Transcribed from Science, Vol. XV, 994-996 (1902).

DIVERGENCE OF LONG PLUMB-LINES AT THE TAMARACK MINE.

In September last two very long plumb-lines were hung in No. 5 shaft of the Tamarack Mine at Calumet, Michigan. They were 4,250 ft. in length, being longer than in any previously recorded instance. They were of No. 24 piano wire and the bobs were of cast iron, weighing fifty pounds each. Great care was taken that there should be no interference from projecting objects nor from dropping water, of which, indeed, there is not a great deal in the shaft. Measurements between the lines taken at surface and at their lower extremities showed a divergence to the amount of 0.11 ft. A divergence of 0.07 ft. remained after the western wire had been moved about 1.25 ft. further west to insure its freedom from obstacles. Thinking that the air pipes which run down the western end of the shaft might, through magnetic action on the bob nearest them, be causing this divergence, I advised the use of lead bobs in a plumbing of No. 2 shaft, which took place a little later. Although the length of the lines in No. 2 was about 120 ft. less than when they hung in No. 5, and although the lead bobs were used, there was as yet a divergence of 0.10 ft.

The publication about this time in the Houghton Daily Mining Gazette of the fact that a divergence had been observed attracted wide attention, and brought forth many attempts to explain its existence. Those immediately cognizant of the conditions had no satisfactory theory to offer. One of the explanations 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 engineers and other trained persons held to this theory. 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 either bob towards the ends of the shafts are different, the stronger being toward the end nearest to which it hangs. Furthermore, these differences of attraction tend to diverge the lines. Their amounts, however, are in this case so insignificant as to put them quite out of consideration in attempting to explain the divergence. Their sum is only a few hundredths of a grain, and the consequent divergence only about 0.001 ft.

Professor Hallock, of Columbia University, suggested the theory of repulsion between like poles at the lower extremities of the wire, but afterwards modified this to include repulsion between like consequent poles distributed along the wires.

Permission having been granted me to carry on further experiments in No. 4 shaft of the Tamarack Mine, there were hung in this shaft bronze wires No. 20 B. & S. gauge, carrying 60-pound lead bobs. These lines were approximately 15 ft. apart and 4,440 ft. in length. By a simple system of triangulation the distance between the mean positions of their lower extremities was determined, while the distance between them at surface was directly measured. It is thought that these distances were compared with an error not greater than 0.003 ft. A small convergence of 0.28 ft. was observed. The steel wires were then hung in the same position at the top, and the positions at the bottom observed, both with lead and with iron bobs. The bronze wires were hung a second time, but somewhat nearer together, and were found practically parallel. The steel lines showed a slight convergence. Subsequently the bronze wires with lead bobs were hung in No. 5 shaft in the same position, as nearly as might be, as was occupied by the steel wires in September. The divergence was greater, amounting this time to 0.141 ft. The results are exhibited in the following table:

Date, 1902.	Shaft.	Wires.	Bobs.	Distances in feet.		Convergence –. Divergence +.
				Surface.	Lower Extremities.	
Jan. 3	No. 4	Bronze.	Lead.	15.089	15.061	-0.028
" 6	" 4	Steel.	Lead.	15.089	15.074	-0.015
" 6	" 4	Steel.	Iron.	15.089	15.062	-0.027
" 9	" 4	Bronze	Lead.	14.607	14.611	+0.004
" 16	" 5	Bronze	Lead.	16.709	16.850	+0.141

The data shown in the table seemed to afford ample experimental proof that neither gravitation nor magnetism could account for the divergence originally observed. Further, it seemed that the results pointed clearly to the currents of air in the shafts as the disturbing cause.

Until No. 5 shaft is connected with other portions of the mine its ventilation is accomplished by dividing it into two parts by means of a tight casing which sets off one compartment and the ladder-way, at the western end of the shaft, to serve as an air chimney for the up-cast draft. At the time of the September and January plumbings there existed at different levels a number of openings in this casing. The west wire hung in the air chimney, and these openings permitted a rush of air from the down-cast side into the up-cast portion, the effect of which would be to move the west wire toward the west and thus produce a divergence. To make the proof as complete as possible it was decided to hang the bronze wires once more in this shaft, but to hang the west one in the compartment next the air chimney, rather than in it. It seemed that if both wires were hung in the downcast portion the divergence These ought to disappear. Moreover, communication between the air chimney and the down-cast portion was carefully stopped off as far down as the extent of the wires, and, to further prevent circulation, the shaft was covered at the top as soon as the wires were in position. Since a considerable difference in temperature exists between the bottom of the shaft and the surface, it was not possible to stop all circulation. There remained a considerable convection circulation whose down-cast portion was concentrated along the casing above referred to. The measurements between the wires were at surface 11.944 ft., at bottom 11.962 ft., showing a divergence of 0.018 ft. This divergence was easily accounted for by the convection current just described.

The difference between the divergence of the steel wires hung in this shaft in September, and of the bronze ones in January is explained by the fact that the circulation in the warmer weather of September was much less vigorous than in January and, further, that the steel wires afforded the smaller surface to be acted upon.

The question of air currents had been considered early in the experiments. That they could account for the divergence was very slowly admitted by the observers, inasmuch as it was difficult to believe that currents of air could be of the steadiness, in both volume and direction, which would be necessary to permit the constancy which was observed in the mean positions of the lines. The mean positions were observed on scales, placed close to the wire. Most of the time scales divided into sixteenth inches were used. For hours at a time the variations of the mean position of a wire would not exceed three or four tenths of a scale division. The mean position was determined by drawing the wire aside and allowing it to vibrate, as in determining the resting point of a balance by the method of vibrations.

The responsibility of the air currents once admitted, it was found by studying the conditions in No. 2 shaft that the divergence there observed could be satisfactorily explained. The shaft is down-cast and the air leaves it at the west end to reach the mine. The small convergence observed in No. 4 shaft can likewise be accounted for by the swirl of the currents as they enter this shaft, which is up-cast. The contour of the walls is such that the currents of air hugging the outside of the curve as they enter the shaft will have a tendency from the west wall toward the center. Moreover, it appears that this tendency will be stronger close to the wall than a little distance away. When therefore on the 9th of January, the west wire was moved eastward, lessening the distance between the lines, the wires hung nearly parallel than when this wire was close to the wall of the shaft.

It seems therefore that a very simple cause was at the bottom of the divergence. 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 reasonable that this steadiness should exist.

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