SOME PROBLEMS CONNECTED WITH DEEP MINING IN THE LAKE SUPERIOR COPPER DISTRICT

THE copper mines of the Lake Superior district are essentially low grade. Their profitable operation is made possible by the great extent of the lodes, their comparative uniformity of character and the investment of great sums of money to maintain operations on a vast scale over a long period of years.

With but one important exception, the lodes are the vesicular tops of ancient lava flows which subsequent to solidification have had the cavities wholly or partly filled by the deposition of various minerals, among which is native copper. They dip at angles varying from 38° to 70°.

The modern shafts through which the rock is hoisted are either inclined, following the plane of the lode, or are vertical. The inclined shafts are of dimensions such as to provide for two railroads of approximately standard gauge on which run the 'skips' which are operated in balance. In addition there is room for the ladder way and air pipes, usually placed at one side. The vertical shafts have compartments providing usually for 'cages' and pipe and ladder way. Several of the inclined shafts are over 5,000 feet long. One has a length of 8,100 feet. Of the vertical shafts the three deepest are, respectively, about 5,200, 5,000 and 4,900 feet deep.

Long before such depths were actually reached there arose the question as to a possible limit set by the ultimate crushing strength of the rock which is penetrated. Manifestly, mining can not go to a depth such that the weight on walls of drifts and stopes will exceed the ultimate strength of the material of which they are composed. There is a widespread impression that the lake mines are approaching such a limit. There are current statements to the effect that pieces of rock occasionally snap off the rock faces because of the great strain, and are violently projected as if propelled by an explosive.

In this connection a few figures will be of interest. The average density of the rock of the copper-bearing series is not far from 2.87, that is, a cubic foot weighs about 179.3 pounds. Therefore, a horizontal square foot of area at 5,000 feet from the surface has above it a column of rock weighing 448 tons. The ultimate crushing strength of the average rock is not well known, but since it is mostly trap this may be safely assumed as at least 1,200 tons per square foot. If, therefore, the square foot above defined carries the entire column above it, it is loaded to much less than half the crushing strength and only at nearly three times the assumed depth will the load reach its crushing limit. At a dip of 38°, the pressure normal to the plane of the lode at 5,000 feet from surface is only 354 tons per square foot. It is in this direction that the crushing forces are mostly called into play. As the dip increases this normal pressure of course diminishes. At 52° it is 278 tons, and at 70° it is 152 tons per square foot.

However, the matter does not end here. The removal of large portions of the copper zone leaves considerable areas of the roof or hanging wall to be supported by the pillars which are left for the purpose, or by the walls of the opening, or by both. The weight on pillars and walls is thus increased and may easily approach the crushing limit. Take, for example, a long pillar 50 feet wide having on either side an open space of 150 feet. Suppose it in a lode dipping 38°. Allowing for neither rigidity nor arching, and supposing the weight on the pillar evenly distributed, at 5,000 feet deep it would be subjected to a pressure of 1,239 tons per square foot, a pressure under which it would fail.

As a matter of fact, in such a case the rigidity of the rock mass distributes a large part of the load out over the rock beyond the walls of the opening. That this rigidity may be considerable is illustrated in several cases where areas of hanging as wide as 200 feet or more have no support between walls, and yet have stood up for several years. They are not, however, at maximum depth.

In such an area a pillar when first cut out may have to carry but little more than its previous load. As the hanging wall slowly bends the pillar must take up more and more of the extra weight. This is not applied uniformly. As the rock between pillars and walls bends downward the tendency is to concentrate the load at the edge or face of the pillar, or wall, much as a beam does when supported in like manner. The outer parts of the pillar may thus become overloaded and here it will fail.

It does so by the splitting off of pieces of rock much as may sometimes be observed with a specimen in the testing machine, though on a much greater scale. These pieces break from the base as well as the top, and, as a rule, like any hard rock under a crushing load, the pillar fails suddenly. Small pieces of rock may fly to a considerable distance, and such occurrences have undoubtedly given rise to the above-mentioned exaggerated impression of the compressive stress to which the rock is subjected in the lowest levels.

The hanging rock mass moves, of course, when the pillar crushes, and the vibration due to the sudden though slight displacement is often conveyed to the surface. The result is a miniature but perfectly genuine earthquake which may be felt over a distance several times that of the pillar from the surface. With the crushing of the pillar and the movement of the hanging a readjustment of the weight takes place, and the process begins over again. Instead of the process being repeated exactly it is possible for the hanging to break in such a manner that the arching effect may protect this pillar, and place the load on others. Eventually, at great depths the hanging and foot must come together, and in one mine the final steps in the process came so rapidly as to completely wreck it.

The pressure normal to the plane of the lode is not the only action which may appear. The pillars are not, as a rule, separate from either foot or hanging. They are parts of the same rock mass, and it is not possible for the hanging to slide over the pillar. In consequence the readjustments which take place when a pillar fails as above described sometimes put an enormous longitudinal thrust on the foot, and in places its surface portion has buckled up under such stress. Also, at points where shaft pillars have been weak, shafts have been pinched and twisted under the same conditions so as to interfere with their operation.

Experience seems to have shown that at the great depths recently reached it is useless to expect to hold up the hanging rock mass for a long time by any scheme of pillars unless far too much of the lode is left in place, and that the only feasible method is to cut away the entire lode and permit the hanging to cave as rapidly as it will to the point where the broken rock fills again the whole space, and redistributes the weight over the footwall. Following this plan, cutting out the lode, or 'stoping,' begins at the point furthest from the shaft, and progresses toward it. With a wide shaft pillar, or with the shaft in the footwall, and with some such general method which avoids concentration of pressure where it can do harm, there seems no reason to anticipate serious difficulties due to crushing for a further depth at least as great as that already attained.

The difficulties of surveying the mine are not markedly increased by depth, except in the case of vertical shafts. When these are deep, and it becomes necessary to carry down an azimuth from the surface by means of two plumb lines hung in the shaft, there is presented a problem of considerable difficulty. It is almost impossible to free the lines entirely from disturbing influences which displace them from their normal positions. If either lines or plumb bobs are of magnetic material the presence of iron pipes in the shaft may result in seriously disturbing them. Falling water may be in such quantity and so directed as also to affect the position of the lines.

However, the air currents, which can not be wholly eliminated, whatever the precautions taken, are the most serious cause of disturbance. The temperature at the bottom of the shaft is higher than that at the top, and in consequence convection currents are formed. The heat supplied from the surrounding rock keeps them up. Indeed, with moderately steady temperature at the surface, and with the shaft idle, a remarkably stable condition of these air currents may come about. Elsewhere observations have been published by the writer,[1] showing that their effect on a plumb line may remain sensibly constant for hours at a time while deflecting the line from its vertical position. The stability of the currents is made possible by the large cross section of the vertical shafts, 10 feet by 22 feet to 10 feet by 30 feet outside of timbers, thus giving a large air body, and the constancy of the rock temperatures, and the supply of heat through the shaft walls. When we take account of the fact that a force equivalent to a horizontal pressure of 10 grains on a 60-pound plumb-bob suspended by a line 4,000 feet long will displace the bob one tenth of a foot from its normal position, it is easy to see how apparently slight causes may produce appreciable error in azimuth.

General attention was first attracted to this problem by the very noticeable divergence of two long plumb lines hung in shaft number five of the Tamarack mine. Of course, divergence alone would not affect azimuth, but the question confronting the surveyor is whether the divergence may not be due to some cause which may also displace one or both of the lines in a direction perpendicular to their plane. In the case mentioned it required a great deal of investigation and experiment to fasten the responsibility on the currents of air.

It is remarkable how many persons are ready to accept as an explanation of such divergence the statement that there is an excess of gravitation on each bob horizontally toward the end wall nearest to which it hangs. All are familiar with the picture in the text-books of the plumb line hanging near the face of a precipice being deflected from the vertical by the attraction of the mountain mass. The idea so strikingly conveyed by this picture while qualitatively correct seems in most minds to be quantitatively wrong. There is an excess of attraction on the bobs as stated, but its amount is far too insignificant to account for any observed divergence. At Tamarack number five it could account for no more than one one-thousandth of a foot. The convergence of vertical lines in that instance is over three times this amount.

The fact remains that the surveyor who must thus transfer an azimuth from the surface down a very deep shaft has a problem the proper handling of which must involve a careful study of the local conditions, particularly in regard to air circulation.

Increased depth tends to lessen the output of a given shaft, and in the effort to prevent this, and also to reduce hoisting

[1] See *Engineering and Mining Journal*, April 26, 1902, also *Electrical World*, April 26, 1902.

charges, loads have grown larger, likewise the speed at which they are hoisted. Loads of nearly seven tons are being raised on some of the inclines at speeds up to 40 miles per hour.

A considerable item in the hoisting charges is the cost of maintenance of the skip road, the expense per ton for this purpose increasing with the length of the shaft. The usual skip road is carried on heavy timbers which are placed transversely along the foot, and support large stringers to which the rails are spiked. The expense of maintenance of this road for great depths is such that some of the mines are substituting for it a road consisting of a rail attached to a concrete stringer which is borne directly on the rock of the footwall.

The stringer proper is about 13½ inches wide by 14 inches high. Beneath it and supporting it is a mass of concrete 16 inches to 18 inches wide extending to the rock. The depth of this supporting mass varies considerably, depending on the irregularities of the rock face to which it is attached. It ranges all the way from 4 inches to 2½ feet, and there is no reason why these limits might not occasionally be exceeded. The stringer and supporting mass are structurally one piece, being molded together. The stringer portion is reinforced by means of a 1⅛-inch steel cable passing longitudinally through its interior. The rail is attached by bolts which are spaced three feet apart, and hold it by means of clips which grasp the rail flange. The bolts pass through the stringer into a rectangular opening about three by four inches in section, which passes quite through the concrete, and affords access to the lower end of the bolt.

In building the road a form of plank is constructed having the cross section of the stringer, and a length of 15 feet. To its lower side are nailed the cores for the bolt openings just mentioned. The top is left open. From one to three of these forms are supported in place underground by suitable means, and to the sides are nailed boards extending downward to the rock. These make the form for the supporting part underneath the stringer proper. When all is firmly secured the rock face is thorougly washed, and the concrete is filled in, beginning at the lower end. The mixture used is one part Portland cement, three of sand and five of crushed rock, and it is tightly rammed in place. As the filling proceeds the top of the form, or the cover, is completed by nailing on short pieces of plank. In the roads which have been built at a slope of 70° the structure is anchored to the footwall by heavy bolts spaced 8 feet apart. When the concrete has hardened sufficiently the form is removed and the rail is bolted in place. The road is then complete.

The first of these roads has been operating some three years, and has proved so satisfactory that the others have followed. Expectation regarding cost of maintenance has been fully realized, and, in addition, it has been found that the original cost of the road is less than that of wooden construction. Its disadvantages seem to be confined to the fact that, due to the unyielding nature of the support, the effect of a blow must be absorbed between wheels and rail, resulting in a perceptibly greater deterioration of both. However, this is far more than compensated by the decreased cost in other directions and the fireproof character of the road.

In the effort to counteract the increased costs due to great depth the economical generation, distribution and use of power have naturally received large attention. The long period of operation necessary makes it worth while to expend large amounts of money in installing machinery of large capacity and high economy. The extreme in the direction of high-duty engines is represented at present in the Nordberg quadruple expansion, two-stage air compressor operating at the Champion mine. The engine is equipped with Nordberg's regenerative feed water heating system. It holds the world's record for minimum consumption of heat per foot-pound of work delivered, having shown a duty of 195,000,000 foot-pounds, being about 9 per cent. in advance of its nearest competitor.[2]

But one mine is so situated to be able to make use of water power. The Victoria, located near the Ontonagon River, has a considerable water power available which has been utilized in a novel manner. Distance from source to points of application is not great and the power for both mine and mill is distributed by compressed air. Moreover, the falling water operates directly on the air without the intervention of water-wheel or other machine.

Roughly speaking, this 'hydraulic air compressor' consists of a large underground chamber cut from the solid rock and having a length of 281.5 feet, a width of 18 feet and a depth of 26 feet. In normal operation the lower portion of the chamber is filled with water to a level of 14.5 feet from its roof. The remainder, having a capacity of over 80,000 cubic feet, is filled with air at 114 pounds gauge. The water outlet is through a tunnel 18 feet wide and 10 feet high, the bottom of the tunnel being a continuation of the horizontal floor of the chamber. This tunnel opens into an inclined shaft about 18 by 20 feet in cross-section, the discharge level of which is 271 feet above the water level in the chamber. The outlet for air is a 24-inch pipe leaving the chamber through the roof directly above the tunnel outlet.

[2] See description and report of test in paper on 'A High Duty Air Compressor,' by Professor O. P. Hood, *Transactions American Society of Mechanical Engineers*, 1906.

The inlet for both water and air is through three vertical shafts, each 5 feet in interior diameter, opening through the roof of the chamber at the end opposite to the outlets. Each shaft is tightly lined with concrete, and is continued down into the chamber by means of a somewhat flaring steel casing to a distance of about 15 inches below the water level. Just beneath, and reaching somewhat into the opening of the casing, is a conical boss of concrete. From water level in chamber through the air- and water-tight shaft to the water level at the intake above is 343 feet. This is 72 feet greater than the distance between the water levels at the outlet end, and this difference expresses the available head of water.

At the intake water is admitted through an annular funnel over a hollow ring from the flat inner periphery of which project 1,800 three eighth-inch tubes into the annular opening of the funnel. The water must flow over the mouths of these tubes, and in doing so it produces the aspirating effect which entrains the air in small bubbles. The air comes mainly through the tubes from the hollow ring which has suitable intake pipes extending above the water level. The mixed water and air fall through the vertical shaft, and are discharged radially from the annular outlet formed by the concrete boss and steel casing below. The current through the chamber is slow, and the air disengages itself, collecting in the top of the chamber, and displacing the water. By its pressure on the water surface in the chamber it maintains the 271 feet of difference in level between that surface and the one at the discharge of the outlet shaft.

While running at less than full capacity the water level in the chamber is prevented from being depressed further than 14.5 feet from the roof by means of a blowoff pipe, 12 inches in diameter, which opens somewhat below the normal water level. When the water has been pushed down sufficiently air enters this pipe, and its escape relieves the excess of pressure. When the blowoff is in operation the appearance at its mouth greatly resembles the eruption of a powerful geyser. The stream of spray, due to the entrance of water with the air from the chamber, is thrown sometimes to a height of 400 feet.

The capacity when all intake shafts are operating is about 5,000 horse power. So far but one intake is used. This under test at near its maximum capacity showed an efficiency of better than 82 per cent. while delivering 11,930 cubic feet of air per minute at 128 pounds absolute pressure.

All machinery at the stamp mill and at the mine, whether on the surface or underground, is operated by compressed air. Beside utilizing cheap power the compressor has obvious advantages over the usual machine in the absence of parts to get out of order and in low cost of attendance.[3]

The foregoing examples are presented to Section D as illustrating the type of problems which are arising in connection with the extensive operations at great depths on the low-grade lodes of the Lake Superior copper district.

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WHY HAS THE DOCTRINE OF LAISSEZ FAIRE BEEN ABANDONED?[1]

Perhaps the most remarkable change which economic opinion has undergone during the last fifty years has been the change from the extreme *laissez faire* doctrines of the classical economists to the modern doctrines of governmental regulation and social control. And yet there has been very little attempt to explain why *laissez faire* has been so generally abandoned. Its abandonment has been gradual and almost unconscious, not so much the result of any rival abstract doctrine, as the cumulative effect of experience, which in hundreds of individual cases has brought men face to face with the practical limitations of the let-alone policy. The movement is fast bringing us back to the old view by virtue of which economics was first named *political* economy.

The revival of governmental activity in economic affairs is due to causes which are partly political and partly economic. This paper has to do chiefly with the economic causes and we shall, therefore, merely note in passing the chief political aspects of the problem. One reason for the extension of governmental control of industry is the growing strength of governmental control in general and of popular confidence in it. *Laissez faire* was a natural doctrine in a time when governments were weak and inefficient. Change of power has brought change of the theory of power. Compulsory workmen's insurance we find in the strongly developed German Empire; railway rate regulation follows increased power and centralization of government. It may even be said that much of the modern government regulation of industry resulted from the attempt of governments to extend its powers in self-defense. It has been felt, for instance, that if the government did not control the railroads, the railroads would control the government. Government regulation here has taken on the aspect of a struggle for supremacy. Just as England feels the

[3] See description by A. L. Carnahan in the *Mining World* of August 25, 1906, and by C. H. Taylor in *Mining and Scientific Press*, August 18, 1906.

[1] Address of the vice-president before Section I.—Social and Economic Science—at the New York meeting of the American Association for the Advancement of Science.