

## SCIENTIFIC EXPERIMENT IS ENDED

### Government Co-operates with Mining College Officials in Tests Concerning Earth's Density. Delicate Instruments.

With the close of the week a series of observations made at the North Tamarack mine came to an end, which comprised an experiment that will add materially to the scientific knowledge of the world and, it is confidently believed, will aid in solving some of the anomalies of gravity. The experiment was inaugurated and carried out by Professor Fred W. McNair, president of the Michigan College of Mines, and he was assisted by John F. Hayford, chief of the computing department of the United States coast and geodetic survey at Washington; Prof. James Fisher and Nathan S. Osborne, of the staff of the Michigan College of Mines, and J. B. Watson, chief engineer of the Tamarack mine; in addition thereto, the Tamarack Mining Company afforded every possible convenience for the execution of the work, and Assistant Superintendent William E. Parnall, Jr., rendered valuable advisory aid. While tests of gravitation are as old as the discovery of the Newtonian law, about the year 1700, there has never before been an opportunity equal to that afforded in the deep shafts of the Tamarack copper mine to make an exhaustive experiment such as the one just finished. With full justice to the men who executed the work, too much credit cannot be given to the mining company, whose interest in the scientific problems involved made the undertaking possible.

The most essential instruments used were owned by the United States government and were shipped here from Washington at national expense under supervision of Mr. Hayford. The instruments are of the most delicate nature, some never being touched by human hands; these are handled with hooks fitting into lugs and are laid carefully into chamois skin receptacles when not in use. The Michigan College of Mines also furnished many valuable instruments for the work.

#### Purpose of the Experiment.

The purpose of the experiment, was to determine the density of the earth by observing the force exercised by gravity on pendulums swinging on the surface and at varying depths beneath. Observations were taken hourly, night and day, with but short intervals of interruption, for nine days.

The results obtained so far consist merely of memoranda, from which computations will be made. It is impossible to say when the final report on the work will be ready for publication, but it will be little less than a year.

The computations from the data obtained in the experiment just ended will be completed in November but this is little more than an initial step in the full work. To attain the desired end there is a long and laborious series of observations yet to be made on rock density, distribution of surface material, topography, and many other local conditions. These will be carried on in the physical laboratory of the Michigan College of Mines. Considerable field work will be necessary for this, while part of the data may be compiled from field observations already made and recorded.

With each individual scientific observation there goes an interminable list of corrections based on latitude, longitude, altitude, atmospheric conditions, temperature, microscopic variations in instruments, "personal equations," and so on through a lexicon of "what-nots" known only to science.

The computations from the data obtained by the pendulum experiment will be made in the proper division in Washington, under the immediate supervision of Mr. Hayford. All computations on the coordinate data yet to be collated will be made in the mining college under the direction of Prof. McNair. The government computations will be forwarded to Houghton, and the full report on the subject will be prepared by Prof. McNair. This work will be finished probably next fall and the initial publication of the results will be made by the government in a report issued by the coast and geodetic survey, which is under the jurisdiction of the treasury department.

#### The Equipment Used.

The equipment furnished by the government consisted of two sets of

pendulums for making the gravity experiments, a chronograph for recording the underground observations on the surface; two chronometers; and an astronomical transit for taking observations of the stars in order to regulate the chronometers. Several complementary appliances are required with each of these instruments, and the pendulum sets are quite elaborate in the equipment. Each set consists of four interchangeable pendulums, a vacuum chamber in which the pendulum swings, an air pump, several delicate thermometers, and an observation telescope or flash box for watching the swinging pendulum and noting stated coincidences.

This flash box consists of a small telescope mounted on a box which contains a mirror; the light from an attached lamp falls on the mirror and is reflected through a slit in the box; this slit is closed by a shutter, and by means of an electric wire connected with a chronometer it is caused to flash even seconds. The light from this flash falls on two mirrors, one fixed and the other attached to the swinging pendulum. The coincidental flashings on these mirrors, to be explained later, are the essential points watched by the observers – the heart beats of the experiment, so to speak. There is a coincidental flash every four minutes, and throughout the experiment the exact time, to the nearest second, was recorded of four flashes in each hour.

The chronograph consists of a revolving cylinder driven by a weight and controlled by a ball governor; a fountain pen actuated by a screw draws a continuous spiral line on this cylinder as it revolves. This pen is also connected electrically with the chronometer and it makes a notch or irregularity in the line with each second as the electric circuit is broken. The circuit can also be broken by an instrument similar to a telegrapher's key in the hand of the observer, and a notch in addition to that made by the second beat is thus inserted in the line.

#### How Underground Records Were Kept.

This was the method of signaling stated coincidences to the surface from the underground station, where the conditions were such that memoranda could not be kept, the chill and damp and darkness

making it impracticable. For this purpose a telegraph line was run down the shaft and through the drift to the station. A revolution of the cylinder on the chronograph requires an exact minute. Thus, by counting the lines drawn by the pen as minutes, and counting the notches which show the second beats, to a point where a notch appears irregularly, the exact instant of that signal can be ascertained. The stated coincidences at the surface station were recorded as memoranda by the observer, no chronograph being used.

One of the chronometers, as already mentioned, was used to beat the seconds by electric connections. The other was used by the surface observed in making memoranda. These chronometers are of exceptional workmanship, being valued now, as second hand instruments, at \$691 by the government. One of them was regulated in Washington to a point where it was gaining only one-eighth of a second a day, equal to a minute in about 16 months. When the chronometers were shipped every precaution was taken. They were enclosed in leather cases and packed in cork lined boxes, with great caution to the express company. Notwithstanding this care, however, the better one was gaining two seconds a day during the experiment, according to the sidereal observations taken nightly. No attempt is made to regulate the chronometers away from the Washington office; the instrument is permitted to run as it will and the error is allowed for in computed the results.

#### **A Wonderful Spirit Level.**

The astronomical transit consists of a telescope about four feet in length, mounted on an axis and provided with graduated circles for determining the declination. Accompanying the transit is a spirit level of exceptional delicacy. As an illustration of its sensitiveness it was laid on a pier of brick masonry, built up from a depth of eight feet in the earth. This pier was four feet square to the surface of the ground, and from that point to a height of three feet it was 15 inches by three feet, the whole surmounted by a sandstone cap. The cement was well set, and the pier was what is ordinarily termed absolutely rigid. The illustration was made by bracing the feet on the floor, and pushing with full force against the pier. This caused the bubble in the glass tube of the level to fluctuate one-sixteenth of an inch. By bracing the body against the

wall, and pushing with full force on the masonry, the bubble could be made to fluctuate over one-eighth of an inch.

To further demonstrate how near rigid the masonry pier was, and how sensitively the level responded to the test, it was explained that a line carried to a height of a mile and caused to sway to the same extent as did the pier when the bubble moved one-sixteenth of an inch, would be three-quarters of an inch out of perpendicular at its extremity; or, to be more technical, the bubble fluctuates one-sixteenth of an inch when the spirit level is placed at right angles with a line two and one-quarter seconds out of the perpendicular; or again a radius describing an arc of 1-564,000th of a circle causes the instrument to show a fluctuation on one-sixteenth of an inch in the bubble.

#### **Gazing at the Stars.**

Throughout the experimental work on gravity, eight nightly observations of the stars were taken when the weather permitted, to determine the efficiency of the chronometers. The observer held a circuit breaker, made on the principle of a telegraph, instrument in his hand, and as a given star passed the meridian it was recorded on the chronograph, exactly as the underground records were kept, which has already been described, showing to the thirty-six thousandth part of an hour how far the corresponding second beat of the chronometer varied from the true time.

As each of these observations was taken, the delicate spirit level was placed on the axis of the transit, and any irregularity in the adjustment of the instrument caused by expansion or contraction resulting from atmospheric conditions, or variations of any kind whatever, were noted and the error will be computed and deducted in the final summing up of the experiment. The transit used in this experiment was made by Troughton & Simms, London, Eng., in 1848, and has been in continuous use by the coast and geodetic survey since that time. It is one of the four owned by the department, a second being a twin to it and the two others of more recent make.

#### **Housing of the Instruments.**

The temporary quarters built at the location to carry on the experiment were small board structures covered with tar paper. They consisted of a one-room building containing an inner room of corrugated iron in which a uniform temperature was maintained, and in which the vacuum chamber containing the

swinging pendulum was placed; a small shed containing a boiler to supply heat for the uniform temperature room; and an observatory containing the astronomical transit; two piers of masonry, as nearly rigid as possible, were required; one was for the transit and the other for the vacuum chamber. These were similar in construction, and one of them was described in the foregoing reference to the delicate spirit level used on the transit.

The underground station was less elaborate. No permanent temperature room or steam heat was required, as the mine temperature is unvarying, while star gazing was out of the question. There was simply the pendulum apparatus, and the telegraphic and telephonic connections with the surface station.

The Michigan College of Mines furnished many valuable instruments for carrying on the experiment. In fact, whatever could be obtained here that would answer the purpose was used. This included a chronometer, which was used alternately with the Washington instrument, in order that the error might be equalized; several self-recording thermometers and straight thermometers of the most delicate nature; a Johnson thermostat, by which the steam for the radiator in the permanent temperature room was regulated; and several telegraph instruments, besides several other minor accessories.

#### **The Pendulum Apparatus.**

The pendulums with which the experiment was made were constructed to beat half seconds, which swinging in an approximate vacuum. The atmospheric pressure in the vacuum chamber was one-twelfth of the normal, eleven-twelfths having been exhausted by the air pump.

Four pendulums constitute a set. One of these is hung stationary in the chamber, and a thermometer is attached to it. The temperature maintained by this pendulum is recorded as the temperature of the swinging pendulum along side of it. This is done in order that the swinging instrument may not be interfered with, and also to facilitate the reading of the thermometer in a stationary position. The three other pendulums are used alternately for swinging, so that any error in their weight or measurement may be equalized. They are built as nearly alike as lies in human power, but there may exist a microscopic variation which even the most delicate instruments could not record. Each pendulum is of brass and is

about nine inches long, weighing probably three pounds. It has a circular bob or weight, slightly convex and with a knife edge. The rod or stem is also knife edged, and thus a minimum resistance is exercised by the remaining pressure of one-twelfth of an atmosphere in the chamber.

In the head of the pendulum is an opening through which the supporting bar passes. In the top of this opening is an inverted plane of highly polished agate, one-sixteenth of an inch wide and an inch long. On the top of the supporting bar is a corresponding agate, but polished to a knife edge. It is upon this edge that the plane rocks when the pendulum is in motion, and the resultant friction is practically nil. When a pendulum is started the swing is two-thirds of an inch. At the end of eight hours it is still swinging three-fifths of an inch, having lost in amplitude, but without perceptible loss in the time consumed in an oscillation.

Under normal conditions at a specified latitude and altitude these pendulums beat half seconds. It is by observing the variations from this standard at different depths in the earth's body that it is hoped to ascertain the distribution of density. The Newtonian law of gravity, which is assumed by the experimenters to be correct, relates to homogeneous bodies, which the earth is not. The weight of the earth as ascertained by its gravitational influence on the planets, is much greater than the product of its mass multiplied by the average weight of the constituents which make up the crust; this product, of course, would be the weight, were the earth homogeneous. Hence, it is a natural supposition that the center is made up of the heavier metals, such as iridium, platinum, gold, silver, mercury, lead, copper and the like.

According to the law governing homogeneous bodies, the pull of gravity should grow gradually less as the center is approached, until finally it becomes zero. By noting the variation from this law when applied to the earth through experiments in the deep mines, it is confidently hoped that another law, governing the distribution of density in the terrestrial mass, may be discovered.

#### **Noting the Coincidences.**

The method of noting a coincidence in a pendulum experiment is as interesting as the work is delicate. A mirror three-eighths of an inch wide and five-eighths of

an inch high, is mounted in a stationary position along side the head of the swinging pendulum. The flash box, described previously, throws a horizontal line of light across the center of this little mirror. Another mirror, exactly the same size, is mounted in the pendulum head beside the stationary one. When the pendulum mirror is tilted either up or down by its swinging motion the horizontal line of light, of course, is reflected above or below the center. It is only when the flash occurs at the instant that the pendulum mirror is in a perpendicular position that the reflection is made in the center; then it is naturally on a straight line with the flash in the stationary mirror, the two mirrors reflecting an unbroken line of light six-eighths of an inch long across their two faces. This is called a coincidence, and the time of its occurrence is recorded to the nearest second. Since the flash occurs once in a second, and the pendulum beats once in a half a second, or in other words, the pendulum is gaining on the flash box at the rate of two to one, it overtakes and passes the flash about once in four minutes. In gravity experiments four of these coincidences are recorded every hour, consuming about 15 minutes' time. At the Tamarack experiment the underground station and the surface station made their records simultaneously, and it is from this data, as well as from the co-ordinate information yet to be ascertained and compiled, that the computations will be made.

Since the pull of gravity grows less toward the center of a body, it would be natural that the pendulum should swing slower, not being brought back to the vertical position so quickly, down in the mine, 4,550 feet below the surface, where the first test was made. It is upon the difference between the theoretical speed of the pendulum and the actual speed, as shown by the results in this work that the calculations will be based.

Once during the experiment just concluded a pendulum was left swinging in the vacuum chamber for a period of 19 hours and at the end of that time, it was moving through quite an arc, still faithfully beating the half seconds. It is not known how long it would have continued to swing. The pendulums were allowed to swing in Washington for several weeks before being brought here, and their action carefully noted. After they are shipped back this operation will

be repeated, and should any discrepancy occur it will be computed in the results. Two underground stations were established at the North Tamarack, one at a depth of 4,550 feet and the other at 1,100 feet, both in as near a vertical line as possible. At each station, when the work was half finished, the surface and underground apparatuses were exchanged, in order that any variation might be equalized.

The last observation was taken at 11 o'clock Thursday night. Friday the underground equipment was brought to surface and yesterday the outfit was packed and sent to the express companies for shipment.

The interest manifested by the government in the work as been intense, passing beyond all expectations. Prof. McNair visited Washington some months ago and laid the matter before the coast and geodetic survey. Mr. Hayford, to whom the matter was referred, occupies practically the third position in rank in the service, being subordinate only to the superintendent and assistant superintendent of the survey. All the computers, as well as the direction of the field work; are under his immediate supervision. His interest was so great that he at once made application to be detailed on the experiment, and his request was granted. As a result Prof. McNair has been assisted by a man who is probably without a superior in geodetic work.