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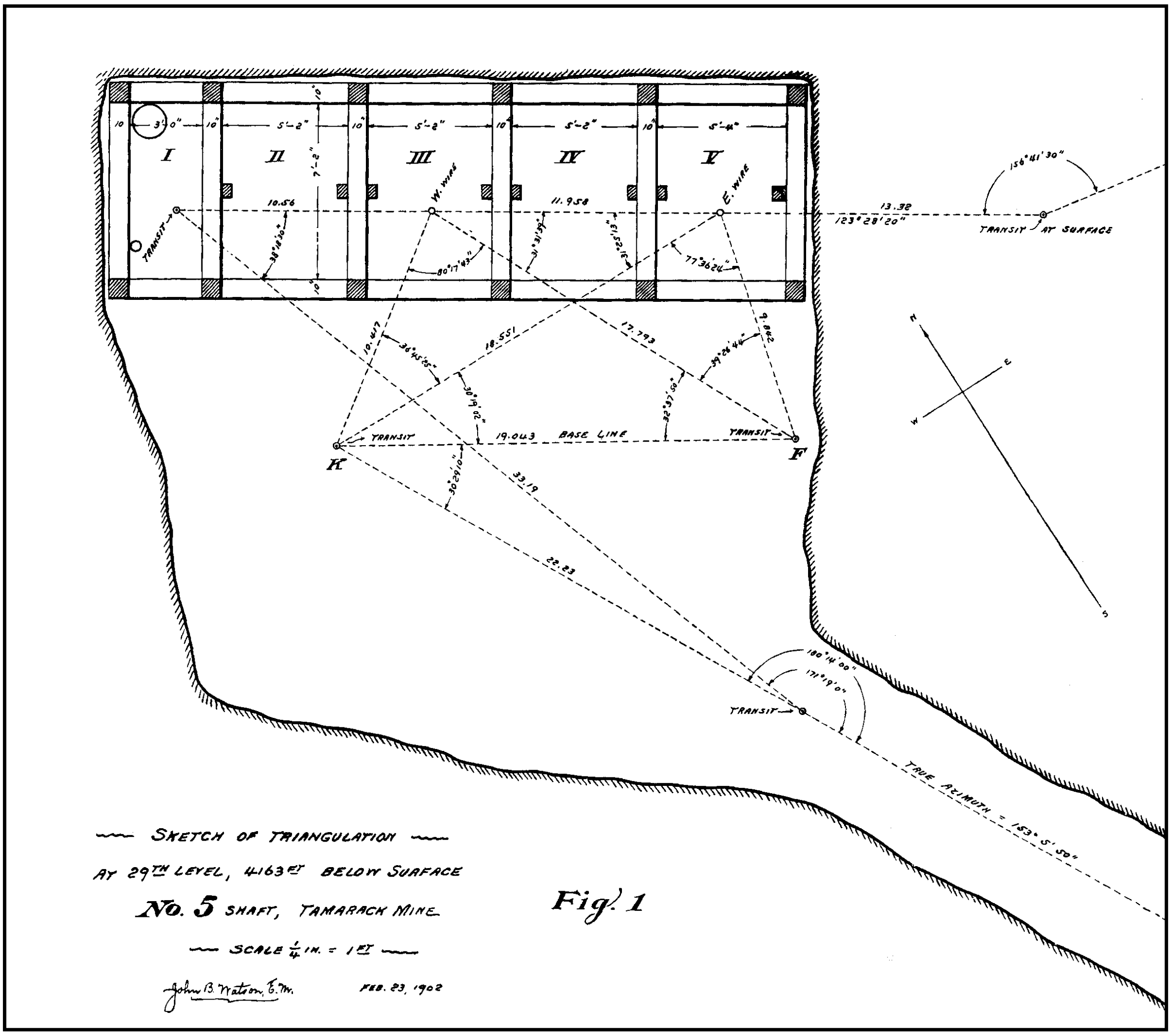
THE DIVERGENCE OF LONG PLUMB LINES AT THE TAMARACK MINE

By Prof. F. W. McNair, Michigan College of Mines.

In September last it was my fortune to be present together with Professor James Fisher of the College of Mines at a “plumbing” of No. 5 Shaft of the Tamarack Mine. The plumbing was under the direction of Mr. J. B. Watson, the chief engineer for the Tamarack Mining Company.

The method employed was the well known one of transferring an azimuth from surface to some underground level by means of two plumb lines hung in the shaft. The remarkable feature lay in that the depth of the chosen level, and, consequently, the length of the lines was greater than in any previously recorded instance. The lines as hung were 4,250 feet in length; they were of No. 24 piano wire, and the bobs were of cast iron weighing 50 pounds each. The latter were swung in pails of cylinder oil for damping the vibrations. Great care was taken that the lines should be free, and that they should be protected at the bottom from dropping water, of which, indeed, there is not a great deal in the shaft. No attempt was made to completely stop vibration. Scales were erected behind each wire, and its mean position determined by observing the extent of the swing. When the wires had settled into a state as near quiescence as it was expected they would reach, a check measurement was taken between them at surface, and between their lower extremities at the 29th level. The upper measurement was 16.32 feet, that below 16.43 feet, showing a divergence of the lines to the amount of 0.11 feet. As the west wire, which had been lowered in the center of the shaft compartment in which it hung, and had been moved to the east until it was about half a foot from the dividers between that and the next compartment, it was inferred that some projecting object might be interfering with its freedom. A careful exploration of the shaft, occupying between two and three hours, revealed no such interference. To make certain, however, this west wire was moved westward toward the center of the compartment 1.26 feet. When all was quiet again, measurements as before were taken, showing a distance at surface of 17.58 feet, and at the 29th level of 17.65 feet, there being yet a divergence of 0.07 foot.

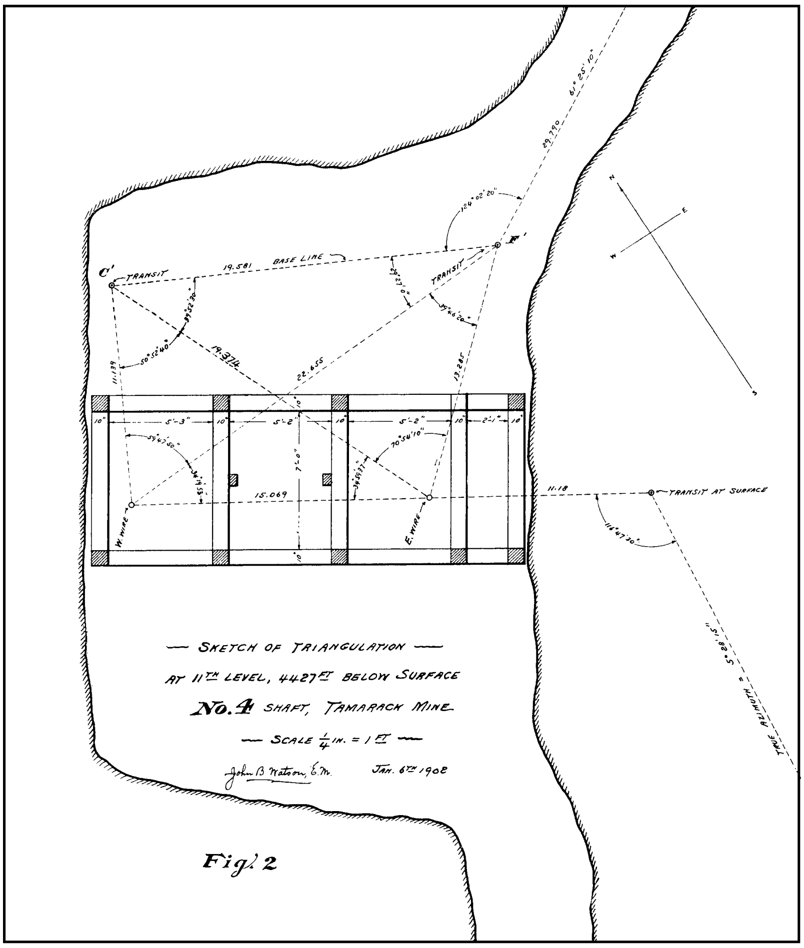


PLUMBING DEEP SHAFTS IN THE TAMARACK MINE.

Possible causes were at once freely discussed among those who were present. Gravitation being suggested, I drew attention to Newton’s theorem of the attraction on a mass within a closed spherical shell, adding that the same must be true in a tube of great length. I was inclined to explain the divergence on the theory that the air pipes in the west end of the shaft (of which there are two, a 16-inch in the northwest corner and a 4-inch one near the southwest corner) were acting as magnets, and, because of its proximity, were attracting the bob on the west wire out of its normal position. The distance from the west bob to these pipes was something like 7 feet. The east bob being 24 or 25 feet away would of course be affected to a much less degree. The behavior of the west wire seemed to confirm such a theory. There was considerable torsional vibration in both wires, and it seemed that a slight horizontal polarity in the est bob, which would at times coincide with, and at others oppose the field created by the pipes, might account for the observed irregularity in the vibration of this wire when compared with the vibration of that hanging in the east compartment. The latter remained remarkably steady throughout the entire time it was under observation. Under the circumstances I advised the use of lead bobs in a plumbing of No. 2 shaft, which took place about a week after that at No. 5. I did not advise a change to wire of non-magnetic material for it did not appear to me that polarity in the wire, which would of course exist, could develop sufficient force to bring about the observed divergence.

To my surprise Mr. Watson reported that the wires hung in No. 2, although about 120 feet shorter than in No. 5, and although lead bobs had been used, yet showed a divergence of 0.10 foot, and, further, that from comparison with other surveys, he had reason to believe that the azimuth of the wires at the bottom was considerably greater than at the top. At the surface they were 12.60 feet apart. An examination of the magnetic conditions yielded a possible explanation of the greater azimuth in that the air pipe in the southwest corner of the shaft terminated not far below the bob on the west wire. A repulsion between the lower end of this pipe and the lower end of the west wire, presumably of the same north polarity, might account for the increased azimuth. It could not however account for the divergence.

The publication about this time in the Portage Lake *Mining Gazette* of the fact that a divergence in the plumb lines had been observed, attracted considerable attention, and brought forth many attempts to explain its existence. Those most familiar with the conditions had no satisfactory theory to offer. To them it was evident that more data must be secured before the cause could be correctly assigned.



PLUMBING DEEP SHAFTS IN THE TAMARACK MINE.

Among the proffered explanations, two are worthy of notice. The first was that the divergence was due to the greater attraction of the material at the end of the shaft for the bob hanging nearest it. It is remarkable how many trained persons, engineers and others, held to this view. There seems to exist a general lack of appreciation of the forces of gravitation, except in the single instance of the force between the earth and objects upon it. It is, of course, true that the attractions on each bob toward the ends of the shaft are different, the stronger being toward the end nearest to which the bob hangs. Further, these differences tend to diverge the wires, but their amounts are so insignificant as to put them quite out of consideration. The sum in this case is only a few hundredths of a grain, and the consequent divergence about a thousandth of a foot.

The second explanation worth notice was offered by Professor William Hallock of Columbia University. This was that of mutual repulsion between like poles at the lower extremities of the wires. It was subsequently modified (see *Electrical World and Engineer*, February 8, 1902), to include as well repulsion between like consequent poles distributed along the wires.

Meantime the management of the Tamarack Mine, with its characteristic interest in scientific things, had granted me permission to carry on further experiments in No. 4 Shaft. This shaft is particularly adapted to experiments of this kind, especially as it is much freer from magnetic material than any of the others. Mr. Watson entered heartily into the project, and the experiments which were conducted were hardly less under his direction than mine. The actual work was shared by Professor Fisher and Instructors N. S. Osborne and E. D. Grant of the College of Mines, and by Mr. Slock, assistant engineer at the mine. Phosphor-bronze wire No. 20 B. & S. gauge was chosen for the lines; 60-pound lead bobs were hung at the bottom, first in oil, but subsequently in water, the latter being found by far the more satisfactory medium. These lines were hung as far apart as the conditions in the shaft would permit, and were approximately 4,440 feet in length from point of suspension to bottom of the bob.

Means were taken to locate the wires in a horizontal plane. At first a base line was laid off for each wire. The wire was observed by transits simultaneously from both ends of the line, and the two wires were under observation at the same time. This scheme was almost immediately abandoned for the simpler one of a single base line common to the two wires. A transit was mounted at either end of the base, and it observed alternately each wire. The method is exhibited in Fig. 1 which is a horizontal cross section of No. 5 Shaft at the 29th level, and also in Fig. 2, a cross section of No. 4 Shaft at the 11th level. In each figure W and E are the positions of the wires, while K and F in the one and F′ and C′ in the other are those of the transits. In each case the base line was tied to permanent marks in the neighborhood of the plat at which the observations were taken. Scales were erected behind the wires in a position perpendicular to the line of sight, and as near the wires as was convenient. Most of the time a scale in sixteenth inches numbered decimally was used. At first the wires were allowed to vibrate as they would, but for most of the observations they were set vibrating parallel to the scale on which it was desired to read mean position by drawing them aside from half to three-quarters of an inch, then allowing them to swing freely. An odd number of readings was taken, as in the method of determining the zero point of a balance by observing the vibrations of its pointer. Great care was taken to protect the wires as far as possible from disturbing influences, such as currents of air and dropping water.

As showing the constancy of the mean positions of the wires, it may be of interest to quote an example from observations at No. 4 Shaft, and one from No. 5. I quote, from the note book, observation sat No. 4 Shaft, January 9, 1902:

Station C, east wire, McNair		Station C, east wire, Watson	
Left.	Right.	Left.	Right.
56.6	...	...	74.5
58.1	63.4	51.0	67.5
60.5	64.3	57.5	68.0
59.0	65.5	55.0	70.5
60.7	62.8	50.5	67.0
59.3	65.4	56.0	66.5
57.0	62.2	50.5	64.2
		57.3	66.8
Mean position 61.3		Mean Position, 61.7	

Mean of the two sets, 61.5

The interval of time between the above sets is not recorded in the note book, but is remembered as being between one and two hours.

Again, from the note book, No. 5 Shaft February 23, 1902:

Station F, west wire,		Station F, west wire, Fisher	
Left.	Right.	Left.	Right.
44.5	...	...	58.3
45.3	60.6	47.3	57.8
45.9	60.2	49.7	56.2
49.2	58.7	49.9	54.6
49.0	56.6	52.0	54.7
49.1	56.4		
48.8	56.0	Mean Position, 53.0	
Mean position 52.8		Time, 3.40 p. m.	
Time, 11.40 a. m.			

Mean of the two sets, 52.9

It will be seen from these examples that the mean positions of the wires were very constant for considerable periods of time.

The angles in the figures were read by repetition to some mark of the scale near to the mean position. They were afterwards corrected for the difference between the mark chosen and the mean position of the wire assumed from the observations. Check measurements of distances from instruments to wires were taken, the wires being held as near as might be in the mean positions. It is thought that the distance between the mean positions of the wires was determined with an error not greater than 0.003 feet.

After hanging the bronze wires in No. 4 Shaft and finding a small convergence, it was decided to hang the steel wires in this shaft in the same position at the top as the bronze lines, and note their positions at the bottom, both with lead bobs, and with iron bobs. The bobs were first in oil, subsequently in water. The results for distances between the wires are exhibited in the following table:

Plumb Lines in No. 4 Shaft, Tamarack Mine.

Date				Dist. in feet		Cov'nce
1902.	Wires	Bobs	Medium	Surface	11th	in feet
Jan. 3	Bronze	Lead	Oil	15.089	15.061	0.028
6	Steel	Lead	Oil	15.089	15.074	0.015
6	Steel	Lead	Water	15.089	15.074	0.015
6	Bronze	Iron	Water	15.089	15.062	0.027
9	Bronze	Lead	Water	14.607	14.611	*0.004

*Divergence.

Whatever might be the cause for the slight convergence observed, the results of these observations seemed to afford ample experimental proof that neither gravitation nor magnetism could account for the divergence originally observed in No. 5 Shaft. The shorter distance between the bronze wires as hung the second time was due to the necessity for moving the western one to avoid contact with pieces of steel wire which were lodged in the west compartment on the breaking of the line which had hung in this compartment on January 6. After the compartment was supposed to be clear, the west wire was moved east to further ensure its freedom.

About the middle of January the bronze wires were hung in No. 5 Shaft as near as might be in the positions occupied by the steel ones in September. The distance between them at the top was 16.709 feet, while at the bottom the observations gave 16.850 feet, showing a divergence of 0.141 feet. This divergence it will be noted is greater than that observed in the case of the steel wires in September. We were now convinced that the behavior of the wires was to be explained by assuming that one or both of them were deflected from the normal position by the currents of air which circulated in the shaft. This suggestion of air currents had been made early in the work. It was treated with scant courtesy in the beginning, because it did not seem probable that the currents of air could be steady enough, both in volume and direction, to permit the constancy of mean position which had been observed. However, the hypothesis once admitted, it appeared that it might account for all of the observed phenomena. Desiring to make the proof as complete as possible, it was decided to hang the bronze wires once more in No. 5 Shaft, but this time to place the west wire in the compartment next the air shaft rather than in it.

It should be remarked here that during the sinking of this shaft, and until it is connected with some other portion of the mine, its ventilation is accomplished by dividing it into two parts by means of a tight casing between Compartments II and III, Fig. 1. Compartments I and II form the so-called air shaft. An up-draft is induced in this air shaft causing a down-cast in the other three compartments. At the time of the September and January plumbings there existed at different a number of openings in the casing. These openings permitted a rush of air from the downcast side into the upcast compartments. The effect of these currents of air would be to move the est wire toward the west. If these openings were closed off and the west wire hung in the compartment next the air shaft, No. III of the figure, it seemed that the divergence would disappear, provided it were due to the assigned cause. They were hung in these positions on February 3, the east wire hanging as near as might be in the position occupied in September and January, the compartment next the air shaft. The positions are shown in the figure. Communication between the air shaft and the downcast portion had been carefully stopped off as far down as the 29th level. Further, to prevent circulation as much as possible, the shaft was covered at the top as soon as the wires were in position. It was quickly evident that circulation could not be wholly stopped. There was yet a considerable convection current down close to the casing of the air shaft, and up in the two eastern compartments, the cause for this current being the difference in temperature between the top and bottom of the shaft. Its distribution is explained by the fact that before the shaft was covered, the down-cast current was strongest close to the casing. As the covering failed to stop circulation, the strongest portion of the down-cast naturally maintained the position it already occupied. The measurements between the wires were, at top 11.944 feet, at bottom 11.962 feet, showing a divergence of 0.018 feet. This divergence was easily accounted for by the convection current above described.

The difference between the divergence of the steel wires in September and of the bronze wires in January is readily accounted for by the fact that the circulation in the warm weather of September was much less vigorous in January, and, further, that the steel wires afforded the smaller surface to be acted upon.

Consideration of the currents in No. 2 Shaft, which is downcast, accounts for both the divergence and the increased azimuth there observed. The small convergence in No. 4 may likewise be accounted for by the swirl of the currents as they enter this shaft, which is up-cast. Although an effort was made to stop these as far as possible during the actual observations, it was not practicable to entirely cut them off. The contour of the walls of the plats above the eleventh level in the shaft is such that the air currents from the cross cuts hugging the outside of the curve will on actually entering the shaft have a tendency from the western wall toward the center, and this tendency will apparently be stronger close to the wester wall than a little distance from it. Consequently, when the west bronze wire was moved away from this wall the wires hung more nearly parallel than when it was close to the wall.

It seems, therefore, that a very simple cause was at the bottom of the divergence which attracted so much attention. The remarkable fact is that the currents of air should be so constant in their action. When, however, the great depth of the shafts is considered, also the constancy for considerable periods of time of the temperatures which may influence these currents, it seems after all reasonable that this steadiness should exist. The experiments have shown that the engineer who has before him the problem of plumbing a deep shaft has very considerable difficulties to overcome in the matter of the influence of the circulation of air in the shaft on his lines. He should study this circulation very intently before deciding where to hang them, and in order to estimate the dependence that is to be placed on his results when the lines have been hung.