons while the others vary from thirty thousand to fifty thousand tons. This shows conclusively that these deposits must have more than passing mention.

The shipping facilities are good,the St.Louis and San Francisco railroad passing through the county with a branch going to Salem and Sligo,which gives direct communication with the furnaces of these places. The ore is hauled to the railroads with wagons. This entails a great expense as the roads during the winter months are nearly impassable. This drawback could be largely overcome by the installation of short tram lines.

Mining of the Ores.

The mining of the ore bodies of this county has been carried on by open cut methods and wherever underground work was attempted,it was carried on without judgement or system usually resulting in caving the workings,thus securing only the ore lying very near the surface.

This failure to get all the ore of the deposits has resulted in the wide spread idea that the ore bodies are far more limited in extent than they really are.

In studying the ore deposits of this county the following mines were visited.

Meramec Mine.

This mine which lies about six miles south of St.James,was opened at an early date and was worked extensively for years but is now shut down. The ore is essentially hematite,both the specular and the dull variety being present. Limonite occurs as an alteration of the hema-

atite here. The sandstones dip toward the central area. The sides of the excavation is sandstone which shows plainly the effect of the dissolving power of the solutions it has been subjected to. Chert,derived from the dehydration of colloidal silica stained more or less by iron, occurs quite plentifully hhrough the mass. As the bottom of the excavation was filled with water it was not possible to examine the floor or bottom of the bed but it appears to rest upon sandstone. This was one of the most important mines of this field,having produced nearly four hundred thousand tons. Analyses of ore will be seen attached. This mine is situated in section one,township thirty seven north, eight west.

Winkler Mine.

This mine is near the eastern boundary of the county situated upon a branch road known as Winkler switch. The hills here are smooth and rounding,the surface being covered by a dense growth of small trees The inclination of the strata could not be ascertained accurately,the surface for a considerable area about the mine showed float ore.At present the mine workings are filled with water and is partly caved but at some lesser excavation near the main mine could be plainly observed the sink phenomena characteristic of these deposits. Here we noted overlying or capping some of the ore a sort of chert breccia. This was undoubtedly the remains of the dissolved sandstone that once occupied that position. As we approached nearer the ore the chert became more iron streaked until it resulted in the bed of hematite ore. The ore here is a dull red and massive character containing considerable soft ore. However,the ore from this mine is a very remarkably pure one as will be seen from attached analyses. The amount produced could only be approximated as we were unable to procure reliable data concerning the amount mined. About twenty five thousand tons would be a conservative figure. This mine is located S 1/2. Sec.14. T.26 N 6 West.

Stimson Mine.

This mine or series of excavations lies between two small hills or slopes. A great deal of surface ore lies scattered about. The whole area surrounding the mines bears unmistakable signs of solution and sinking. The ore that has been worked consists of a good grade of hematite. The sides of the deposits are composed of white, and streaked silicious clays while a great deal of chert is found scattered through the deposits. Some copper ore was noted here. Samples of which were tested. The results are among the analyses of copper ore attached. The floor of the excavation was sandstone. These mines have produced about six thousand tons. It is located in S 10,T36 N and 6 W.

Lenox Mine.

This mine,which is situated in the eastern part of the county and is now being worked,is interesting for here was the first place in the field we saw underground work attempted. This mine occupies what appears to be a series of parrallel fissures running in the same general direction as the joint cracks of the country rock, [illegible] these "fissures" may be bedding planes thrown out of their normal condition by the dissolving action alluded to in this paper and they may represent mineralized joint cracks. The work at the mine has been insufficient to determine this point. While a great deal of development work has been done it has been of such a character that it is of almost no value in determining the class of deposits it represents.

The mine was opened by a shaft 110 feet deep and levels [illegible] run at uneven intervals. The levels have been run along the deposit for about 500 feet and are still in ore. The ore consists of a goog grade of hematite aboth red and sepcular mixed with which is consid erable ochre and some clay and chert. The width of the deposits could not be ascertained for the reasons before mentioned,but the development that has been done shows a width of about fifty feet.

Between the main bodies of ore are bands of decomposed sandstone which has assumed a character of clay, white, streaked and yellow. The chert in these deposits was of the kinds before mentioned resulting from silica being deposited from solution.

There has been produced from this deposit about fifteen thousand tons while there is several times this in sight in the mines. The grade of the ore is good as will be seen by enclosed analyses. At this mine was noticed some Copper ore although in insufficient quantities to be mined with profit. This mine is located in Sec.36 T 37, N and 7 W.

Reide Mine.

This mine is located near the Lenox property to the west. It is situated near the summit of a rather large plateau which shows very plainly the effect of the decomposing influence it has been subjected to. This ore deposit dips at a slight angle back under the plateau and was worked by the open cut method. Here we found pieces of ore which showed plainly the oolite structure peculiar to the deposit formed in lime and also some piece of partially replaced limestone.

Also southwest of the main deposits were found large bolders of marcasite. This had no doubt represents a lense of limestone which has been replaced by iron and copper ore. The iron is a fair quality while the copper showing was the best we saw in the district. This mine has not been worked in late years as an iron property although some work was done prospecting for copper. ### While the work #### only disclosed small amount of rather low grade copper ore, it does not prove conclusively, the property worthless, since but copper carbonates were found. About 3000 tons of iron ore has been produced from this property and a few cars of copper ore have been shipped.

Analyses of ore attached.

Of the deposits representing the replacements in limestone a short description of the deposits south of Rolla will be introduced. Here on a rather abrupt slope to the south is seen outcropping a deposit of iron ore.

This deposits lies between two limestone beds and conforms to their stratification planes. The bed upon the surface has been changed largely to limonite but still some retained the crystal form of the original pyrite. In places the ore deposits was replaced by silicious oolite. This deposit or band was followed for nearly two miles to the northwest proving conclusively its bedded character. This deposit may represent the replacement of oolitic limestone.

Analyses.

Ore from Stimson Mine.

		Copper %	Iron %.
No. 1	Specular Hematite	0.	58.3
" 2	Red "	0.	49.83
" 3	Copper vein	3.44	28.74
" 4	Sorted Copper Ore	12.91	21.81
" 5	Clay of Iron Deposit		18.21

The following more complete analyses were made of ores suitable for smelting.

	1	2	3
Copper	12.9	3.44	0.
Iron	21.81	28.74	58.3
Aluminum	3.54	3.60	3.53
Silica	19.68	22.03	12.10
Calcium	1.07	1.53	1.05
Magnesium	0.	1.	.21
Water	13.	13.	13.

Reide Mine.

		Copper	Iron.
No.1	Picked Specimens Azurite	38.24	11.31
2	" " Malachite	31.28	18.25
3	Grab Sample from Cu.8ft Dump	3.67	24.71
4	Iron Ore Specular	.00	48.23
5	Iron Ore Red		44.33

The following more complete analyses were made:

	1	11	11
Copper	10.34	5.13	0.00
Iron	20.13	24.17	48.23
Aluminum	3.91	4.14	2.07
Silica	23.14	20.12	3.04
Lime	5.06	7.31	0.00
Magnesium	.93	1.07	
Phosphorous	.045	.083	.0306

Lenox Mine.

		S.	P	Cu	Fe.
No. 1	Picked Specimen Copper Ore	41.17	1	41.17	10.23
" 2	Azurite and Malachite			14.3	27.41
" 3	Specimen Hematite	.109	.10409		63.05
"4	Red Hard	.093	.0303		58.0301
" 5	Soft Ore	.082	.0391		67.53

The following sandstone were run for iron. These were mostly obtained from beds overlying the iron deposits.

	S	P	Fe	Si.
1	2.03	.304	23.67	58.27
2	1.02	.153	18.27	61.42
3	.012	.003	12.14	74.18
4	.03	.012	14.13	68.28
5	1.203	.033	10.28	70.14

In conclusion, summing up the evidence both field and theoretic, there very good reasons for believing that the deposits which have been worked and are not being worked are not the only deposits of magnitude in the county but by intelligent prospecting along lines already suggested other large and valuable deposits will be found. From the manner of the ores concentration it is not to be expected that every deposit will have a surface outcrop neither is it probable that every depression will be found to contain an ore deposit but when these phenomena occur, together with other evidences of mineralization, the condition at leat warrents the expense of prospecting by pits or otherwise.

Practical Hints in Regard to Locating These Deposits.

Solid heavy bedded strata would not be considered favorable as here we do not have the conditions favoring solutions, etc. Sharp hills and steep bluffs characteristic of the former conditions would not be favorable even though we should find considerable surface ore but we must look for smooth rolling hills or plateaus with humerous sinks and then when there are pieces of ore and chert mixed with the soil the conditions would warrant close investigation.

The prospects for the future we would consider bright. The excellent quality of the ore, the advent of more modern mining method and of transportation and the lessening production of other localities of the state will eventually cause the iron masters to recognize this field with more seriousness than in the past.