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Report on the onyx deposits of Boiling Springs Cave

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THESIS

FOR THE

Degree of Bachelor of Science

IN

MINE ENGINEERING.

SUBJECT:

"Report on the Onyx Deposits of Boiling Springs Cave."

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MAY, 1901.

REPORT ON THE ONYX DEPOSITS OF BOILING SPRINGS CAVE.

Situation and Surroundings.

Boiling Springs Cave or King Cave, as its late owners named it, is in Sec.28, Township 37, Range10 W., Pulaski County, Missouri. The nearest village is Arlington on the Frisco Railroad, on the east bank of the Gasconade River.

The mouth of the cave is at the head of a small ravine about one half mile from the Gasconade River. This ravine is about two hundred yards up the river from Boiling Springs, a familiar land mark in that part of the State.

Topography.

The country in the neighborhood of the cave is very hilly and broken, this part of the State being in the Ozark Uplift.

The wagon road from Arlington is located in a valley approximately parallel to the river but on the other side of a chain of bluffs which form the east shore of the Gasconade.

About a mile from the cave this road ascends the ridge, and leads directly past the abandoned shaft sunk into the cave. The character of the surface is so stony and uneven that a good wagon road cannot be constructed and kept in repair except under a considerable expense. This is especially true in changing from valley to ridge, as the wash from rains down the steep hillside will cut up and scour the road bed. These topographical features materially effect our transportation problem, as will be seen later.

The locality seems to have been well wooded at one time, but a great deal has been cut away for railroad ties, the river being an easy mode of transportation to the nearest railroad. Post oak, black jack and black hickory are the principal varieties on the hills, while in the valleys sycamore, cotton wood and elm are found.

Small springs abound and quite a number of a relatively large size are found at intervals of a few miles on the banks of the Big Piney and the Gasconade;however, water for a good boiler supply would probably have to be hauled to the cave in wagons or pumped from the creek in the cave.

The elevation of the ridge above the river level is from two hundred to five hundred feet. The highest point of the cave hill being about three hundred and fifty feet above the river level.

Along the Gasconade the scenery is bold and picturesque. Long lines of limestone bluffs often rise in perfectly perpendicular bluffs two hundred feet high from the water edge,equal in beauty though not in grandeur to the canons and gorges of the Rockies.

Geology.

Structure.

The structural features of the locality are those of an eroded acline. The bold,prominent bluffs are the outcroppings of the Third Magnesian Limestone, of the Ordovician System.

This limestone is enormously developed in this county, and in the adjacent part of Phelps County.

It is capped in places by the Second Sandstone,but on the cave hill itself the greater part has been eroded away,leaving large fragments scattered over the hill side. These limestone beds are often cleft in all directions from base to summit by vertical fissures, but no displacement or faulting movement is apparent.

Solutions of the wall rock and redeposition of $CaCO_3$ has filled in all of the smaller fissures,so that where a horizontal section is visible,as in the roof of the cave,the bed has the appearance of a net work.

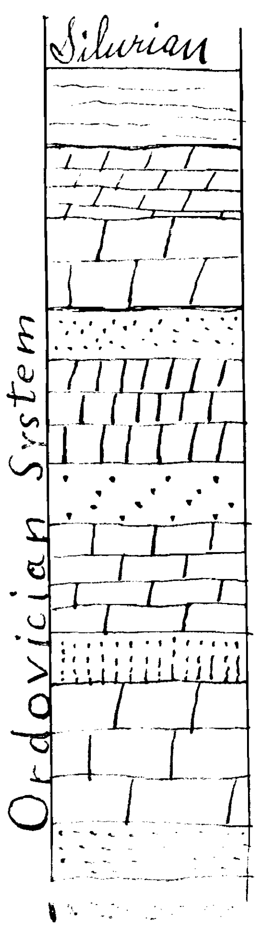
period. Excepting the slight superficial deposits of the Quaternary, all the strata exposed in this county are Paleozoic, and this is limited to the Ordovician.

The Third Magnesian, which is the great country rock of this district, is one of a series of four magnesian limestones, each on a base of infusorial sandstone, which make up such a large part of the exposed strata of the Ozark Uplift.

These limestones, on account of the alternating layers of sandstone and also on account of their large contents of silica and magnesia, have been called First, Second and Third Calciferous by some geologists. They are probably contemporaneous with the Calciferous of New York.

The Third Magnesian Limestone is the second Limestone above the Cambrian, upon which the first basal sandstone of this series lies unconformably.

The following section of the Ordovician of Missouri is constructed from data gathered from the various Geological Surveys of Missouri, including Swallow's.



Onyx Deposits.

The third Magnesian throughout Pulaski County is remarkable for its cavernous structure. These caves are formed by the solvent power of water, charged with carbon dioxide on limestone.

The soluble acid carbonate of calcium is formed and reprecipitated as neutral carbonate when the excess of carbon dioxide escapes, either by relief from pressure or the evaporation of the water, as

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2 \quad \text{and}$$

$$Ca(HCO_3)_2 = CaCO_3 + H_2O + CO_2$$

In this way a small fissure in the limestone may be enlarged into a vast cavern. After this process of solution has gone on for a time, it is usually followed by that of redeposition. In fact, both processes seem to be going on simultaneously in this cave.

The water from the surface percolates through the limestone roof, and remains for a time suspended in the form of drops from the ceiling. Here it evaporates partly, and its contained calcium carbonate will crystallize out on the surface, and an icicle like tube will gradually be formed by successive drops.

This tube is enlarged externally by the saturated water flowing over it, precipitating its dissolved carbonate, and the well known stalactite is formed. A similar though more massive formation from the floor upward, formed by dripping water, is called stalagmite.

The two may meet, forming a pillar. If this process is continued long enough the entire cavity may be refilled by this stalactitic rock.

As the water dissolves only a very slight amount of the impurities in the limestone, it will be seen that the redeposited material is of a much purer calcium carbonate than the original limestone. On examination of the crystalline form of specimens from this cave, most of them undoubtedly consisted of calcite, but some with a fibrous structure, radiating from the center and of a silky lustre were probably aragonite.

Geology of Cave.

The mouth of this cave is a vast opening in the limestone hill, about 200' X 100' X 30' (high). The front part of the mouth is filled nearly up to the roof with debris, from fallen ledges of limestone and soil. At the end of this mouth, 200' from entrance, two passages begin. One to the left becomes very small and narrow, and is apparently filled up with stalactitic material. The other, to the right is along the bed of a creek which issues from the cave. Following this creek up stream we enter a passage which soon narrows down to about twenty feet across from rock wall to rock wall, and about six feet high above the water level. A reddish yellow clay forms the creek bottom and banks.

These clay banks, at places, almost close up the passage. Up to Sta. 8 (shown on map), about 500' from beginning of passage, the roof and sides are bare of stalactites of any considerable size. At Sta. 8 the passage is narrowed down by a mass of onyx, but it again widens into the bare passage beyond.

From Sta. 8 another passage leads to the right. This is also bare for several hundred feet. A big stalagmite at its mouth makes this passage inaccessible with an instrument.

From Sta. 8 to 14 no marked change occurs. In some places, where clay banks extends nearly to the roof, a stalagmitic coating forms on the clay and this is connected to the roof by a forest of small pillars. Sta 14 is near the bottom of the abandoned shaft, and here the first great change occurs. The passage widens out into a big chamber which must at one time have been well filled up with stalagtitic formations. Hugh blocks have been quarried from this chamber. Blocks of the quarried material lie scattered about in the debris at the bottom of the shaft.

To the north end of the shaft another passage full of stalactites leads in the direction of the left hand passage in the mouth of the cave.

This passage however soon narrows down, and it may be, that originally it connected with the left hand passage, but has since been filled up with the crystallized rock.

From Sta.14-15 the passage widens out and becomes much higher, being more like a continuous chamber now. The onyx is now seen on all sides in massive forms, and immense stalactites hang from the roof which is about thirty feet high. This seemingly massive character of the stone does not extend very far however, as at Sta. 16 another change manifests itself. In explanation of the phenomena to be described presently, we should state that the walls of the chamber between Sta. 14 - 16 are approximately vertical. The creek evidently had a much higher level at one time, and has gradually cut its way by solution and erosion down to its present level. Now if the walls are vertical, without any projecting ledges or shelves, it shows that the creek did not change its course while cutting from one level to another. The growth of the onyx deposits following the receding creek bed would not meet any obstruction in the shape of clay banks and consequently, having an undisturbed period of formation, a massive block would be produced. From Sta 16 on the creek in cutting from one level to another, did not keep in the same course but was deflected from one wall to the other. The result was that as soon as the stalagmitic shell had formed on the shore clay bank, the creek cut to a lower level, undermined the clay bank and left a shell of onyx projecting from the wall, not unlike an awning for a window.

This process was repeated in another position of the creek and again undermined. Successive levels of the creek bed are thus recorded by tier upon tier of umbrella shaped shells of onyx; each shell having long pendent ~~fingers~~ fringes of stalactites haigning at its outer edge, a scene wonderfully beautiful, but this very beauty being effected by a condition which renders the onyx valueless.

This shell like formation continues up to Sta. 19 where another change takes place. Beginning at this station the roof rock seems to change in its strength and tenacity. Great blocks of limestone which fell from the roof fill up the creek bed; ledges project from the sides and seem ready to break at any moment, while the creek forced to the wall by the fallen blocks is continually undermining new ledges. The roof at places where the limestone is broken away, seems to be of chert. The limestone itself is very silicious, and, where it has been exposed to the atmosphere, a sandy residue is left on the surface, due to the solution of cementing calcium carbonate.

Although onyx is found for some distance from this station, on the left side of the passage, none of it occurs of sufficient extent to be of any commercial value . The survey was therefore terminated at this station.

Quality of Onyx.

The color of this onyx is usually of a pure white to cream. Banding is not as common as in most onyx, but occasionally the stone is marked with rich reddish brown bands in concentric order, not unlike the structure of a tree stem.

It takes a high polish and has a brilliant lustre, but it has the coarse, crystalline structure peculiar to cave onyx, as compared to that of genuine travertine or spring onyx.

It is translucent but this is also inferior to that of most travertines.

Bottom of Shaft

Large sized pieces can often be obtained but these may not be solid throughout, but may have some interior cavity. It does not dress as easily as the finer grained spring onyx.

Uses.

It may be put to all the uses that the regular travertines are, but as it is deficient in color as compared with these, its use would probably be restricted to the less highly decorative wainscotings, small ornaments and certain forms of bas relief, in which line it would not be brought in competition with the high grade, colored travertines.

Mining.

History. The first work done on this mine was in the fall of 1892. A shaft was sunk to the chamber which showed the best deposit of onyx. It would have been cheaper to have built a road in the cave passage to the mouth of the cave, but as the owner of the mouth wanted an unreasonable price the project was given up.

Only one carload of onyx was shipped by this company, as it was found to be unworkable, owing to minute fissures along cleavage planes.

This may have been partly due to improper blasting. Attempts were then made to extract some of the more choice deposits in blocks of such size, that they could be used for massive architectural work. A few months were spent in trying to get out one of these blocks when this was ~~mined~~ ruined by a blast. The mine was then abandoned in disgust, the machinery removed and the buildings left to decay.

Mine. The shaft which was sunk by this company is about 7' X 10' section and must have involved about 100 feet of sinking, 8ft. soil and detritus, and 92' solid rock. The old workings were confined to one chamber.

Probably not more than a total of three or four carloads have been hoisted out of this mine, And most of this was left hear the shaft. Some blocks of solid onyx 4' X 4' X 6' could still be obtained from this chamber.

The next chamber to the south could also supply a few such pieces, but it is the passage to the north of the shaft which might develop into a large producer. This passage may have led to the mouth of the cave through Sta. C. originally, and if this is the case, a great amount of onyx may be obtained by reopening this passage by a tunnel and extracting the onyx with which the old passage has been filled. All subsequent recommendations in this report will be made with this object in view. The distance between Sta. C. and shaft has been accurately determined from the survey notes, and the estimates will be made for a tunnel in a straight line between the two points. This estimate would be for the worst possible case, for should the old passage deviate from this straight line, the increased amount of onyx found, would pay for the extra tunnelling.

Drainage and Pumps.

The creek in the passage keeps the workings sufficiently well drained, so that no pumps would be required, except possibly to obtain a supply of water from the creek for the boiler and for the water jacket of the air compressor.

This water is strongly impregnated with $CaCO_3$, but any water that could be obtained in the neighborhood, either from the river or wells would have the same objections. An ordinary lift and force pump could be use d to pump water into a storage tank of about 2500 gallons capacity.

A sump would have to be dug in the creek bed, and a pipe leading from it tp the pump chamber at bottom of shaft. The difference in elevation would not be over 15 ft., the horizontal distance about 25 ft. From the bottom of the shaft the line of pipe and pump rods can be placed in one of the corners and led up to the storage tank. The pump itself is attached to the head frame, and driven by the engine by a system of rods.

Ventilation.

The natural ventilation from the shaft to the mouth or vice versa, depending upon the season of year, is sufficient for all operations in the chambers, and the exhaust from the drill will afford ample ventilation for the working face of the tunnel.

Mode of Working.

The old company experienced great difficulty in obtaining large blocks free from small cracks and fissures along cleavage planes. This difficulty, partly due to injudicious blasting, might be overcome by quarrying smaller blocks, about 3' X 3' x 2', which would not require such heavy charges of explosives, and thus lessen this tendency to crack and shatter. These blocks would be sufficiently large for slabs of the cheaper onyx wainscotings, small ornaments, vases, columns, etc., and it is only in articles of this kind that cave onyx can be made to pay. Furniture tops and large wainscotting slabs, which would require large blocks, would have to be brought into competition with the high grade Mexican onyx, which easily crowds it out of the market.

Attempting to compete with the Mexican onyx in this line has probably been the cause of most of the many failures of cave onyx companies.

Experience alone can determine which is the best method of working this particular deposit, but it would probably be best to restrict the use of explosives as much as possible, and use plugs and feathers and other mechanical means for all blocks that can be obtained in this way.

Where explosives are necessary, a slow acting powder should be used. Light charges, lightly covered and often repeated are better than tightly tamped, heavy charges, as they have a splitting and not a shattering effect.

One Leyner Compressed Air Rock Drill, three inch cylinder, would be sufficient to drill all the holes necessary.

The drill holes should be along the line of fracture desired. The holes should be simultaneously exploded by electricity, all the exploders being connected in series.

As far as this is possible, the blasting should be done after the men go off shift in the evening.

Timbering.

That part of the shaft which is sunk through the overlying soil and wash, about 8' in all, should be timbered to prevent rock and dirt from falling down the shaft.

The timbering may be of the simplest kind; ordinary cribbing, built up log house fashion resting on the shelf of limestone; post oak saplings, about five inches in diameter, answer very well for this purpose and form a cheap and abundant local supply. The shaft in the solid limestone does not need timbering, nor do any of the tunnels in the passages below, as the country rock is sufficiently firm.

Roof and Floor.

The roof or hanging wall is perfectly safe as far as the strength of the overlying rock is concerned, but all stalactitic masses should be detached from the roofs of the passages, which are to be used, as the vibration of drilling may loosen them and make them a source of danger.

The floor in the natural passages is of clay, and too soft to make a good road bed but rubbish from quarrying and broken stalactites are available to make excellent ballast.

However, it would not be necessary to lay more than one hundred feet of track that would require ballasting.

Underground Tramming.

The maximum load to be hauled, would not exceed 6000 pounds including the car. A twenty pound rail would be sufficiently strong for this load.

Post oak ties five inch face, four inches deep about five and one half feet long spaced one and one-half feet apart center to center, should be used in this case.

As the track to be used would only be in short stretches in the neighborhood of the shaft, or in the straight tunnels, there would not be any sharp curves and there would not be any advantage in using the narrow gauge system, while the increased stability of the track, and greater steadiness of a stone truck or car would be a decided advantage, of a broad gauge of about 42". An ordinary flat topped truck or push car would be the best vehicle to convey onyx from the working face to the shaft. This truck with a maximum load can be easily pushed by two men. The grade should be about one percent, in favor of the load. This provides for an easy return haul of the empty truck.

The track should lead directly under the shaft, so that the blocks of onyx can be attached to the hoisting cable.

Hoisting.

The maximum weight that would be put on the hoisting cable would not exceed three tons, the ordinary working load being about twenty cubic feet of stone weighing 175 pounds per cubic foot, or 3500# in all. Using a factor of safety of five, this would require a five-eighth inch, cast steel, hemp center cable. A cable of this diameter should not be used on a drum and sheave of less than 2 1/4' diameter.

The frame work at the top of the shaft, for supporting the head sheave, can be made entirely of wood. The construction is shown in the drawing of the surface plant.

All dimensions for posts and beams have been calculated for hickory as this is the best available wood for this purpose. Two counter-balanced doors close up the shaft, while the onyx block hangs suspended just below the head sheave. A truck running on rails is then pushed on to the doors and under the block, which is then lowered onto the truck and wheeled direct to the wagons.

Dressing.

We recommend that the stone be shipped to the market as it comes from the quarry without any preparation, other than the removal of very acute angles and excessive projections from the general figure.

Surface Plant.

Power Plant. Air Compressor.

A 3" cylinder, rock drill requires about 130 cu. ft. free air per minute. To furnish this amount of air would require an air compressor of 9" diameter, 12" stroke and 150-175 revolutions per minute.

To isothermally compress one cubic foot free air to 80# gauge pressure requires .1325 Horse Power. For 130 cubic feet, 17.22 HP would be required. Allowing about 40% for friction, the power delivered to the compressor would have to be about 25HP. E.P. Allis makes a steam actuated air compressor of these dimensions, water jacketed to secure isothermal compression.

The air is transmitted to the mine by a 3" pipe, left by the old company. The loss of pressure in such a large pipe for the short distance is negligible.

Hoisting Machine.

To estimate the size of this engine the average load of 3500# (20 cu.ft.) is assumed to be raised 125' in one minute.

$$\frac{3500 \times 125}{33000} = 13.2 \text{ HP Theoretically required}$$

Allowing 50% for friction, a 20HP engine would answer our purpose. This engine is made complete with drum and gearing.

Boilers.

If the hoisting engine and the air compressor were working continually at full load we would require about a 60HP boiler, or about 25% excess of boiler capacity over engine capacity. But the hoisting engine would be used very little during the day for hoisting, and for operating the pump it would run at light load for part of the day. A 40HP boiler would then be sufficient for our purpose, as the compressor would be shut off for the short time needed for hoisting.

A tubular boiler would be the best kind to use, as it is less expensive than the water tube boiler, and on account of larger steam and water capacity, would be better able to withstand the violent fluctuations in load which occur in hoisting.

Shops.

A small blacksmith shop will be necessary for different kinds of repair work, but mainly for sharpening drills. A portable forge, anvil, hammer and drill sharpening tools would complete the simple equipment. A bench for carpenter work and a small chest of tools is all that is needed in this line.

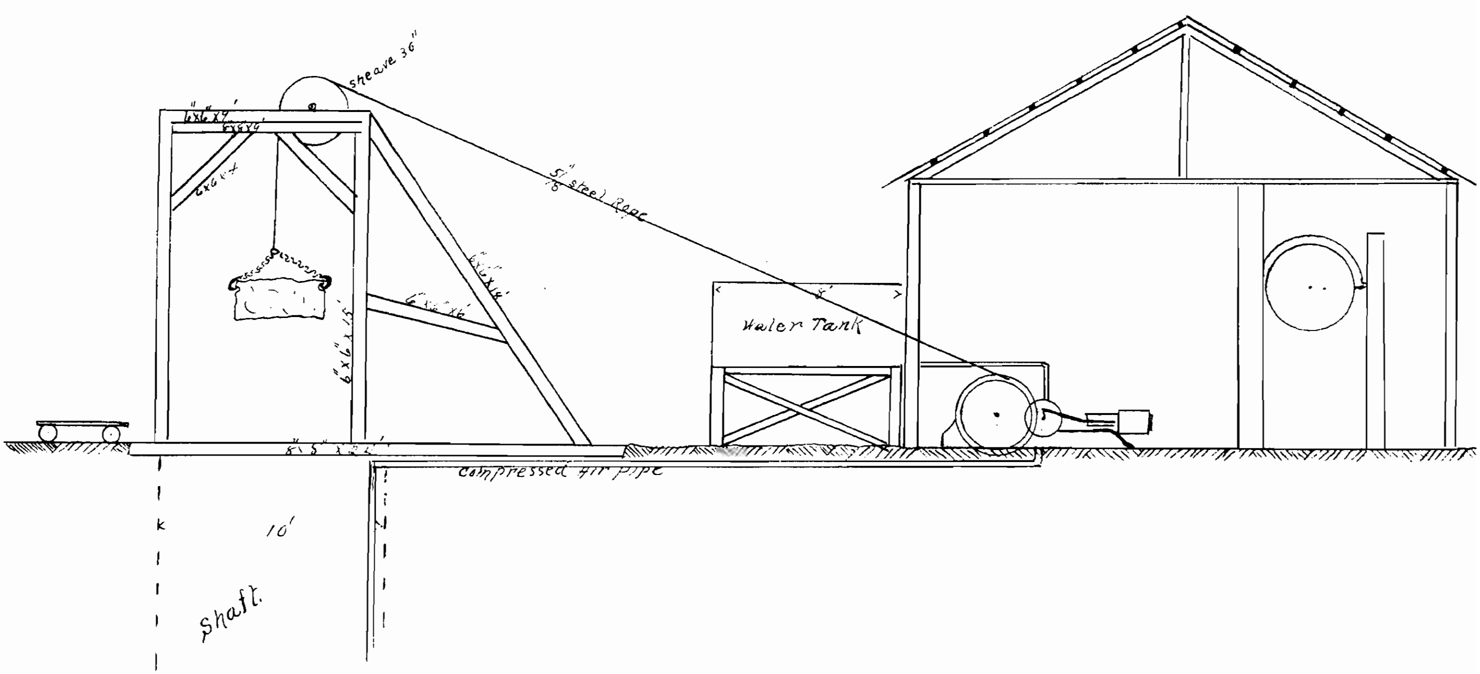
The blacksmith should be able to do all the simple blacksmith and carpenter work.

Buildings.

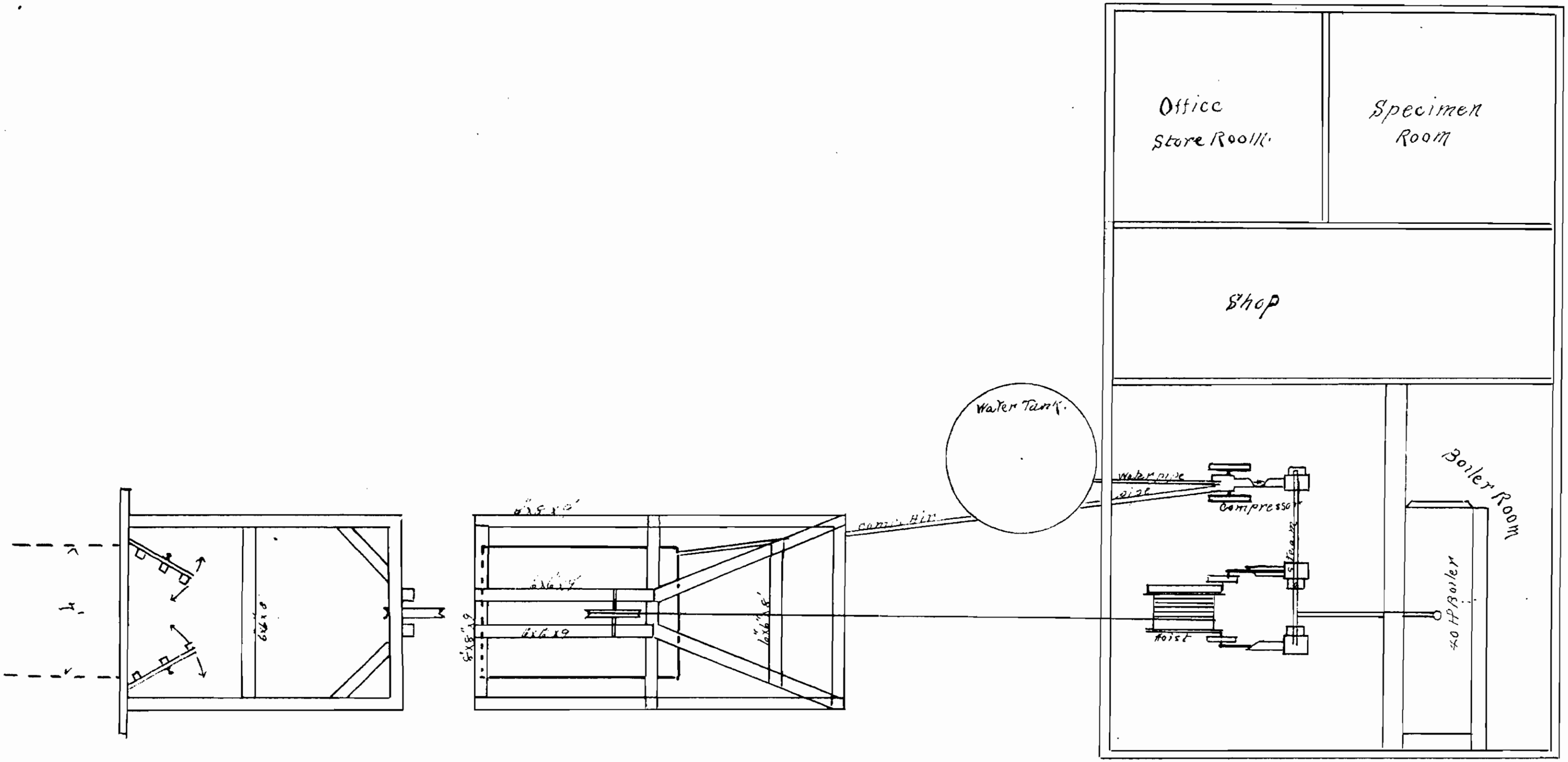
The buildings for the engine room, boiler room, blacksmith shop, office, etc. should be cheaply put up, as it is intended to serve only for the year or so that the plant will be in operation, and at the end of that time can be sold for old lumber only.

The arrangement of the rooms is shown in the drawing.

SURFACE PLANT



ELEVATION


Office
Store Room
Specimen
Room
Shop
Water Tank
Boiler Room
Compressor
Hoist
40 HP Boiler

PLAN

Disposition of product.

The nearest market for the quarried stone would be St . Louis. This city would possess especial advantages on account of the proposed World's Fair.

Not only in the class of buildings to be put up would there be many avenues open for its utilization, but also, in the innumerable knick knacks that can be made from it and which find ready sale at such places.

The nearest railroad station is Arlington, a distance of five miles. The wagon road to this point is in an extremely bad condition, and owing to the hilly and rocky country it could not be improved, except at considerable expense.

It would be best to have the hauling done by contract. A four horse team would probably be necessary to haul a 20 cu. ft. block to Arlington, and one team could make two trips daily.

Many of the farmers in the neighborhood would contract to do this hauling and load it on railroad cars for not more than $3.50 per trip.

A flat car, having a capacity of about 50000#(300 cu.ft.onyx) would cost about $40.00 from Arlington to St. Louis, making the freight charges about $.14 per cu. ft.

Statistics.

Production.

The capacity of a mine of this kind cannot be closely estimated as there are no data available for work carried on under similar conditions.

The daily production however would not be likely to exceed one 20 cu. ft. block per day. Working 10 hours per day for 30 days, a month, the monthly production would approximate 600 cu. ft. This low production is due to the extreme care with which the material must be mined, and also to the fact that is must be taken out of a tunnel, instead of an open quarry.

Labor.

As drilling would not be carried on at more than one face at any time, the number of laborers required would be small. A drill man and his helper and one man doing miscellaneous work about the mine are all that would be required below.

The surface men should consist of an engineer, a blacksmith who should also be a fair carpenter, as he would not be kept busy in either capacity, and an extra man for tramming, loading, etc., who could assist underground when not needed at the surface.

A foreman having some experience in this kind of work, should be put in charge, to direct all the work and keep all the accounts.

The daily account for labor would be

One drill man		$2.
Three laborers	at $1.50	4.50
One engineer		2.00
One blacksmith		2.00
One foreman		4.00
Total daily wages		$14.50

Monthly Expenses.

Labor at 14.50 per day	$435.00
Fuel, 1 1/4 cords per day at $2.00	75.00
3 kegs powder, including freight at $3.00	9.00
Oil, illuminating and lubricating	3.00
Contractors hauling, 30 trips at $3.50	105.00
Freight, 2 cars at $40.00	80.00
Miscellaneous running expenses	10.00
Total monthly expenses	$717.00
Total running expenses for year	8604.00
Interest on the sum for the year at 6% calculated for each month to end of year	118.30
Total including interest.	$8722.30

Cost of Plant.

Timber in place for shaft, upper 8'	10.00
" " " " head frame.	15.00
" for 150 sleepers	5.00
Miscellaneous mining tools	5.00
200' of 1" pipe at 5 1/2 ¢	11.00
Fittings for 1" pipe	4.50
" for abandoned 3" pipe, (left by old company)	24.60
Pump and rods	20.00
1 40 HP boiler including injector and fittings	450.00
1 20 HP hoisting engine and drum	1400.00
1 25 HP. air compressor	700.00
Connection for air compressor	25.00
Steel air receiver	75.00
1 3" cylinder, rock drill, complete mounted	285.00
50' wire wound air hose	28.00
Building for engine house and shop	250.00
Blacksmith shop equipment	60.00
Carpenter tools	25.00
170 ft. of cast steel, wire rope at 17¢	28.90
Sheave and Bearings	27.00
Grapple hooks and chain	5.00
500' of 20# rails at 4 ¢	134.00
2 trucks	90.00
Total freight and drayage	250.00
Miscellaneous	200.00
Total	$4128.00

Total cost of plant	$4128.00
Interest at 6 %	247.70
Total including interest	4375.70
Total running expenses	8722.30
Total expenditure for year including interest	$13098.00

Conclusion.

Merits of Property.

Deposits of Value.

The quality of the stone has been described under Geology.

The quantity in sight is limited to about 1000 cu. ft. in the chambers near the shaft. Some large blocks could be obtained, and quite a number of smaller ones, that would be valuable on account of their banding. If the shaft chamber was originally connected with the mouth through Sta. C which is not unlikely, and judging from the dimensions of the present passages, this passage would probably have been at least 40 sq. ft. in cross sectional area.

The shortest possible length of the passage could not be less than 200', and probably it was much longer.

A tunnel 200' long, 6' X 6', if in solid onyx would contain 7200 cubic feet.

As there are no other promising prospects in sight, it would not be at all safe to count on striking any greater quantity. Mining 20 cubic feet a day these deposits would be exhausted in little more than a year.

We will therefore assume that the mine be worked for one year only and at the end of that time, the machinery, equipment, lumber of buildings, tracks, etc., be sold for some fraction of the first cost. 30% of original value could probably be realized.

Total running expenses for the year, including int.	= $8722.30
" cost of plant, including interest	4375.70
" expense at end of year	13098.00
Selling machinery, equipment, etc. at end of year for 30% of original value	= 1238.40
Net cost of the campaign	$11860.60

20 cubic feet per day for 1 year = 7200 cu. ft.

Cost of 1 cubic foot of onyx F.O.B. St. Louis = $1.65.

Advice.

The price of onyx varies from 50¢ to $50. per cu. ft. Good specimens from this cave may bring $5 to $10 per cubic foot, while some of it would probably have to be sold for 50¢. Submitting sample pieces, from blocks left on the surface by the old company, to some jobber, may elicit some information as to what the average price per cubic foot would be.

But even if a satisfactory price can be obtained, we would not advise building a plant, without making further investigation.

These cave marbles are often very deceptive. The deposit may be a mere veneering over the face of the rock, and although there is apparently an abundance, judging from appearance alone, the actual amount of available stone may be very small.

It would be well to equip two men with the necessary hand tools and powder, and set them to work exposing all these doubtful faces. Especially should this be done at the terminals of the proposed tunnel.

If sufficient extent and continuity of the deposit is thus shown, and if your business manager is assured of an average price, allowing a wide margin above the $1.65 cost per cubic foot; the erection of a plant along the lines suggested in this report would probably be a paying venture.

It should be borne in mind however, that there is a great element of uncertainty in working deposits of this kind, as they are rarely uniform for any great distance either in texture or in color, and the enterprise necessarily partakes of the nature of a lottery.

Respectfully submitted by the

Examining Engineers.

I.J.Stauber

F.R.Koeberlin.

Underground Traverse Notes. Right Hand Passage.

Sta	Az.	Dis	+X	−X	+Y	−Y	ΣX	Σy
1								
	109° 36'	209.86	197.70			70.40		
2							+197.70	−70.40
	164° 44'	61.45	16.18			59.28		
3							+213.88	−129.68
	130° 52'	87.76	66.37			57.42		
4							+280.25	−187.10
	86° 4'	109.56	109.30		7.51			
5							+389.55	−179.59
	115° 53'	81.37	73.20			35.52		
6							+462.75	−215.11
	100° 8'	52.66	51.84			9.25		
7							+514.59	−224.36
	167° 6'	33.02	7.37			32.19		
8							+521.96	−256.55
	39° 50'	84.76	54.29		65.09			
9							+576.25	−191.46
	11° 54'	90.08	18.58		88.14			
							+594.83	−103.32
10								
	76° 17'	47.55	46.19		11.28			
11							+641.02	−92.04
	332° 7'	67.41		31.53	59.58			
12							609.49	−32.46
	344° 36'	38.37		10.19	36.99			

Sta	Az	Dis	+X	−x	+y	−y	ΣX	Σy
13							+599.30	+4.53
	285°11'	84.76		81.80	22.20			
14							+517.50	+26.73.
	330°48'	38.83		18.94	33.90			
(shaft)S							+498.56	+60.63
14							+517.50	+26.73
	51°.25'	54.25	42.41		33.83			
15							+559.91	+60.56
	88°25'	83.79	83.76		2.32			
16							+643.67	+62.88
	43°.22'	42.40	29.11		30.82			
17							+672.78	+93.70
	91°.54'	53.70	53.67		~~1.78~~	1.78		
18							+726.45	+91.92
	69°8'	162.99	152.30		58.06			
19							+878.75	+149.98

Left Hand Passage Traverse Notes.

Sta	Az	Dis	+X	+Y	ΣX	Σy
2					+197.70	−70.40
	28°.21'	48.40	22.98	42.60		
A					+220.68	−27.80
	53°.47'	65.11	52.53	38.47		
B					+273.21	+10.67
	49°12'	31.13	23.56	20.34		
C					+296.77	+31.01

Surface Traverse Notes.

Sta	Az	Dis	+X	−X	+Y	−Y	Σx	Σy
1							00	00
	317°14'	83.55		−56.73	+61.34			
2'							−56.73	+61.34
	99°51'	208.55		+205.47		−35.68		
3'							+148.74	+25.66
	85°39'	341.68		+340.70		+25.92		
4'							+489.44	+51.58
	44°39'	12.85		+9.14		+9.14		
5'							+498.58	+60.72

Surface, Σx to Sta 5' 498.58 Σy = 60.72

Underground, Σx to Sta S. 498.56 Σy = 60.63

.02 .09

Azimuth and Length of Tunnel.

Σx at Sta S +498.56 Σy = +60.63

Σx at Sta. C. +296.77 Σy = +31.01

+201.79 +29.62

Length of Tunnel = $\sqrt{(201.79)^2 + (29.62)^2}$ = 204.96'

Tan $\theta = \frac{29.62}{201.79}$ = .14678, θ = 8° 21'

Az. from Sta. S to Sta. C = 270° − θ = 261° 39'

Topography of Cave Mouth from Sta.A.

R. R.	Ver ∠	Az	Hor. Dis	Ver. Dis.	Elev.
Sta.A					873.
42	+13°–	67°14'	39.8	+9.2	882
60	+14°30'	32°6'	56.2	+14.5	887
42	–2°10'	224°34'	41.9	–1.6	871
150	–4°14'	236°50'	149.2	–11.1	862
100	–3°40'	253°.16'	99.6	–6.38	867
110	–3°4'	275°.19'	109.6	–5.8	867
120	–0°.18'	282°4'	120.0	–0.6	872.
145	–4°–	278°13'	144.2	–10.0	863
135	–2°33'	278°56'	134.7	–6.0	867
120	–2°10	256°50'	119.7	–4.5	868
100	–3°11'	245°21'	99.6	–5.5	867
110	+2°30'	243°15'	109.7	+4.7	878
130	+0°.34'	245°34'	129.9	+1.3	874.
175	+4°17'	264°27'	173.9	+12.9	886
170	+3°38'	273°12'	169.3	+10.7	874
176	+2°46'	279°31'	175.6	+8.4	881
200	+3°50'	278°8'	199.1	+13.3	886
200	+5°15'	264°36'	198.2	+18.3	891
200	+5°41'	255°5'	198.0	+19.7	893
240	+6°51'	257°29'	236.6	+28.3	901
230	+6°53'	261°36'	226.7	+27.3	900
200	+7°18'	264°51'	198.7	+25.2	898
230	+6°13'	272°12'	227.2	+24.7	898
240	+6°.34'	278°41	236.8	+27.2	900

Surface Level Notes from Sta. 5' to Sta. 1.

Sta	B.S.	H.I.	F.S.	Elev.	
B.M.				1000	+ mark on large rock near
	00	1000			top of shaft
5'			4.27	995.73	Level of top of shaft.
		1000			
			11.735	988.26	
	2.07	990.33			
			10.42	979.91	
	0.44	980.35			
			11.49	968.86	
	0.47	969.33			
			11.66	957.67	
	0.35	958.02			
			11.30	946.72	
	0.49	947.21			
			11.81	935.40	
	0.54	935.94			
			11.99	923.95	
	1.10	925.05			
			26.56	898.49	Took reading on tape
	4.47	902.96			over bluff
			2.36	900.60	

Underground Level Notes from Sta. 1 to Sta S (shaft).

Sta	B.S.	H.I.	F.S.	Elev.
1.				900.60
		902.96		
			10.92	892.04
	1.78	893.82		
			10.78	883.04
	0.50	883.54		
			9.60	873.94
	0.19	874.13		
			5.60	868.53
	4.05	872.58		
			3.64	868.94
	3.26	872.20		
			3.53	868.67
	6.09	874.76		
			2.71	872.05
	2.75	874.80		
			6.64	868.16
	6.24	874.40		
			5.58	868.82
	4.96	873.78		
			0.79	872.99
	11.39	884.38		
			0.90	883.48
	9.26	892.74		
Shaft)S			0.00	892.74

Depth of shaft between Sta.5' and Sta.S. =102.99 by level. This was checked by measuring a plumb line between these 2 Sta which measured 103.60