SEISMIC RESEARCH PROGRAM
ROCK BURST PROBLEM
LAKE SHORE MINES

Report No. 5
August 15 - April 15
1940 - 1941

Ernest A. Hodgson

SEISMIC RESEARCH PROGRAM
ROCK BURST PROBLEM
LAKE SHORE MINES

Report No. 5
August 15 - April 15
1940 - 1941

Ernest A. Hodgson

SEISMIC RESEARCH PROGRAM

ROCK BURST PROBLEM

LAKE SHORE MINES

*****

Report No. 5. August 15, 1940 to April 15, 1941

Ernest A. Hodgson

***

Of the four previous reports on this work, No. 3 brought the general account of the rock burst research to the date August 15, 1940. Report No. 4 deals solely with the operation of the surface seismograph, from the date of its installation (December 19, 1939) to the end of 1940. The present issue carries forward the general record from August 15, 1940, to April 15, 1941.

As in previous issues, the arrangement presents a condensed, but fairly comprehensive, account in section I; the elaboration of certain details follows, in titled sections which follow the sequence of the résumé. Reference items are given in a series of appendixes.

I. <u>Résumé of Progress: August 15, 1940 to April 15, 1941</u>.

At the closing date of the third report, a memorandum had just been presented to Lake Shore Mines, recommending, among other things, the leasing of a seismic prospecting outfit from Dr. L. Don Leet of Harvard University, for the purpose of determining the frequencies of the elastic vibrations in the rock, as generated respectively by bursts and by blasts and other mine noises. The recommendations were approved. Arrangements were made to have Mr. Gibbs leave for Harvard to assemble, pack, and ship the Leet equipment, as soon as certain work, immediately pending at the mine, could be completed.

In part, this work consisted of constructing a battery-operated amplifier for the mine seismograph, which could be used in a long exploratory cross-cut on the 3075'-level, running north from the mine proper for more than half a mile. The remote end of this long-disused cross-cut is not supplied with electric current.

The amplifier was completed and installed on August 29 in the above-mentioned cross-cut (designated 3052X-C); the hydraulic strain gauge, previously reported as constructed.

was installed in 3001-W drift; and the routine operation of these and of the surface seismograph was made familiar to Mr. H. M. Butterfield who, at the time of the closing date of Report No. 3, had just been appointed to assist in the rock burst program.

Mr. Gibbs left for Harvard on September 4, driving down via Ottawa where he interviewed the Customs officials re the shipment of Leet's equipment. The seismic apparatus was stored in various units at Cambridge and at the seismic station at Harvard. Leet was away at the time but the equipment had been constructed by Gibbs and stored by him after it was last used, so he was able to get it into shape in a short time.

While in the vicinity of Cambridge, Gibbs interviewed various experimenters in the field of high pressure research (Birch, Bridgman, Pierce) and others engaged in the manufacture or use of special radio equipment (General Radio: Burke, Tuttle). He was able to interest them in the studies at Kirkland Lake and to pick up some valuable hints on procedure, especially in the matter of filter design.

It was arranged that Gibbs should arrive back at Kirkland Lake on or about September 19 and that Hodgson should leave Ottawa to arrive there at about the same time. Mr. R. G. K. Morrison of Nundydroog Mines, Mysore, India, engaged by the Mining Association to investigate the rock burst situation, was scheduled to be in Kirkland Lake at about this time and Messrs. Yates and Shenon of Sudbury (International Nickel Co.) planned to be present when the Leet equipment was tested. Prof. Geo. B. Langford (Professor of Mining Geology, University of Toronto) who was in the district at the time arranged to be at Lake Shore Mines for a day or so while the early experiments were undertaken.

Hodgson arrived at Kirkland Lake on September 21 and Gibbs drove in the next day -- a Sunday. It was learned then that the Sudbury delegation would arrive on September 30, so steps were taken to rush the release of the seismic outfit and get everything in shape for experiments in the mine on or before that date.

The equipment was delivered at the mine on Wednesday, September 25. After assembling and testing, it was taken into the mine for initial experiments on September 27. On Monday, September 30, the equipment was operated in the 3052 X-cut, all those above mentioned being present, together with Mr. Robson of the Lake Shore staff. The records were discussed at the laboratory the next day, after which the group broke up. A brief interim report was presented to Lake Shore Mines under date of October 3. A copy is attached to this report as Appendix I.

It was planned to ship the outfit to Sudbury for experiments in Frood Mine early in October. The expense of leasing and securing the Leet equipment was borne jointly by the Frood Mine (International Nickel Co., Sudbury) and Lake Shore Mines. Hodgson returned to Ottawa on October 4.

Gibbs went to Sudbury with the equipment on October 8, experimenting there until October 24. The frequency investigations were carried out at two locations, one on the 2000'-level, the other on the 2800'-level. Considerable difficulty was experienced, due to moisture and acid-charged ground-water affecting the equipment, to the practically constant interruptions by mine noises, and to stray electric currents affecting the galvanometers. Good frequency records were obtained after some difficulty, but experiments to obtain rough values of the speed of propagation of the sound waves through the rock could not be carried out without extensive modification of the equipment. As the instruments were leased, this was out of the question. The Leet apparatus was shipped back to Lake Shore Mines on October 25.

Experiments to determine frequency were resumed at Kirkland Lake by Gibbs, assisted by Mr. O. E. Andrew of the Lake Shore staff, who had been appointed to assist in this work after Mr. Butterfield left Lake Shore early in October. Frequency studies were made again in 3052 X-cut and also on the 2950'-level, in a specially prepared location in 2920W X-cut. This location is close to the west pillar. As the ground is loose extra precautions had to be taken; special timbering and lagging were put in as shown in Fig. 6.

The experiments at Lake Shore and at Frood showed definitely that:

(a) Blasting always generated vibrations, in the frequency range of about 40-60 cycles per second.

(b) Some blasts had, superposed on the above low frequency, a higher order of from 200-400 cycles per second.

(c) The few cases where strain bursts alone registered were found to show frequencies only in the higher range.

(d) Other mine noises (tramming, hoists, crushers, etc.) generated frequencies less than 100 cycles per second.

To determine whether the high frequencies could have been due to some characteristic of the equipment, extensive experiments were carried out by Gibbs in the Lake Shore laboratory. A geophone was subjected to various frequencies controlled by an oscillator and to amplitudes which were kept within appropriate limits. It was found that no high frequencies registered on the seismograms when the geophone was subjected to low frequencies and that it recorded the high frequencies faithfully as to period but at a much lower amplification than for the low frequencies.

It is concluded that:

(a) Blasts generate rock vibration frequencies of 40-60 cycles per second.

(b) Other mine disturbances generate frequencies of less than 100 cycles per second.

(c) Bursts generate frequencies of 200-400 cycles per second.

(d) Blasts in strained rock induce the low frequency and, at the same time, often release energy which causes the high frequency, characteristic of bursts.

(e) The discrepancy in amplitude of recorded low and high frequencies is due to the non-linear amplification of the equipment. The energy in the burst frequency is relatively greater than the records indicate.

(f) The high frequencies attenuate with distance much more than do the low frequencies.

Some attempts were made to determine sound velocities in the rock at Lake Shore Mines; but, as at Frood, the difficulties were too great to be surmounted in the limited time available and with leased equipment. Experiments were concluded at Lake Shore on November 19 and the equipment was shipped back to Harvard on November 21.

Efforts were made at once to secure filters which would suppress oscillations up to 200 cycles per second but give good amplification for higher frequencies. Owing to the pressure of war work, General Radio, Cambridge, Mass., could not undertake the construction. They kindly furnished specifications, however, and the filters were finally made by the Hammond Co. of Guelph. These were given an exhaustive series of tests in the Lake Shore laboratory by Mr. Gibbs.

It was found necessary to change the terminal impedance of the filters from 250,000 ohms to 20,000 ohms. Under the new conditions, the cut off was sharp to 200 cycles and the amplification beyond that frequency was reasonably flat to nearly 5000 cycles, The data were plotted by Mr. Andrew for both values of the terminal impedance. The curves appear as Fig. 14. An explanation of the testing procedure, as done by Gibbs, is given in a letter from him to Mr. Hammond dated March 10. An excerpt from this letter appears as Appendix II.

The mine seismograph, equipped with the filter, was set up in the rear of a safety shelter on the 4200'-level where it was operated for some days early in March. This location is not only at considerable depth but it is in strained ground and close to extensive mining operations. Andrew sat beside it several days during blasting time watching the record while listening to the blasts. He found that:

(a) Not all blasts registered,

(b) Most of the heavy ones were recorded.

(c) No records of bursts alone were made while he was there.

(d) Some disturbances, presumably strain bursts, were registered at other than blasting times and those were usually registered also on the surface seismograph.

It was concluded, tentatively, that:

(a) Some of the larger blasts or those nearer the equipment were able to pass the filter, simply because of their magnitude.

(b) Considering the location and its nature, it is highly probable that most of the blasts release inherent strain in the rock and so generate both high and low frequencies.

Hodgson arrived in Kirkland Lake on March 15. It was decided to remove the mine seismograph to the surface for the following test. It was to be set up, side-by-side with the surface seismograph and operated first without the filter. Tests were to be made, setting the gain so that both instruments would record with about the same amplitude. The records would thus show both blasts and bursts. Then the filter was to be installed on the mine seismograph and the gain stepped up the amount known to be necessary to care for the reduction in amplification due to the filter. The records should then differ if the filter were effective in eliminating blasts in unstrained rock. As many blasts occur in the upper levels and so probably do not release strain, it was confidently expected that the records from the two seismographs would differentiate between bursts (or blasts releasing strain) and blasts not associated with strain.

It was found difficult to get the two instruments to record the same with the filter removed. Finally, tests were run on the two geophones to see if they were comparable as pick-ups. They were not. Investigation disclosed a friction in the surface geophone. When this was eliminated, the two geophones gave practically the same results under varying tests.

During the intervals during which trial runs were being made, the Leet seismograms were sorted and indexed, those showing no records being discarded. There were hundreds of feet of these obtained at the Lake Shore and Frood experiments. Some recording was done by simply sitting beside the equipment set up in the mine and turning the crank, winding out many feet of photographic paper in the hope of recording a nearby strain burst when no blasting was in progress. Several bursts were so recorded but, of course, the bulk of the seismograms so run had to be discarded.

The time-marking device of the surface seismograph consisted, up to this time, of a shunt which sent a small current through the recording galvanometer for two seconds at the end of each minute. A semaphore arm for eclipsing the light for the timing interval had been constructed in the machine shop at Ottawa and taken to Kirkland Lake by Hodgson. This was installed in such a way that its eclipsing edge now divides the recording spot at its zero position as did the opaque screen on the cylindrical lens as described on page 7 of Report No. 3. The screen on the lens was removed. The zero position of the spot was set well to the left of the cylindrical lens as viewed from the front of the recording box. The offsets were thus all to the right (downward on the sheet) but could use the full width of the lens instead of only half as before. The time impulse shifts the semaphore to the left, making a mark upwards. The time marks are thus on the opposite side of the record line from the recorded burst and blast offsets. A full-size section of a typical record appears as Fig. 15.

The changes in the optical system required many adjustments to the surface seismograph equipment. The comparisons between mine seismograph and surface seismograph were, practically, not yet begun when on March 23 Mr. V. E. Hollinsworth arrived from Ottawa with his microgauge and equipment. The comparison experiments were postponed indefinitely while part of the mine seismograph equipment was taken over for use in the microgauge experiments.

Hollinsworth had been experimenting during the late summer of 1940 with an electric gauge for rapid testing of machined parts. The device is very sensitive, showing a deflection of about a quarter of an inch on the meter for a movement of 10^{-5} inches at the gauge. It was suggested (see Appendix I) that such a gauge might yield valuable information if designed to be placed deep in a diamond drill hole run into a pillar to reach the pressure zone of a dome.

The gauge, redesigned by Hollinsworth with this object in view, was the subject of experiments by him at Ottawa from early November to the middle of March. At Ottawa the power source is 60 cycles and the voltage fluctuations, while present to some extent, are not severe. The gauge was made quite stable for experiments at Ottawa.

It was known that the power source at Lake Shore was 25 cycles and that the voltage fluctuations were severe. The efficiency of the device for clamping the gauge at any desired depth in the hole was suspect. Moreover, there was no certainty that the bore hole, only 1.5 inches in diameter, would be deformed appreciably by pressure. For these reasons it was felt that experiments should be carried out at the mine.

The equipment was set up in the laboratory at Lake Shore on March 24. A description of the gauge is given in Section 8 of this report. A block of rock was secured, about as large as a football, having a standard diamond drill hole bored in it (see Fig. 22). It was found that, by pressure on the rock with the hand alone, one could deform the bore hole sufficiently to cause a marked deflection on the meter. Pressure in the direction of the line of contacts of the gauge indicated a shortening of that axis of the hole; pressure at right angles showed the same axis to lengthen. There was no longer any doubt that the bore hole would be deformed by comparatively slight changes in pressure.

The change to 25 cycles necessitated changes in the equipment. Experiments were run in the laboratory for several days. While these were in progress Gibbs arranged equipment, utilizing the Esterline-Angus meter of the mine seismograph, for recording the meter readings continuously. A special, horizontal, diamond drill hole 20 feet deep was made in the rock at the observing station in the rear of the safety shelter on the 4200'-level. The device was taken into the mine on March 27. No difficulty whatever was experienced in clamping the gauge at any desired depth in the hole. The second of the three uncertainties was thus removed, but the third, voltage fluctuation, was found to be extraordinarily severe.

A long, special supply line was run to the station in an effort to avoid the circuits most affected, but the trouble was still much too great to permit the operation of the gauge. After more than a week of experiment, it was decided that a commercial voltage regulator would be required. Enquiry showed that this would cost about $200. and could not be promised for less than five weeks after order. For the gauge to operate continuously an extra Esterline-Angus recorder was also needed or the mine seismograph routine would be interrupted. This would cost upwards of $300. and would require several weeks for delivery.

An interview was arranged with Mr. Blomfield who at once authorized the purchase of the required equipment. It was arranged that the gauge should remain at Lake Shore and that Gibbs should experiment with it in the laboratory with a view to achieving the necessary constant power supply and to ironing out other difficulties connected with continued registration. A second gauge was to be made at Ottawa to be used by Mr. Hollinsworth for obtaining pressure-strain curves of large samples of rock, bored at the mine and supplied for these experiments. The blocks, after being sawn into regular form and lapped will be subjected to pressures applied by a hydraulic press. These will be carried up to the point of failure of the specimens.

Hollinsworth returned to Ottawa on April 5, Hodgson remaining until April 9 for the purpose of completing the digest of the Leet records. Three specimen rocks, two of syenite and one of porphyry were received at Ottawa about the date of closing of this report. They will be sawn and lapped at the Bureau of Geology and Topography and tested at the Bureau of Mines. The skilled cooperation of these organizations makes possible some interesting experiments which could not otherwise be attempted.

As soon as the equipment is ready for further experiments underground, the work will be resumed at Lake Shore Mines. It is believed that this method promises interesting data of a very local character. It is evidently most desirable to measure strictly local conditions. Steps are also being taken toward developing equipment for detecting and recording supersonic vibrations in pillars. This method, too, is considered most promising and should, if successful, yield data which will also be of a local character. Delays in obtaining parts has prevented progress in this line of experiment to date.

The hydraulic strain gauge, described on page 11 of Report No. 3 (See also Fig. 16 of that report), was installed in Section 8 of 3001W drift on September 1, 1940. Deep holes were drilled on opposite sides of the drift into which thrust rods were set with the gauge held between them. Thus the convergence of the walls, behind the loose, was made the subject of record.

Daily readings obtained from this gauge are shown in Fig. 24. It may be noted that, after a period of about two weeks during which, it may be presumed, the lost motion in the connections was being taken up by convergence, the graph drops down from the broken line drawn at an angle of approximately 38° with the axis of abscissae and rises again to meet that line at the time of the large burst on January 19, 1941. This burst was close to the gauge, affecting among other places the adjacent Section 7 of 3001W drift. It may be argued with some reason that the broken line represents the average rate of convergence of the stope and that, when the actual convergence rate is less, strain is building up leading toward another burst in the vicinity. Some other bursts more distant from the gauge but still in the same general area are shown to have little or no effect on the displacement of the graph from the average line.

The graph falls again after the January burst to the last reading on April 7. On April 8 a large burst occurred which involved Section 8 of 3001W drift. The gauge, at the time of writing, has not yet been dug out from the fallen rock. When the mucking operations uncover the location it is expected that the gauge will be found to have been wrecked.

II. Description of the Leet Equipment.

The Leet seismograph was designed for refraction prospecting at comparatively shallow depths. The following description is based on data furnished by Mr. Gibbs who had much to do with designing and building the equipment and who has operated it for many investigations while working with Dr. Leet.

The geophones, of the reluctance type, were made by the Seismograph Service Corporation (SSC) of Tulsa, Oklahoma. They are illustrated in Figs. 2, 3, and 4. Two heavy, U-shaped, permanent magnets are rigidly fastened together by a brass yoke as shown in Fig. 2. The poles of the magnets are separated a little more than the thickness of the iron bar through the coil. This bar and coil are rigidly connected to the frame of the geophone. The magnets act as the inertia mass. They are held above and below by pairs of springs. Various matched sets of springs can be

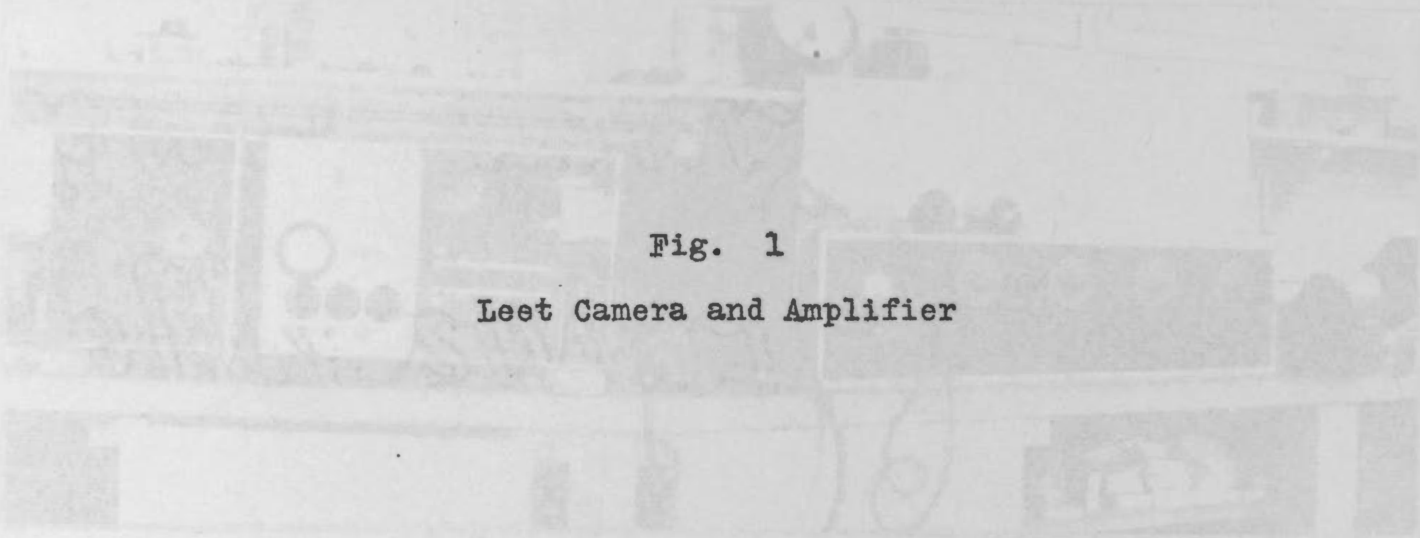


Fig. 1

Leet Camera and Amplifier

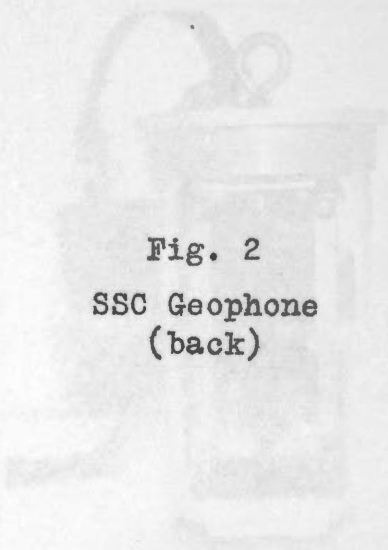


Fig. 2

SSC Geophone
(back)

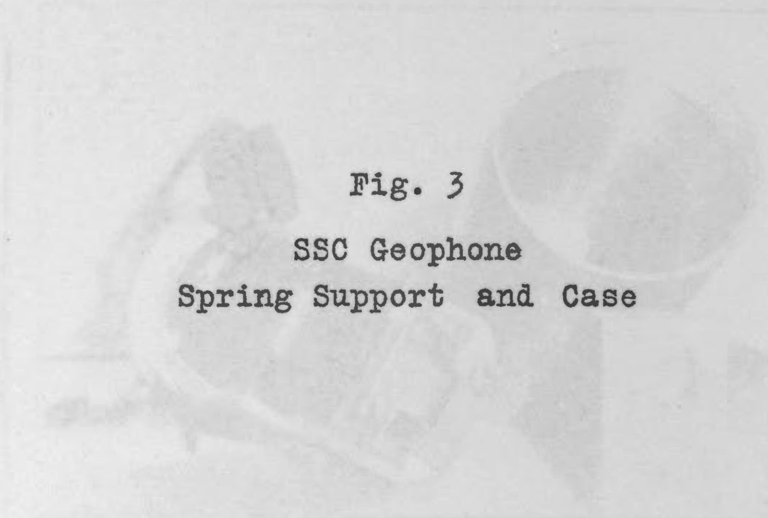


Fig. 3

SSC Geophone
Spring Support and Case

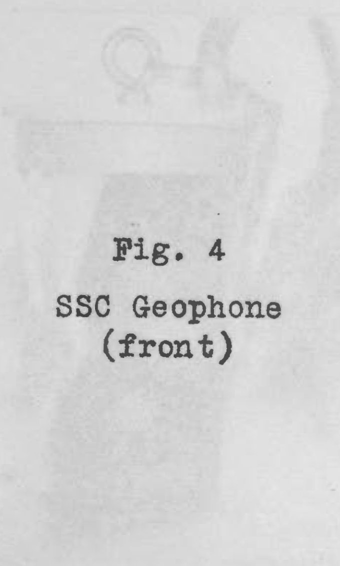
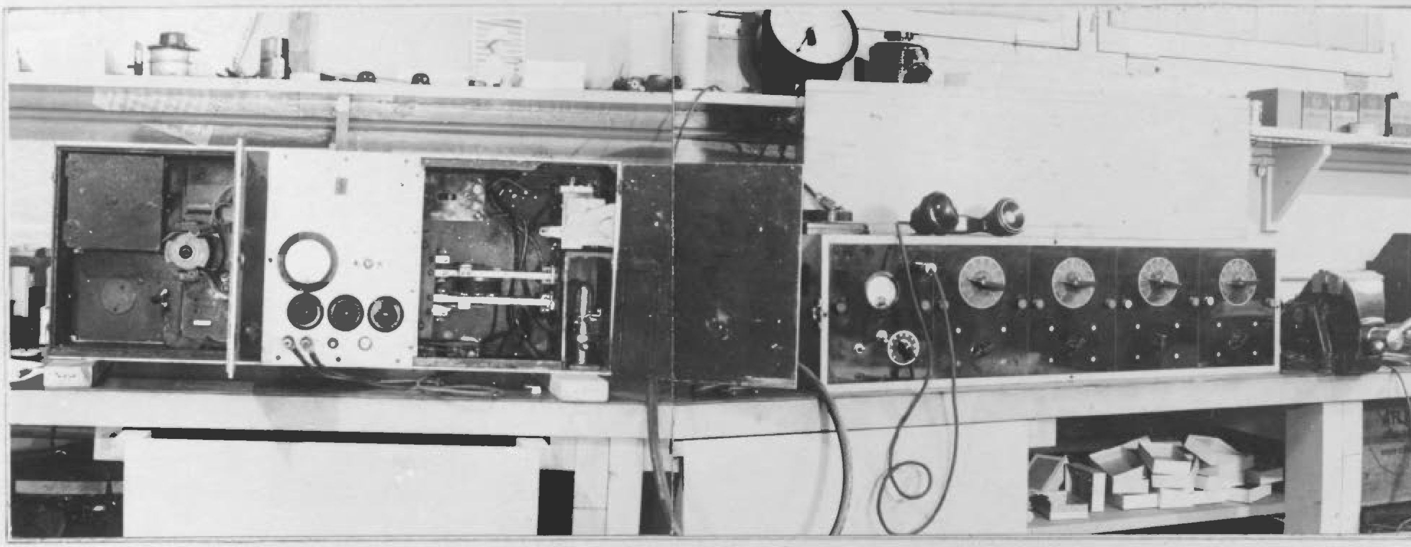
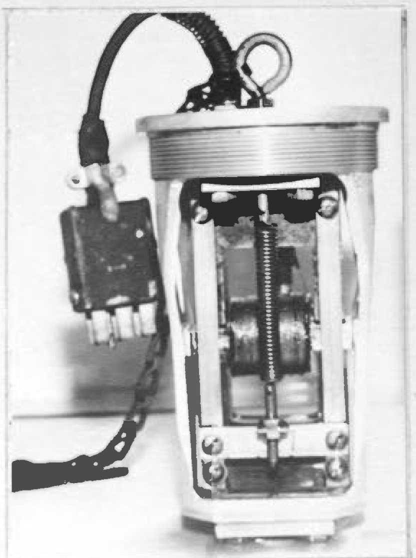
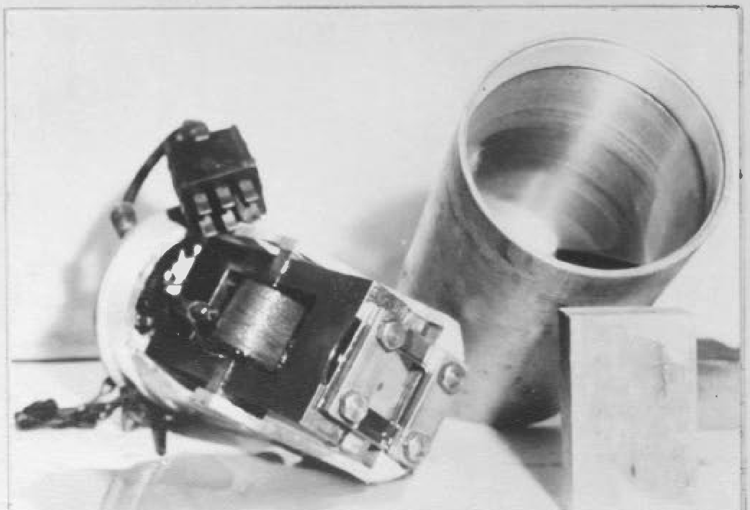


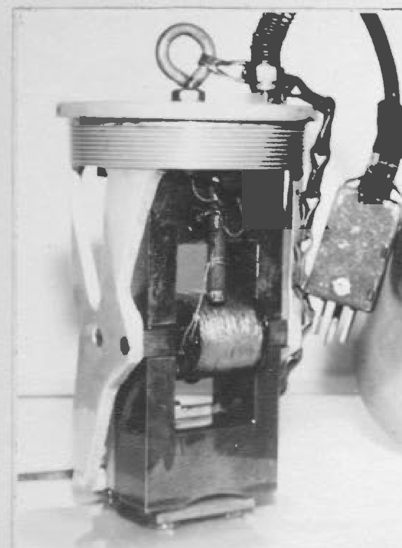
Fig. 4

SSC Geophone
(front)









used giving, within limits, the desired frequency and sensitivity. Damping is attained by partly filling the enclosing cylinder with machine oil (see Fig. 3). The long, coil spring shown in Fig. 2 permits adjustment to centre of the field by overcoming the gravity component. The terminals of the coils are led up to two of the six connecting prongs in the plug. Four geophones are provided.

The connecting cable carries six wires. One of these is used in common by all four geophones. The latter are operated between the common wire and one of the remaining five. The six-prong, cable connectors are coded in such a way that, no matter where the geophone may be inserted into the cable, at any one of a series of input sockets, it will always be connected to its own proper wire and the common one. The extra circuit provided by the cable is used for a telephone connection.

The four geophone circuits are severally connected to four moving-coil galvanometers in the camera (Fig. 1, left), through four separate impedance-coupled amplifiers (Fig. 1, right). The amplifiers are grouped to the right of their carrying box. To the left of this same box is the control panel, containing the master switch and the telephone circuits. When used, the blasting signal is also brought in through this panel and here its amplitude is regulated. The small meter on the panel indicates the telephone current. It shows when the telephone is operating and serves as a good indication of the cause of any trouble which may arise on this line.

The light sources in the camera are two in number, one for recording by means of the galvanometer mirrors and one for registering timing lines on the record. The former source is concealed behind the centre panel of the camera box. The latter appears in the lower right hand corner of the box.

The beam of recording light is projected to the right and is reflected by the mirrors of the galvanometers, located in the upper right hand corner of the box. The beam is reflected to the left and a little below. It passes through a horizontal cylindrical lens and is focussed on a continuous strip of sensitive Haloid paper, 35 mm. wide, provided with marginal drive holes similar to movie film. The paper is fed from a large roll in the dark box in the upper left

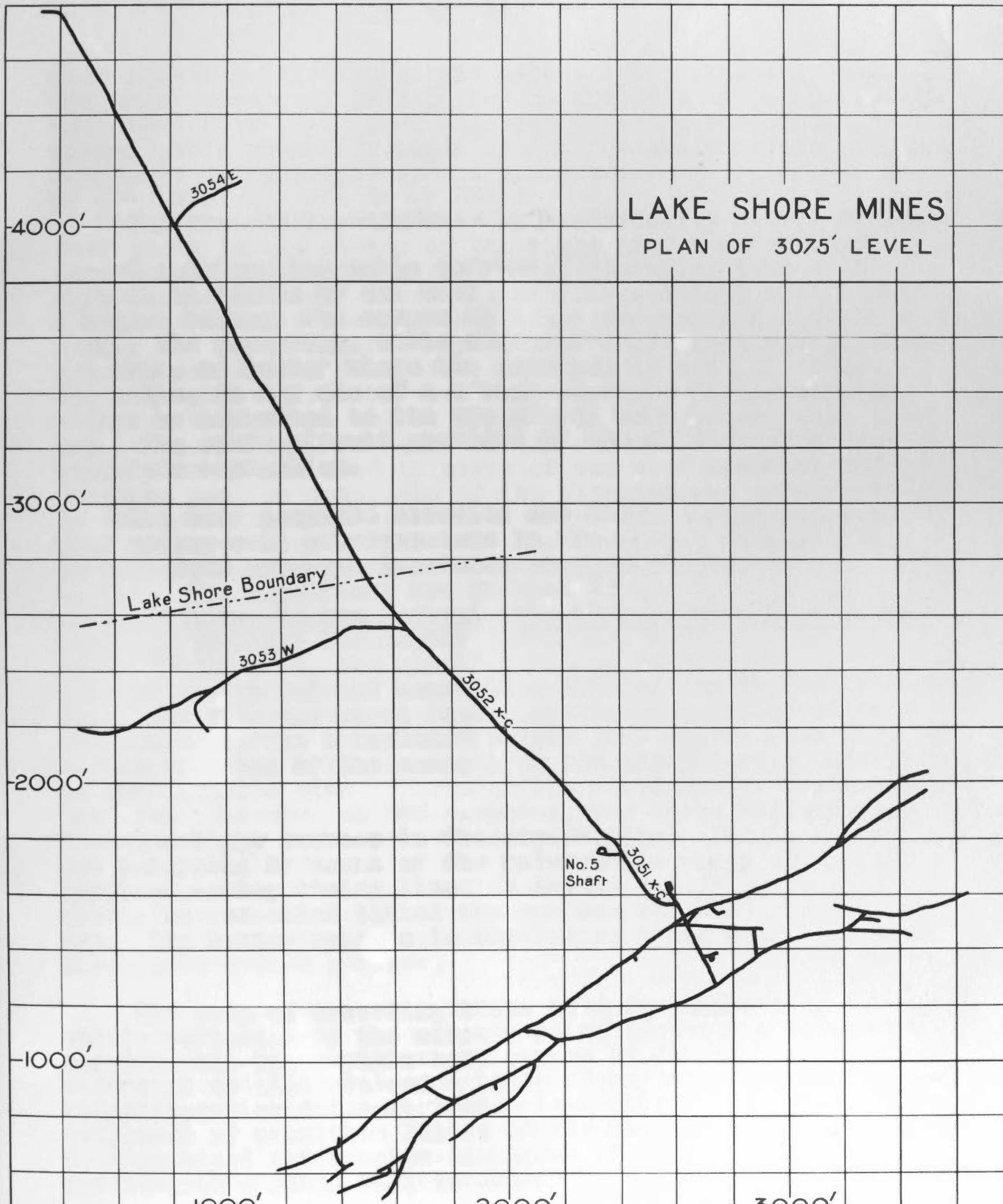

LAKE SHORE MINES
PLAN OF 3075′ LEVEL
3054 E
4000′
3000′
Lake Shore Boundary
3053 W
3052 X-C
2000′
No. 5
Shaft
3051 X-C
1000′
1000′
2000′
3000′
F.C.W. 10.40

Fig. 5

hand corner of the camera and passes over a sprocket-edged cylinder whose axis is parallel to the axis of the cylindrical lens, both being perpendicular to the plane of the photograph. This recording strip is run through by crank winding, the speed being judged by the operator.

The records are timed by an electrically-driven tuning fork shown in the centre of the right hand side of the camera box. Eclipsing slits on the vibrating tine of the fork instantaneously flood the cylindrical lens with light a hundred times a second, each time impressing a fine line across the paper record. Samples of short sections of these records are shown, full size, in Figs. 12 and 13. Only three geophone circuits were commonly used in the experiments at Lake Shore and at Frood. In some cases, only one was in operation. For some of the records a Brush microphone pick-up was used in place of the corresponding SSC geophone and, on some, one of the circuits was connected to the spare Heiland geophone. These extra pick-ups were used to cover more efficiently the frequency ranges likely to be encountered in these special experiments.

III. Initial Experiments at Lake Shore Mines with Leet Equipment.

After two days of assembling and testing in the laboratory, the seismograph was taken underground and moved on a small mine car to a position on the 3075'-level (see Fig. 5). It was operated a little north of the Lake Shore boundary as shown on the plan. Three of the galvanometer tracks were used for pick-ups: an SSC geophone, the spare Heiland geophone, and the Brush crystal detector described in Report No. 2 (appendix Fig. 1). The natural frequency of the SSC geophone as measured in the laboratory was 38 cycles per sec. That of the Heiland geophone was about 20 cycles per sec. The crystal pick-up was rated as being sensitive from 1 to 5,000 cycles per sec.

The spare geophone line was used for signalling through small currents sent through its galvanometer. A telegraph key was used by one observer to note by deflections of the signal record line the occurrence of certain observed noises, regarding which notes were made by another. It was found difficult to make the closing of the key sufficiently short to give a definitive signal. After the first few experiment periods, the method was abandoned.

The experiments were carried out during blasting time. In a few cases only, the air wave penetrated to the observation point and registered, especially on the line from the crystal pick-up. The frequency of such waves was very low, about 20 cycles per sec. (see Fig. 12e) and the amplitude high.

It was found that all the blasts registered with frequencies of from 40 to 60 cycles per second but that in some cases other frequencies of from 200 to 400 cycles per second were registered. These higher frequencies occurred, sometimes, right at the beginning of the shorter frequency series; sometimes, from .08 to .11 sec. before and also right at the beginning. In a few cases, a high frequency registration occurred when there was no blasting and, in others, the frequency characteristic of blasting had no high frequency imposed on its initial swings. It was observed, too, that the low frequency usually decreased slightly after the first few swings.

Samples of records made in Lake Shore Mines during this period are given in Figs. 12a, 12c, 12d, 12e. The description of each appears on the page facing Fig. 12. The observations were discontinued at Lake Shore Mines after about a week, the equipment being taken to Sudbury by Mr. Gibbs for use in the Frood Mine of the International Nickel Co.

IV. Experiments at Frood Mine with Leet Equipment.

The experiments at the Frood Mine began on October 9 and continued until October 24. The first set up was made in a special observing room on the 2800'-level which had been converted from a powder magazine to a seismograph station. This room is adjacent to a travelled cross cut. There was considerable disturbance due to passing trains and electric locomotives. Stray electric currents affected the galvanometer circuits and acid-charged water tended to short the cable.

Small strain bursts are relatively frequent in the Frood Mine. It was expected that good records would be obtained of burst, vibration frequency. The disturbances were so great however that daytime observing was abandoned. Conditions at night were much better and some good records were obtained at this first location.

It was decided to attempt some velocity measurements while the equipment was in a section of the mine best suited to such investigations. Blasts could be set off about 2,000 ft. distant and the development drifts provided a convenient path for the connecting cables.

Experience showed that the equipment could not be used for this work without considerable modification. This was out of the question since the instruments were on lease. The only velocity value obtained was 12,120 ft/sec. This is of the order one would expect but the doubtful values of the basic data render it quite uncertain. The velocity determinations were made difficult by electrical interference on the connecting cables and by the difficulty experienced in getting sufficient energy from the blasts without throwing down a prohibitive amount of muck. One blast of three sticks at 2,000 ft. brought down about ten tons of muck into the drift and failed to register on the geophones.

Attempts to continue velocity experiments were finally halted when the acid-charged water in the drift attacked the cables and necessitated a complete overhaul of the equipment. It was decided to move to the 2000'-level where a set-up was made between manways 27.25 and 27.75 in a narrow travel-way about 30 ft. above the drift. The geophones were placed on solid rock and set with plaster of paris.

Interference here was much less. There were considerably more small strain bursts in the immediate vicinity. A large number of good records of both blasts and bursts was obtained. The average low frequency obtained from all the Frood blast records was 60. The average for the high frequency was 272. The average for the frequency of vibration of small, known, isolated strain bursts was 223.

Samples of records made at the Frood Mine are shown in Fig. 12b, 12f, and Figs. 13a, 13b, 13c, 13d. Further details regarding these records are given on the page facing the group illustrations.

V. Testing Experiments with Leet Equipment.

The very definite recording of two groups of frequencies raised the question of whether the higher values might not be due to some resonance characteristic of the equipment. The arguments against such a conclusion were several: (a) pick-ups of different natural frequencies recorded the rapid

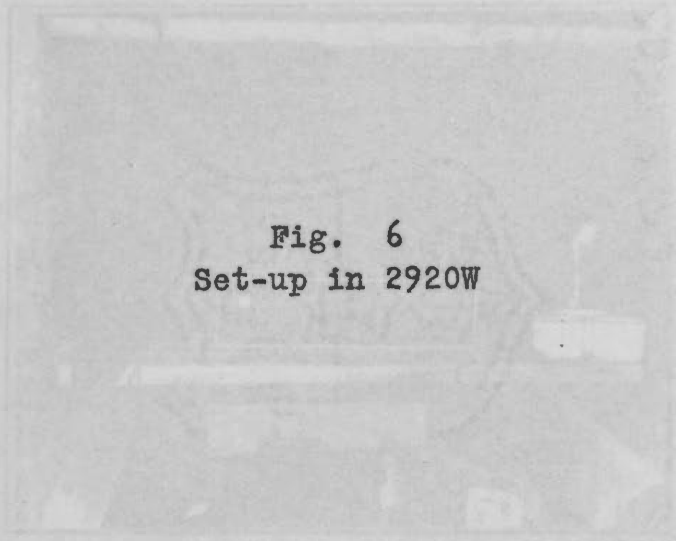


Fig. 6
Set-up in 2920W

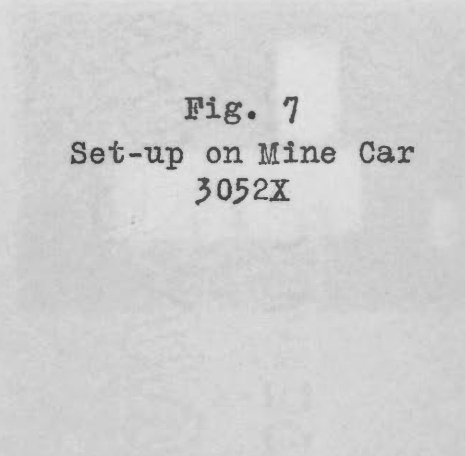


Fig. 7
Set-up on Mine Car
3052X

Fig. 9
Air Turbine

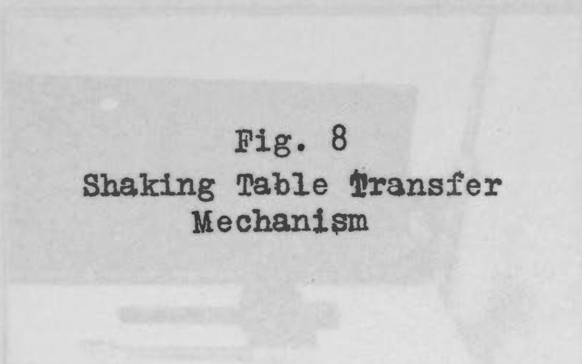


Fig. 8
Shaking Table Transfer
Mechanism

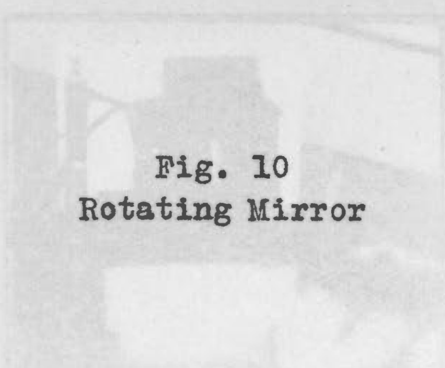


Fig. 10
Rotating Mirror

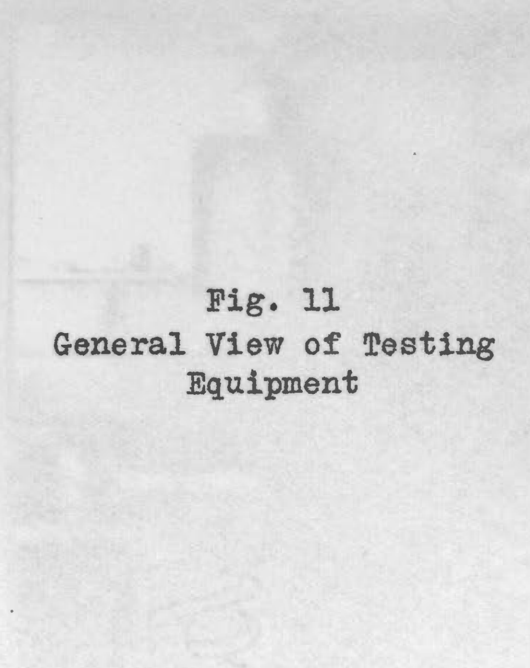
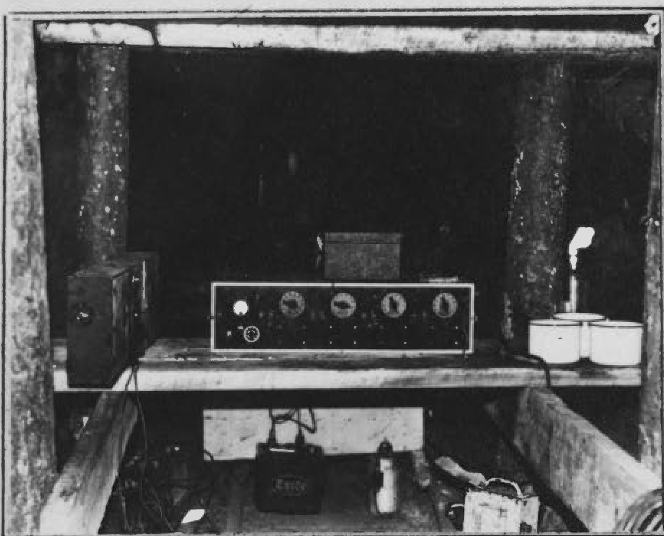
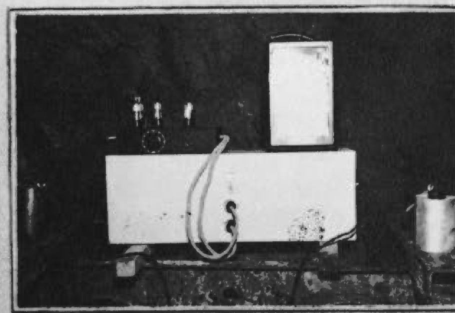
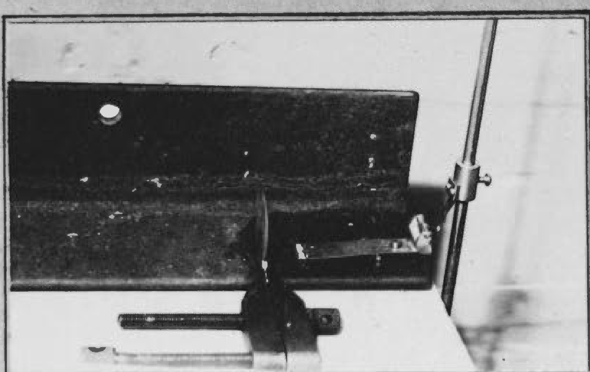
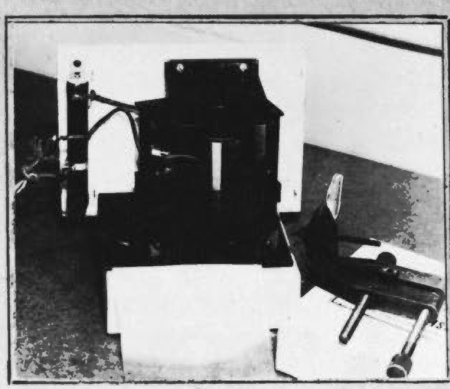


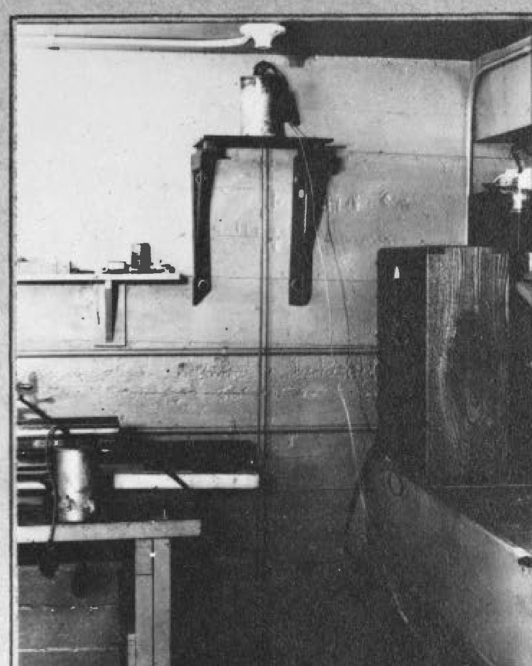
Fig. 11
General View of Testing
Equipment











movements at essentially the same frequency (but different amplitudes); (b) at times the high frequencies occurred when no blasting was recorded and at others blasting frequencies registered alone; (c) the character of the records, made with the same equipment but in different mines, differed somewhat in the frequency values and also in the relative positions of the two frequencies. To satisfy some lingering doubts, Mr. Gibbs, on arriving again in Kirkland Lake after October 25, decided to impress various known frequencies on the equipment and record the movements in the usual way.

The arrangements in the laboratory are shown in Figs. 8, 9, 10, 11. The pick-up geophone was placed on the shaking table shown at top centre of Fig. 11. This consisted of a heavy sheet metal plate resting on four cushions of sponge rubber and supported on heavy brackets on a solid cement wall. For some of the experiments the table and its pick-up were shaken by means of a second geophone excited by a small current of known frequency, supplied from the beat-frequency oscillator shown at right centre in Fig. 11. The driving geophone was placed on the floor and its disturbance communicated to the shaking table by means of the vertical rod.

At bench level the rod was connected to a lever by means of which a beam of light was focussed on an hexagonal revolving mirror shown in Fig. 10. The optical magnification employed was about 2,000. By this means the form of the motion imparted to the table was made visible. The frequency was known from the input frequency, given by the dial on the oscillator.

The system worked well up to 100 c.p.s. when the masses involved proved too great. For higher frequencies the small air turbine (see Fig. 9) from an automobile windshield fan was used as motive power. The blades were removed and a slightly-eccentric fly-wheel substituted. The speed of the turbine, and hence the frequency of the motion imparted to the shaking table, was measured by matching the note of the 20-blade turbine in operation with the beat-frequency oscillator note and dividing the dial-indicated frequency by 20. For frequencies over 100 c.p.s., the rotating mirror method of viewing the table motion became inoperative.

A large number of observations were made at frequencies

Fig. 12a. Record No. 47 (LS).

Small burst with no blast frequency
Some interference from 50-cycle tuning fork used for timing.

Fig. 12b. Record No. 82 (F).

Burst superposed on blast.

Fig. 12c. Record No. 21 (LS).

High frequency .10 sec. before blast frequency and also at the beginning of blast.

Fig. 12d. Record No. 42 (LS).

Same as Fig. 12c, except that the lag of blast frequency is only .08 sec.

Fig. 12e. Record No. 38 (LS).

Air wave from earlier blast, with high frequency preceding a blast by .10 sec.

Fig. 12f. Record No. 75 (F).

Blast, showing high frequency quite missing.
Note lag of successive records due to spacing of pick-ups.

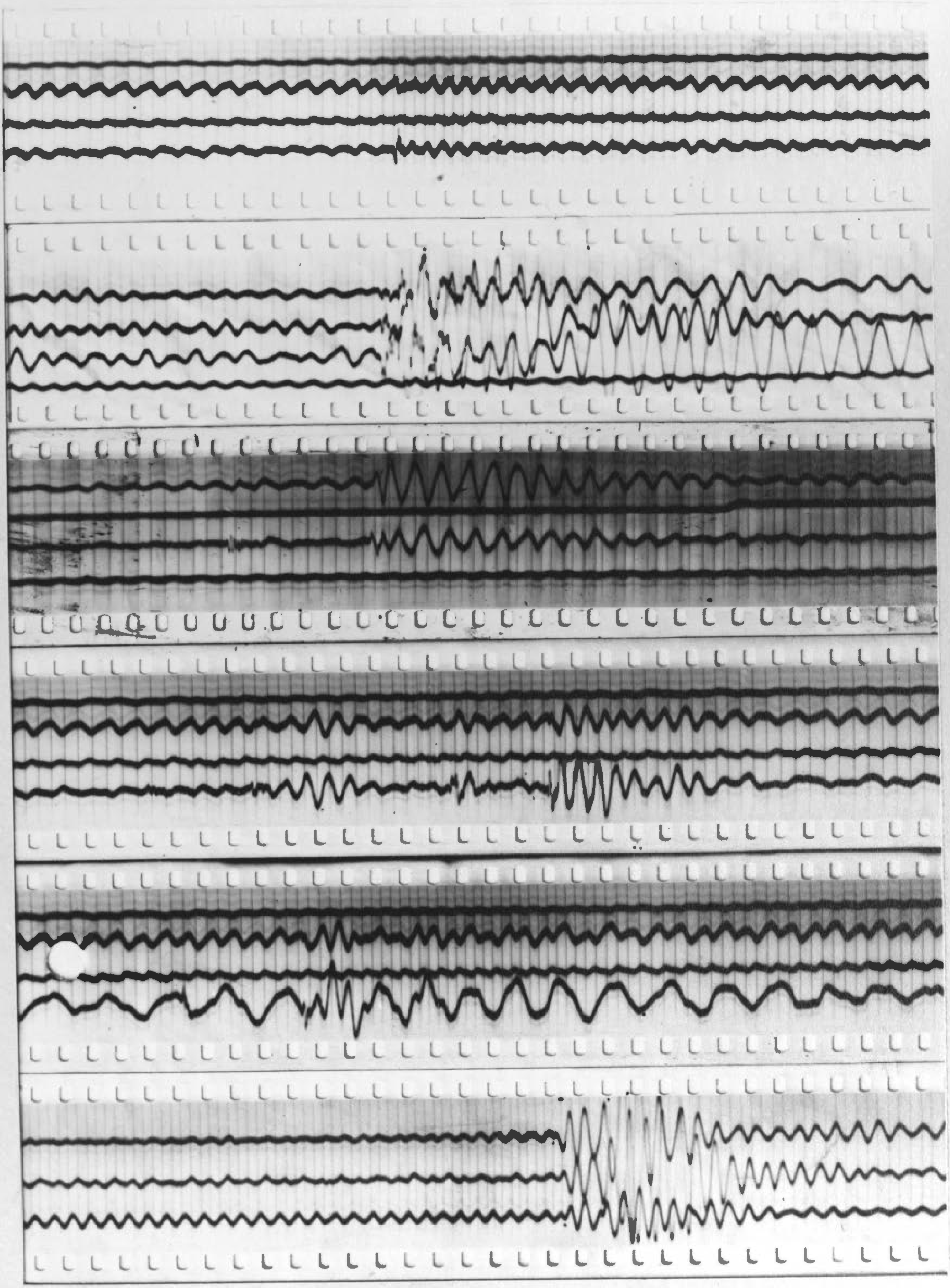


Fig. 13a. Record No. 94 (F).

Showing effects due to tramming.

Fig. 13b. Record No. 111 (F).

Showing effects due to crusher.

Fig. 13c. Record No. 87 (F)

Showing effect of pulling chutes.

Fig. 13d. Record No. 86 (F)

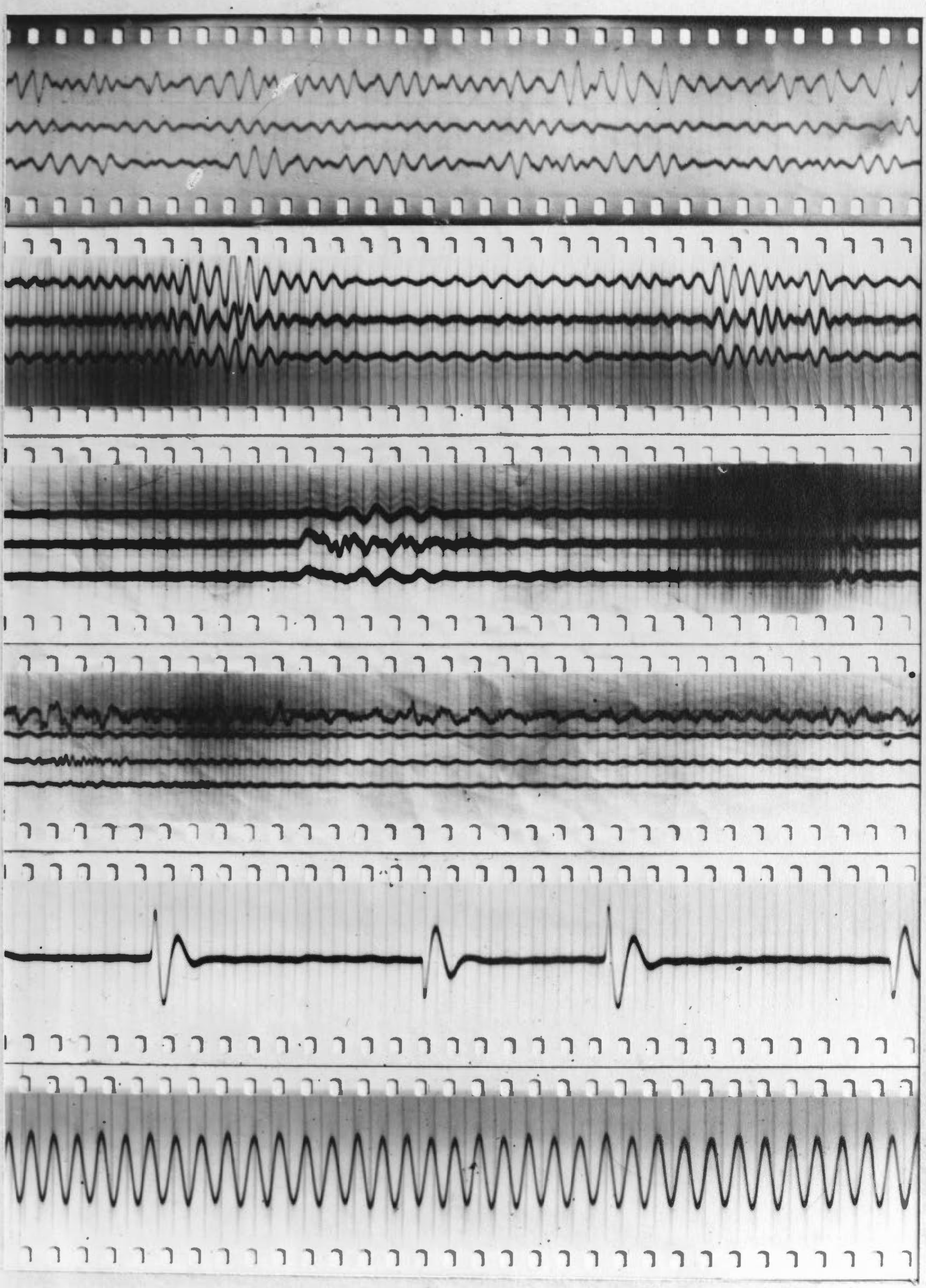
Showing effect of drill in nearby stope.

Fig. 13e. Record No. 140 (LS)

Record made by impressing disturbance on geophone of 2 c.p.s.

Fig. 13f. Record No. 146 (LS)

Record made by impressing disturbance on geophone of 54 c.p.s.



up to about 200 c.p.s., and, in no case, was the recording other than that observed by the rotating mirror. The recorded frequencies matched the input frequencies, as given by the beat-frequency oscillator, directly, or indirectly in the case of the turbine.

Two examples of the records are given in Figs. 13e, 13f. The first of these shows input at 2 c.p.s. and the second 54 c.p.s. The first was chosen for the report since it is in the nature of a series of sharp impulses and the second because it so closely approximates to the average blast frequency.

The entire program of checking the output of the Leet equipment was initiated, planned, and executed by Mr. Gibbs at the Lake Shore laboratory.

VI. Final Experiments at Lake Shore Mines with Leet Equipment.

The final experiments at Lake Shore Mines were of four types:

(a) Records made during blasting time.
(b) Velocity records.
(c) Records of typical disturbances.
(d) Records made in off-shift periods.

The first-type records were made on the 2975'-level, in a specially-prepared shelter in 2920W (see Fig. 6), and also in the long cross-cut, 3052W, where the equipment was simply wheeled into place on a small mine car (see Fig. 7). The results agreed entirely with those reported in Section III above.

Attempts at velocity records were made on the 1000'-level and also on the 4000'-level. The same difficulties were encountered as at Frood. The trouble with moisture was especially pronounced. No records of any value were obtained.

Records were made of typical mine noises, due to tramming, drilling, chute-pulling, etc. These were similar to those obtained at the Frood Mine as shown in Figs. 13a, 13b, 13c, 13d. In no case were mine noises of frequency higher than that of blasting except those caused by the drill (see Fig. 13d). Here the frequency is of the

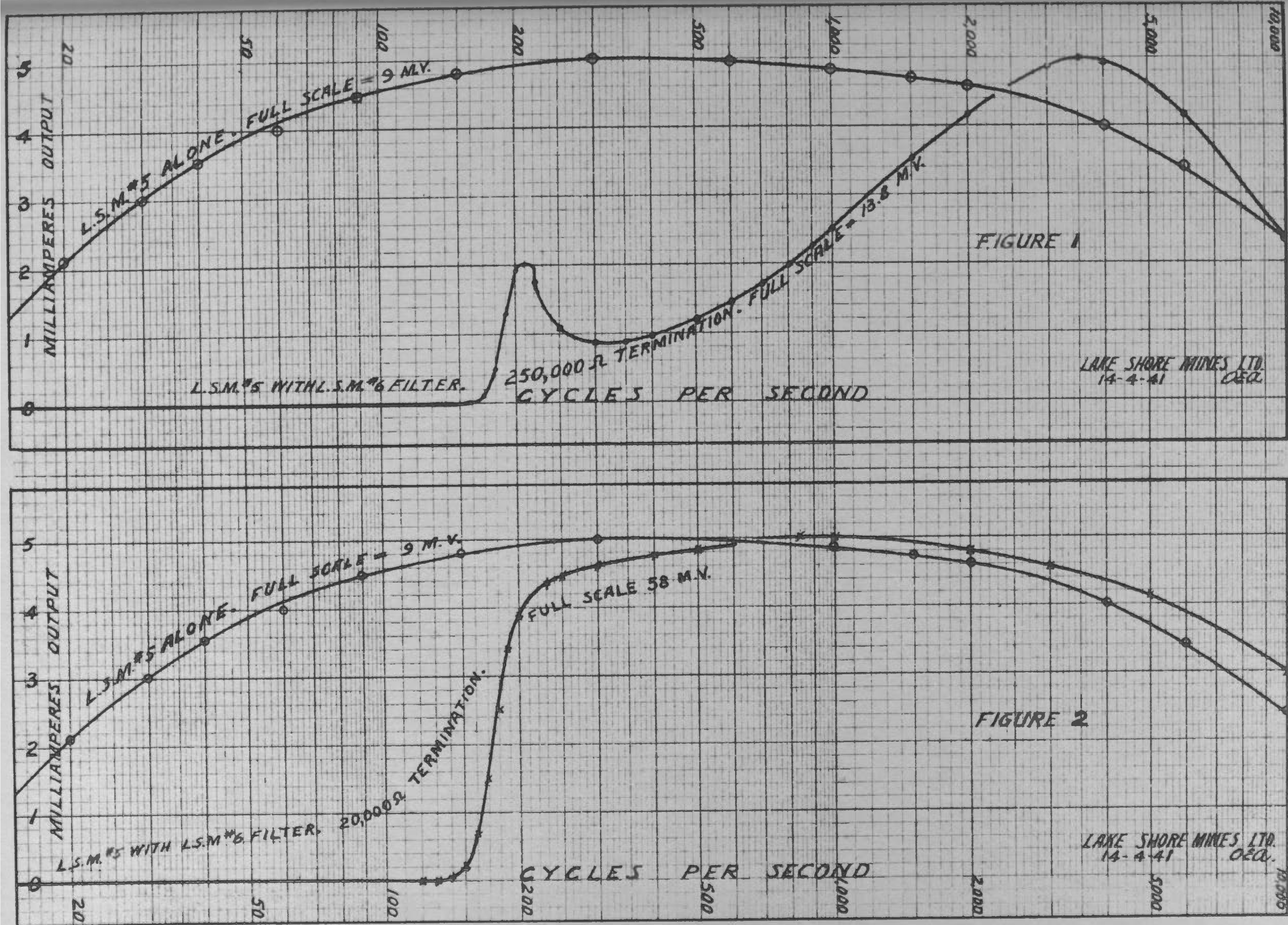


FIGURE 1
MILLIAMPERES OUTPUT
CYCLES PER SECOND
L.S.M. #5 ALONE. FULL SCALE = 9 M.V.
L.S.M. #5 WITH L.S.M. #6 FILTER.
250,000 Ω TERMINATION. FULL SCALE = 13.8 M.V.
LAKE SHORE MINES LTD.
14-4-41
FIGURE 2
MILLIAMPERES OUTPUT
CYCLES PER SECOND
L.S.M. #5 ALONE. FULL SCALE = 9 M.V.
FULL SCALE 58 M.V.
L.S.M. #5 WITH L.S.M. #6 FILTER. 20,000 Ω TERMINATION.
LAKE SHORE MINES LTD.
14-4-41

Fig. 14

order of 250 c.p.s. Drilling does not register, either on the Leet equipment or the mine seismograph, unless it is taking place very near the instruments,- usually in the adjacent stope.

Making records in off-shift periods is a little like trying to take a moving picture of a street accident by repeatedly taking short shots of a busy corner The operator entered the mine soon after blasting time when small strain bursts are most common. He ran sections of record paper at intervals. Notes were made for each section as to what noises were heard and at about what part of the record. Several small strain bursts were registered in this way and one rather severe one at a little distance. The frequencies obtained for these were always high. The method was adopted as an off-chance means of obtaining useful data and using up the remainder of the photographic paper before the lease period expired. It entailed a great deal of work in developing the many feet of paper, scanning it in connection with the notes, and picking out the few useful sections.

The equipment was shipped back to Harvard on October 25.

VII. Filter Designed for Mine Seismograph.

Accepting the deduction from the experiments outlined above, that there is a wide difference in the frequency range of blasts and that of bursts, it became desirable to secure a filter for use with the mine seismograph, which would reject pure blast frequency and accept that of bursts, either alone or released by blasting.

The design and construction of these filters was referred to General Radio Corporation of Cambridge, Mass. Because of the pressure of defense work, they were unable to supply the filters without very considerable delay. However, they kindly furnished the specifications for their construction. The filters were made, with little delay, by the Hammond Manufacturing Co. of Guelph, Ont.

On being tested they were found to require some modification of their terminal impedances. When these were corrected they gave a very satisfactory cut off to a little below 200 c.p.s., as shown by the graph E of Appendix II. They are also shown in somewhat greater detail in Fig. 14. This diagram was made and copied for this report by Mr. O.

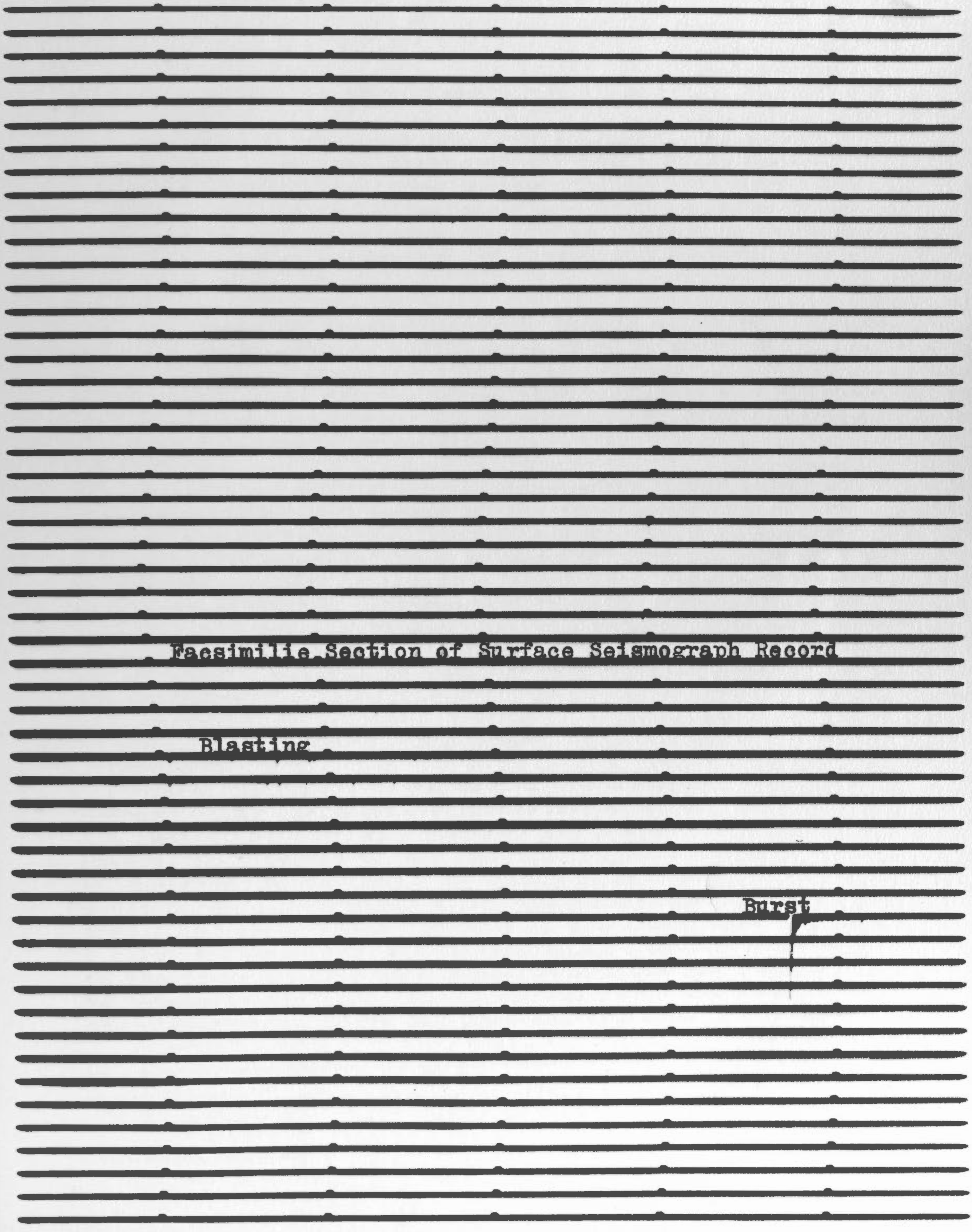

Facsimilie Section of Surface Seismograph Record
Blasting
Burst

Fig. 15

E. Andrew of the staff of Lake Shore Mines.

The mine seismograph has been operated, since about February 25, with this filter in circuit. It has been tested at various positions in the mine and has been found to reduce the number of registrations of blasts but at some locations it passes so many that it is difficult to believe that such a large percentage of blasts can be coupled with induced bursts.

Experiments, carried somewhat beyond the time range of this report (April 15, 1941), have finally shown that, if the seismograph, with its filter, is located in the 3052 X-cut, it records all the known strain bursts very definitely and records only about 5 per cent of the blasting when set at 2.5 decibels attenuation.

The record from the mine seismograph under these circumstances shows all bursts of any importance and so few blasts that it is safe to conclude that these registered blasts are accompanied by a release of strain. The location at the extreme end of the 3052 X-cut (see Fig. 5) results in all blasts being well removed from the vicinity of the instrument. It is believed that its record under these conditions may be taken as a measure of the release of strain in the mine. Further details of this work will be given in Report No. 7.

VIII. Description of the Microgauge*.

This instrument is an electrical measuring device of compact form, designed for installation at any depth in a 1.5 inch diamond drill hole, for the purpose of measuring changes in diameter of the hole due to changes in pressure on the surrounding rock. It consists of a pair of coils wound on soft iron cores which are secured in a rectangular iron frame which forms the body of the gauge (see Fig. 20). A thin, rectangular, iron diaphragm is inserted in slots in the frame to take up a position between the poles. It is thus slightly bent, so that pressure on the frame causes the diaphragm to leave one pole and approach the other.

---

* The text of this section has been furnished by Mr. V. E. Hollinsworth, who designed the microgauge.

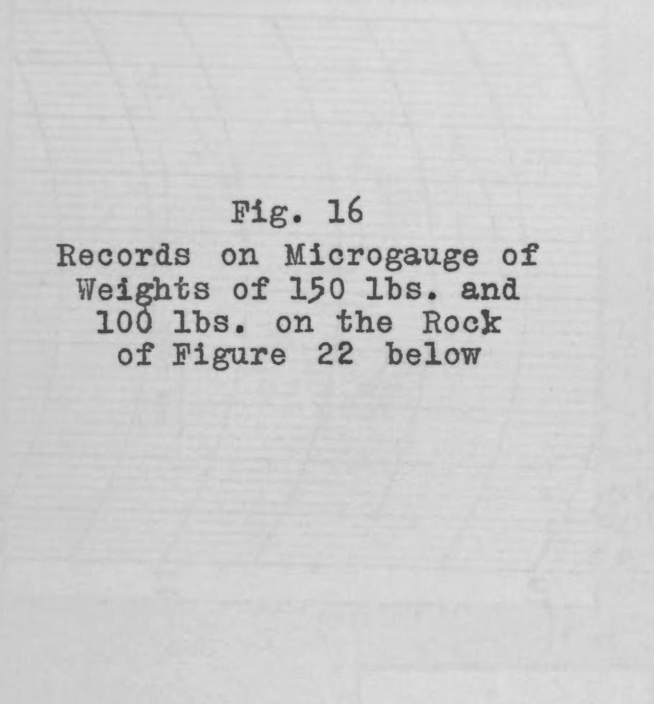


Fig. 16
Records on Microgauge of Weights of 150 lbs. and 100 lbs. on the Rock of Figure 22 below

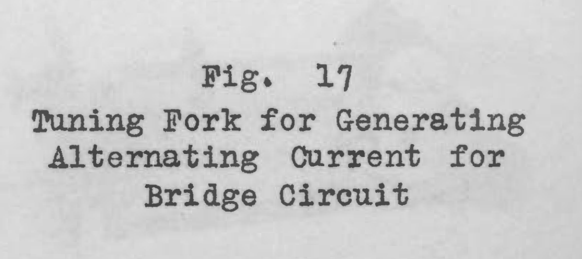


Fig. 17
Tuning Fork for Generating Alternating Current for Bridge Circuit

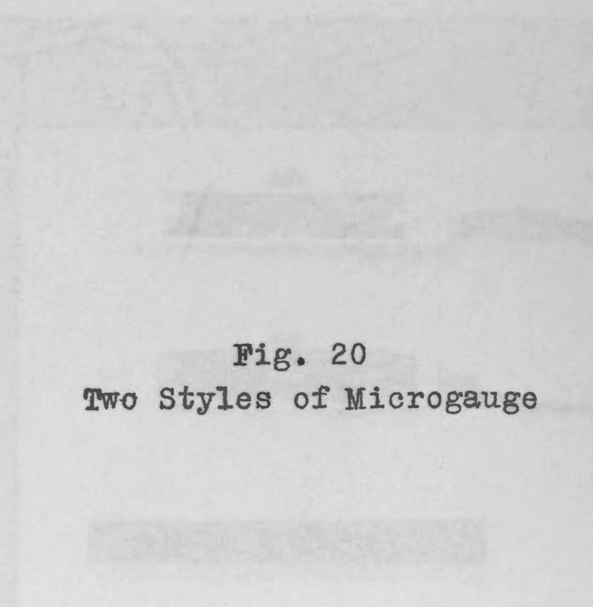


Fig. 20
Two Styles of Microgauge

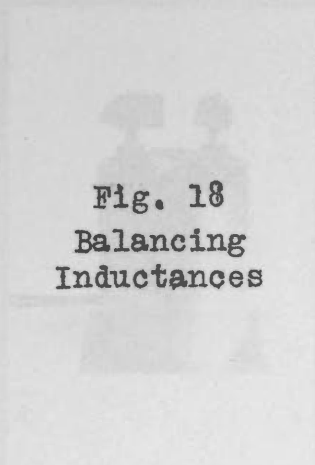


Fig. 18
Balancing Inductances

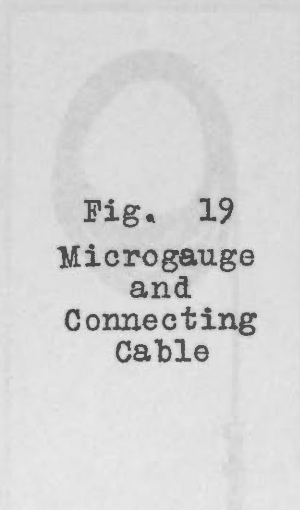


Fig. 19
Microgauge and Connecting Cable

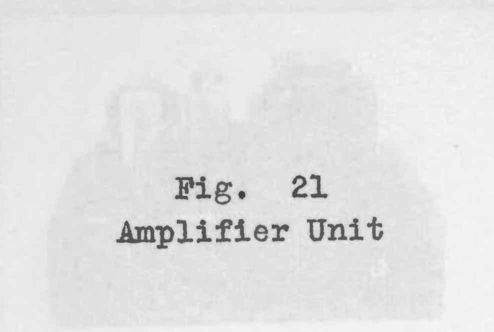


Fig. 21
Amplifier Unit

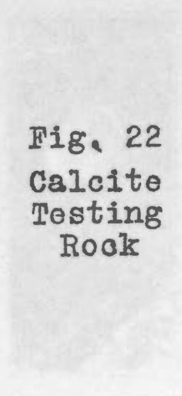


Fig. 22
Calcite Testing Rock

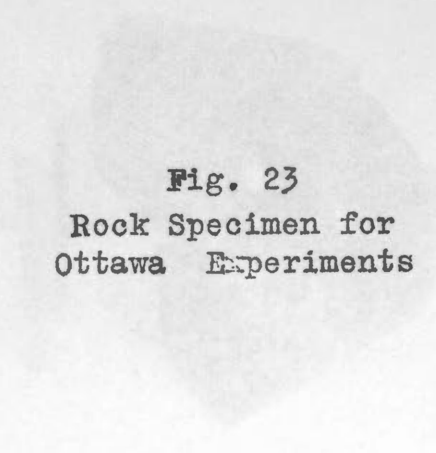
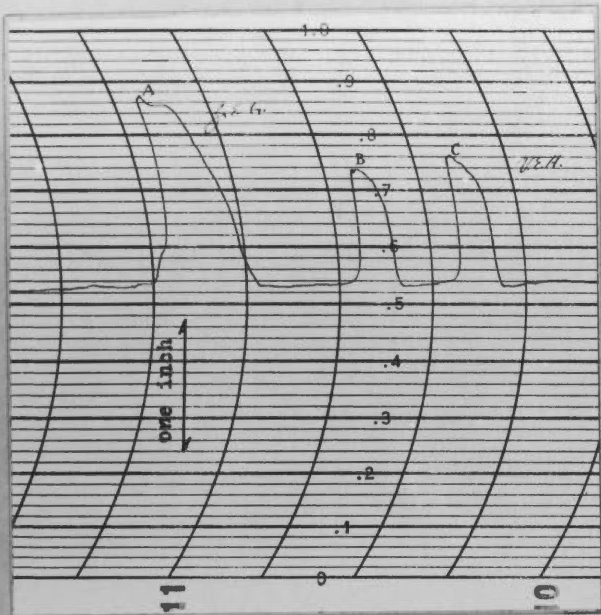
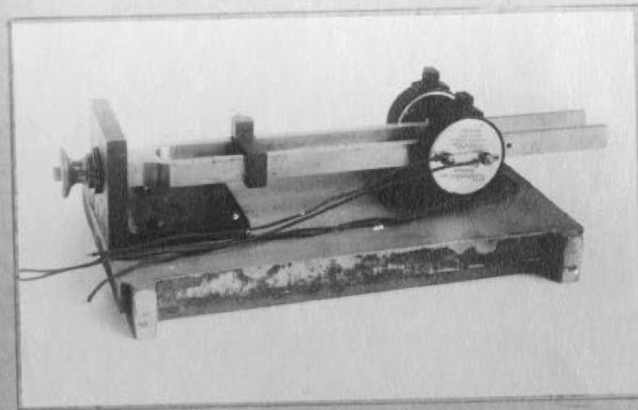
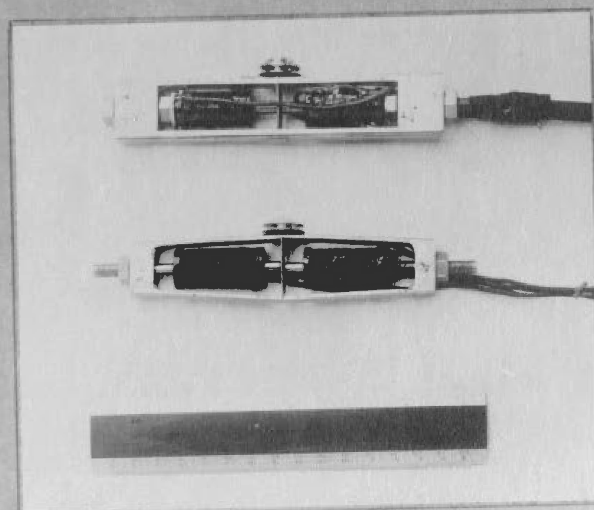
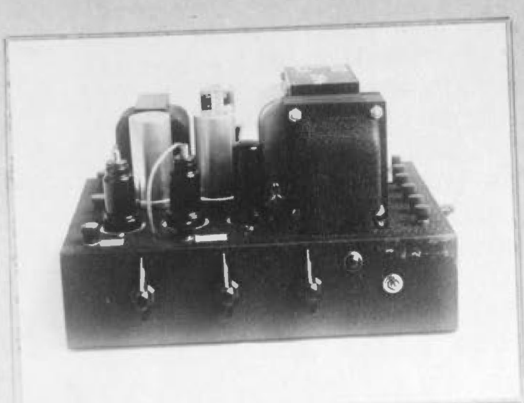


Fig. 23
Rock Specimen for Ottawa Experiments


1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
A
B
C
one inch
11
10



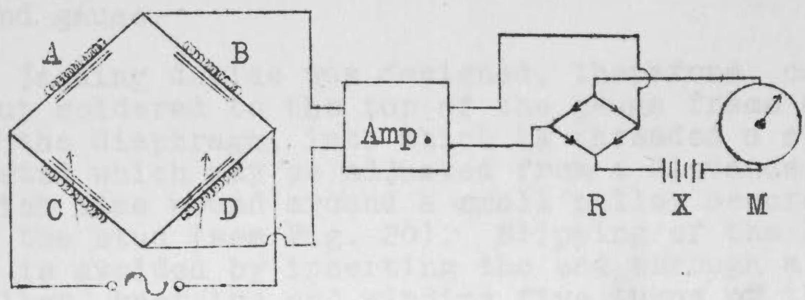





KEUFFEL & ESSER CO

The coils are used as two arms, A and B, of a standard Wheatstone bridge circuit which are balanced against two other arms, C and D, of a resistive or inductive type in the customary way. In the experimental work at Lake Shore Mines during March and April, 1941, arms C and D were variable inductances, i.e., coils in which the iron cores could be adjusted in or out, and were conveniently mounted in a cylindrical container as shown in Fig. 18.

The centre of the bridge, instead of going to the usual galvanometer indicating device, is applied to the input of a two-tube amplifier of conventional design, as shown below. The output of the amplifier is put through a small, dry-disc



Wiring Diagram of Microgauge

rectifier, converting the 60-cycle current, supplied to the bridge, to direct current, which operates a D.C. milliammeter of either visible or recording type.

With the bridge adjusted for balance by means of the variable arms, no voltage is applied to the input of the amplifier, hence no indication is shown on the output meter or recorder. However, the balanced condition may be upset by applying pressure to the gauge frame, so that the diaphragm is moved toward one pole and away from the other, as previously mentioned. This causes a variation in the inductances of the two coils due to the change in length of the air gaps, allowing more magnetic flux to flow through one coil and less through the other.

If, in the original assembly of the gauge, the poles on which the coils are wound, are adjusted very closely to the diaphragm so that the air gaps are of the order of 3×10^{-4} inches, or smaller, then a slight change in the position of the diaphragm appreciably changes the size of the air gaps and hence the values of the inductances depending on these air gaps for completion of their magnetic circuits. The sole purpose of the amplifier is to magnify these small changes to readable values.

To render the gauge of practical use under mine conditions, it was found necessary to enclose it in a moisture-tight tube, as shown in Fig. 19. This prevents rusting and guards against the destructive effects on the coils of excessive humidity. Means had also to be provided for clamping the gauge firmly at any desired depth in the drill hole in such a manner that there could be no lost motion between rock and gauge.

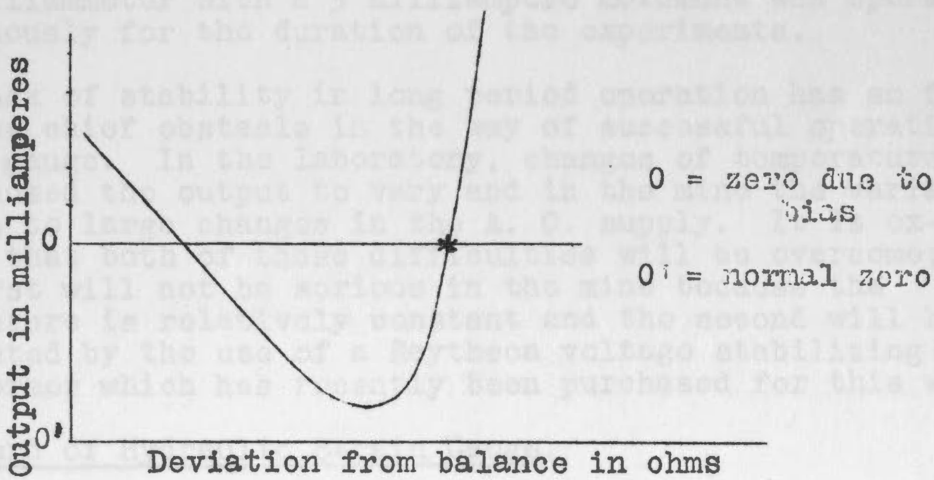
A jacking device was designed, therefore, consisting of a nut soldered to the top of the gauge frame directly above the diaphragm, into which is threaded a stainless steel stud which may be adjusted from a distance by means of a fish line wound around a small pulley secured to the top of the stud (see Fig. 20). Slipping of the line on the pulley is avoided by inserting the end through a hole in the pulley, knotting and winding five turns of the line in the pulley groove. Two such cords are wound on the pulley in opposite directions.

Flat phosphor bronze springs are attached to each end of the tube, providing a friction fit with the drill hole. This steadies the gauge while it is being clamped, and also prevents disturbance of this adjustment by accidental motion of the rubber covered cable leading from the gauge to the bridge and amplifier. The cable is standard microphone type, shielded to prevent stray pick-up.

The gauge is pushed into the drill hole by means of six-foot lengths of quarter-inch iron rod coupled together. These are removed after the gauge is oriented and clamped. No difficulty was experienced at the mine in inserting the gauge in a drill hole to a depth of 14 feet, that being the length of the push rods on hand.

The operation of the bridge is dependent on a stable supply of alternating current of a frequency between 50 and 100 cycles. In the laboratory the 60-cycle supply is very satisfactory, but in the mine where only 25-cycle current is available another source had to be provided. For this purpose an electrically driven 50-cycle tuning fork was used in conjunction with a two-tube, fork amplifier which maintained the oscillation of the fork and provided the required stable voltage and current for the bridge. To prevent troublesome beats between the fork and the first harmonic of the 25-cycle supply, the frequency of the fork was later altered to 62 1/2 cycles by means of clamps.

To check the stability of the bridge circuit and amplifier, a dummy gauge was constructed very similar in design to the working gauge, except for a rigid iron section instead of a moveable vane. This could be substituted for the working gauge by means of a convenient switch and, as it was under no strain, the output meter should give a constant reading.



An examination of the gauge circuit, given at the beginning of this section, shows a bias battery in series with the output meter. This is not essential to the operation of the circuit but a considerable increase in sensitivity is obtained by its use. This gain is derived by purposely unbalancing the bridge, by means of the variable arms, and then bucking the output current, caused by the unbalance, with the bias battery, until the output meter comes to zero. This procedure permits the operation of the circuit at a more favourable position on the bridge balance curve, i.e., from a point part way up the side of the curve where the slope is steep rather than at the bottom where the slope is gradual. This also gives practically a linear output. A curve of output vs. deviation from balance, or ratio of variable arms, C and D, is shown above and the operating point is indicated. It will be noted that this curve is not symmetrical. The lack of symmetry is due to distortion from sine form of the current wave as it passes through the inductances of the gauge to the input of the amplifier. Additional distortion is encountered if the wave form supplied to the bridge by the tuning fork or the 60 cycle line is not sinusoidal. This is especially true where a regulating transformer is used to prevent variation in voltage.

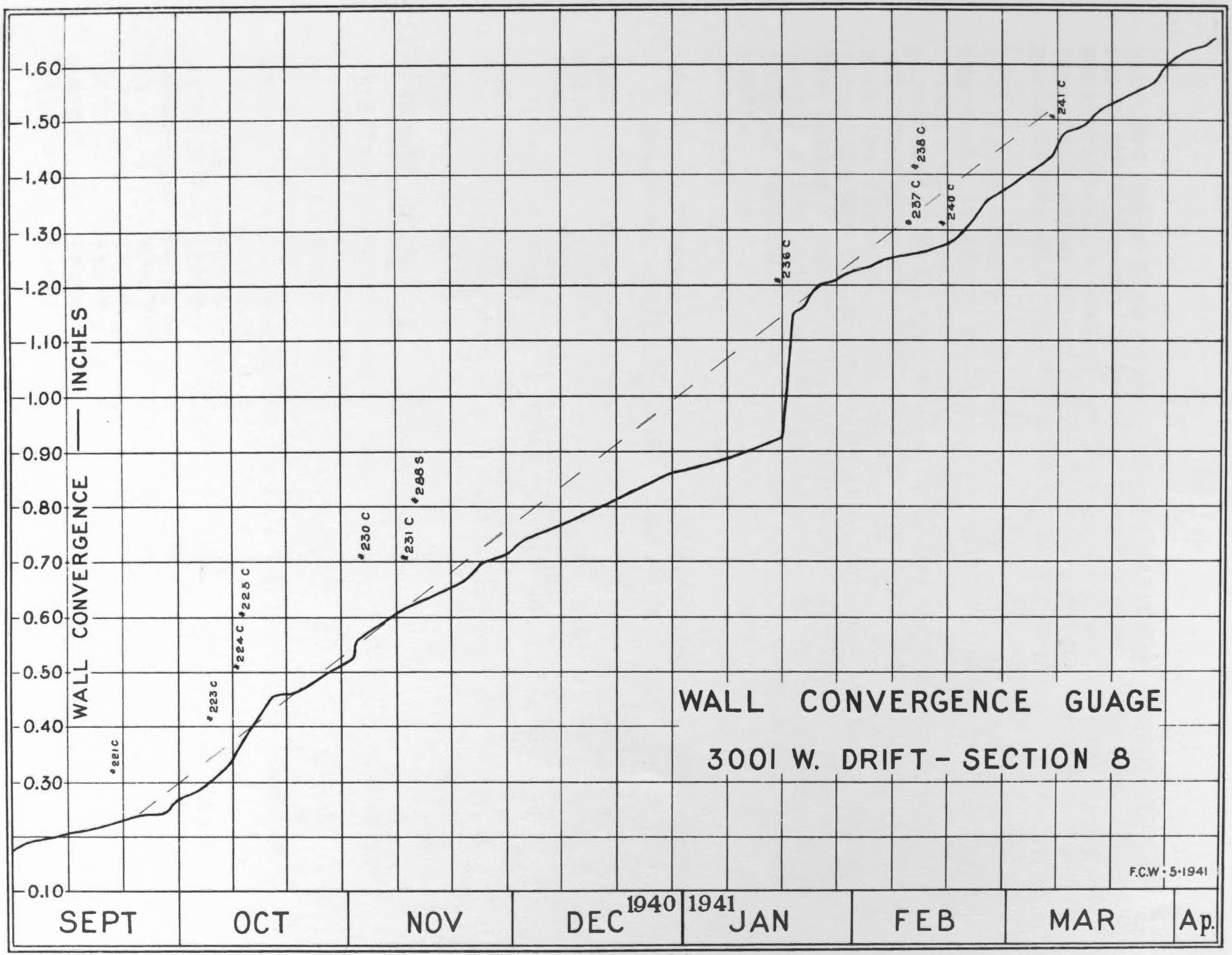
Two types of output meters have been used with the microgauge. For the laboratory work, a large Weston meter having a 3 milliampere movement and a 7 in. scale was found very satisfactory. At the mine, an Esterline-Angus recording milliammeter with a 5 milliampere movement was operated continuously for the duration of the experiments.

Lack of stability in long period operation has so far been the chief obstacle in the way of successful operation of the gauge. In the laboratory, changes of temperature have caused the output to vary and in the mine the variation was due to large changes in the A. C. supply. It is expected that both of these difficulties will be overcome; the first will not be serious in the mine because the temperature is relatively constant and the second will be eliminated by the use of a Raytheon voltage stabilizing transformer which has recently been purchased for this work.

IX. Record of Hydraulic Strain Gauge.

The hydraulic strain gauge, designed and constructed at Lake Shore Mines by members of the mine staff, was described in Report No. 3 (see Fig. 16 of that report). It was installed early in September, 1940, in 3001W drift, Section 8. This was known to be a particularly unstable part of the workings.

The gauge consisted of a heavy, brass cylinder with an internal diameter of about one inch. This is closed at one end by a piston working through a packed sleeve. The other end opened into a glass tube at right angles to the brass cylinder. The ratio of areas of internal cross sections of the tube was found to be 12:1. The liquid used was a coloured light oil.


WALL CONVERGENCE GUAGE
3001 W. DRIFT - SECTION 8
WALL CONVERGENCE — INCHES
-1.60
-1.50
-1.40
-1.30
-1.20
-1.10
-1.00
-0.90
-0.80
-0.70
-0.60
-0.50
-0.40
-0.30
-0.10
SEPT
OCT
NOV
DEC
1940
1941
JAN
FEB
MAR
Ap.
#221C
#223C
#224C
#225C
#230C
#231C
#288S
#236C
#237C
#238C
#240C
#241C
F.C.W. 5-1941
Fig. 24

Two holes were drilled opposite to each other in the opposing walls of the drift, to a depth of about six feet,- well within the spalled surface. Into these were thrust two iron rods which transmitted the pressure of the converging walls to the cylinder and piston respectively.

Daily readings of the gauge were taken. A graph showing these is given as Fig. 24. This was drawn by Mr. Frank Weskett of the Observatory staff from a copy of the original plot furnished by the mine officials. The various numbers written above the graph indicate the bursts which occurred near the location of the strain gauge. The location of these, in the order in which they occurred is given below. The letter C after a number indicates a "crush" burst. The letter S indicates a "strain burst". The time of each is roughly indicated by the position on the time scale of the graph.

No.	Location X-cut or Drift	Section	Total Rock Fall in tons	Classification
221C	3301W :	10-1	10	Light
223C	3001W :	10	10	Light
224C	2801W :		(Damage	Medium
	2819X :		(confined	"
	2918X :		(to	"
	2901W :		(timbering	"
	2902W :		(etc.	"
225C	3301W :	10-1	10	Medium
230C	3301W :	8	45	Light
	3301W :		10	"
231C	3401W :		5	Light
	3413X :		1	"
	3401W :		20	"
288S	3001W :	10	5	-
236C	2901W :	9	20	Medium
	2901W :		50	"
	3001W :	7	10	"
237C	3301W :		80	Light
238C	3401W :		Timber	Medium
	3501W :		100	"
	3701W :		12	"
	3701W :	14	5	"
240C	3202W :		25	Heavy
	3301W :		200	"

No.	Location X-cut or Drift	Section	Total Rock Fall in Tons	Classification
240C	3301W :	10-1	8	Heavy
	3401W :		20	"
	3401W :	9	30	"
241C	3301W :		40	Heavy
	3202W :		50	"
	3301W :		35	"
	3301W :	7-2	30	"

The attention of those not familiar with mine conditions, may be drawn to the fact that some "light" bursts displace more muck (broken rock) than do those designated "medium". For example, 225C is marked "medium", but displaced only 10 tons of muck, while 237C, a "light" burst, displaced 80 tons. That is to say, the intensity of the burst is not measured by the amount of rock thrown down but by general evidence of violence, including the shock noted by the miners underground and on the surface.

It may be assumed that, after a period during which the closure was taking up lost motion in the set up, the broken line on the graph shows the average closure on the gauge. Where the actual closure fell away from the average it was brought back by a large burst (236C). The light burst of early November (230C) was two levels below the drift in which the gauge was set. It seems to have caused a slight return to the average. The "medium" bursts of mid-October (224C, 225C) were in the vicinity also, one above and the other below the gauge location. They seem to have caused the graph to trend upward from the average slope. On the other hand the "light" burst of early February (237C) has no apparent effect.

The graph, after late January, was below the average line. On April 7, 1941, the date of the last reading of the gauge, the trend was still downward from the broken line. On April 8 a large burst occurred which involved Section 8 of 3001W drift, the location of the gauge. The damage done in this burst was considerable. The gauge was buried in the muck. It was probably wrecked.

While this series of observations was not long enough, nor repeated in a sufficient number of places to warrant definite conclusions, the results seem to indicate that the closure is variable and that a slowing up in closure indicates the building up of resistance (and hence pressure) which creates conditions favourable to a burst in the region under investigation.

Dominion Observatory,
Ottawa, Canada,
July 4, 1941.

Ernest A. Hodgson.

APPENDIX I

Report to Lake Shore Mines dated October 3, 1940

GEOPHYSICAL RESEARCH: ROCK BURST PROBLEM

LAKE SHORE MINES

***

Geophysical research on the rock burst problem at Lake Shore Mines was initiated on December 28, 1938. At that time, mine officials suspected that a small local earthquake might have been the triggering cause of an unusually severe burst which occurred at Lake Shore on that date. The Dominion Observatory, in response to inquiries from the mine, discovered that the burst (but no other seismic disturbance) had registered in Canada on the short-period seismographs at Ottawa, Shawinigan Falls, and Seven Falls (near Beaupré, Que.) and also at Weston (near Boston, Mass.).

A list of the larger bursts for the preceding two years was prepared at the mine and compared at the Observatory with filed seismograph records. It was found that two of these, in addition to the one on December 28, had registered at the Quebec stations, which alone had short-period instruments in operation during most of the interval. The mine decided to obtain a surface seismograph with accurate timing equipment (radio, chronometer, etc.) and arranged with the Dominion Observatory to select and install the equipment and to supervise its operation.

Subsequent to December 28, 1938, and prior to December 19, 1939, at which date the seismograph was finally placed in operation at the mine, eight rock bursts occurring at Lake Shore Mines have registered on the seismographs at Ottawa and also at one or both of the Quebec stations. Since the installation of the Lake Shore seismograph, no rock burst has occurred of sufficient intensity to register at Ottawa. If and when it does, purely scientific but very valuable travel-time seismic information will be obtained. In the meantime, the routine continuous operation of the instrument records and times all bursts occurring in the mine.

On the completion of the surface seismograph installation, the mine requested the Observatory to organize geophysical rock burst research in the mine itself. To obtain some idea of mine conditions and to determine the necessary specifications for adequate recording apparatus, an experimental mine seismograph was designed and built at the Observatory and operated in the mine during March, 1940. It was found that:

(a) Bursts and blasts alike recorded and that other operational mine noises also appeared, making the record during on-shift hours a maze of offsets.

(b) Moderately severe bursts, occurring in the mine but not in the stope or section of drift occupied by the seismograph, were on scale.

(c) Bursts seem to be initiated by the blasts and to occur with them.

To enable the necessary instruments to be built and tested, an electronics laboratory was designed and constructed at Lake Shore Mines. This laboratory has been fitted with all necessary machinery and testing equipment and permits the construction and modification of instruments in accordance with the growth of experience.

Incorporating the changes found desirable in the first experimental model, a new mine seismograph was designed and installed on June 10. This equipment makes use of the 25-cycle power supply. It was modified later, for use with batteries, and set up in a disused X-cut on the 3075'-level, where it is now in routine operation.

Various experiments with oscillographs and other equipment have been made to determine the frequency of the vibrations caused by blasts and by bursts. If these differ markedly, filters can be constructed to prevent the registration of all disturbances other than bursts. The frequency experiments failed until within the last few weeks when a portable seismic outfit was obtained from Harvard. Tests with this equipment now in progress at Lake Shore and at Frood indicate that the frequency of blasts at Lake Shore Mines is from 40 to 60 cycles per second. Definitely, this frequency varies between the limits indicated. Sufficient data have not so far been obtained to determine the cause of the variation.

The frequency of bursts has not yet been certainly determined. The present indications are, however, that it is considerably higher than that of blasts. Should this indicated frequency be proved by the further experiments now in progress, it will be a simple matter to prepare a filter to permit the registration of bursts alone.

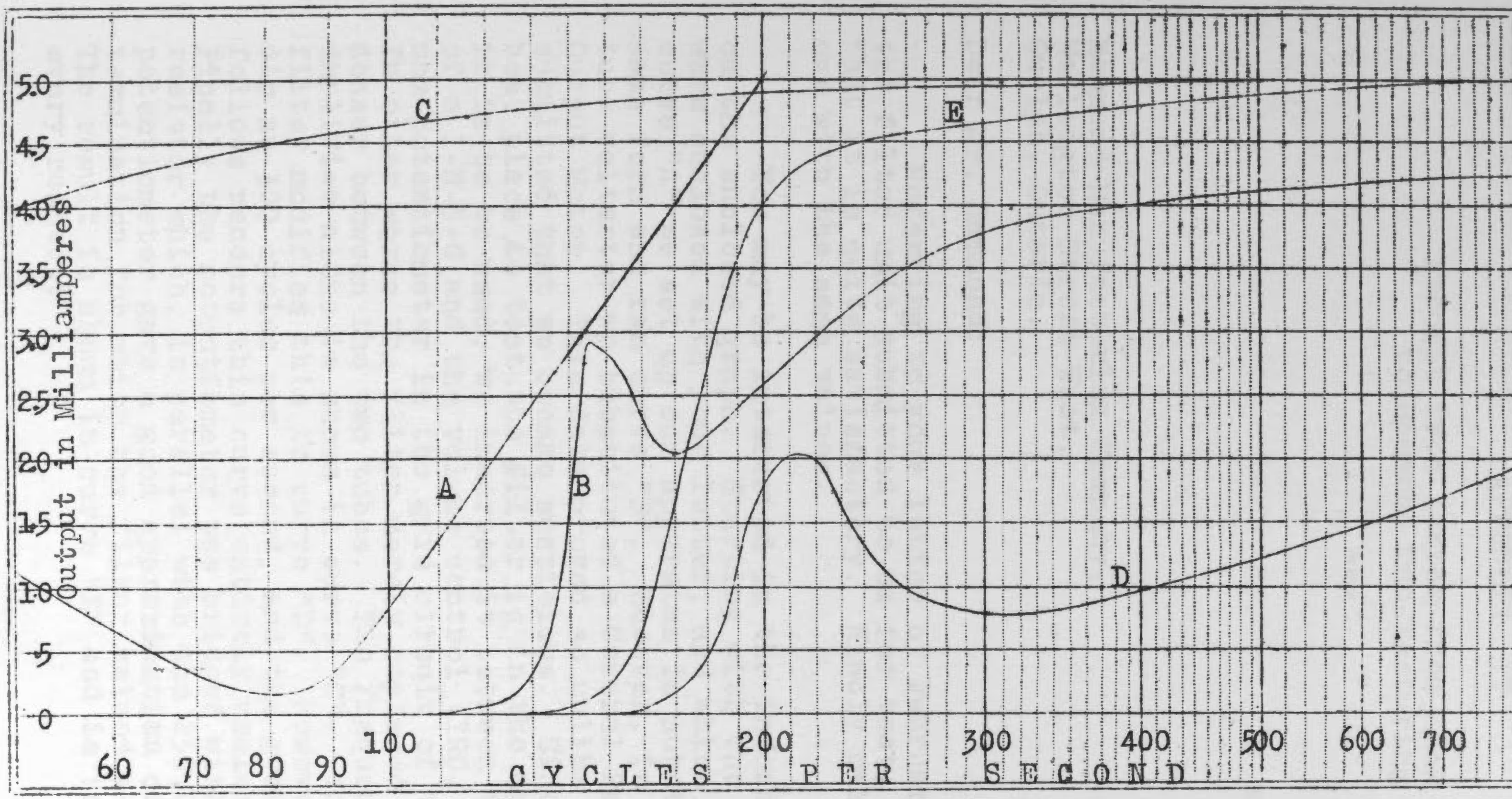
If and when such equipment is in operation, it will be possible to obtain complete and quantitative records of bursts as a matter of routine recording. Statistical studies will be made of these data as they accumulate, with a view to obtaining some indication from the plotted values as to when a burst is imminent. Such graphs, made from the rough data so far obtainable are most promising for this purpose.

Instruments are being designed, which, if the frequency be proved, can be installed in individual stopes to furnish data for statistical studies of purely local activity. This may permit the prediction of bursts in individual pillars.

Seismographs to register much higher frequencies are being designed to determine whether low amplitude, high frequency (and hence inaudible) vibrations occur in the rock as it takes on pressure. If such vibrations can be registered, statistical studies will be made of them also, with a view to prediction of bursts. It is believed that this phase of the research holds considerable promise.

The tentative program now being considered also includes studies of temperature effects and of seismic velocities as related to increasing pressure. Studies of strain gauges are also to be made. One, in operation at the present time, shows a flattening of the strain curve prior to bursts in one particular part of the mine, but further data will be required for generalization. It is planned to construct and experiment with a micro-strain gauge installed so far back in a diamond drill hole as to be in the compression zone of a dome. Continuous records from such an instrument should yield valuable information regarding the variations in pressure as a pillar is reduced.

Lake Shore Mines,
Kirkland Lake, Ont.,
October 3, 1940.



A. Hammond Co. Data
B. LSM-6 terminated in GR. 583-A
C. LSM-5 . . No Filter
D. LSM-5 plus LSM-6, 250,000 ohms termination
E. LSM-5 plus LSM-6, 20,000 ohms termination

Z.E.G.
3/10/41

CHARACTERISTICS OF
L.S.M.-6 Filter
March 1, 1941.

APPENDIX II

Excerpt from letter from Zack E. Gibbs
to Hammond Manufacturing Co.

***

March 10th, 1941.

Hammond Manufacturing Company,
Wellington Street West,
Guelph, Ontario.

Dear Mr. Hammond:

Referring to your letter of February 1st regarding the filter unit submitted to us for test, I am glad to say that it is quite satisfactory. Kindly make up the other one with the same values.

You may be interested in the information contained on the enclosed graph. Starting with the figures which were enclosed with your letter, and which are plotted as curve "A" we set up our apparatus in substantially the same form and ran curve "B". However, in lieu of a vacuum tube voltmeter we substituted a General Radio Type 583-A Output Meter. This data proved so unlike that which you submitted that we became suspicious. Since, after all, the best place to test the filter is in the apparatus with which it is to be used, we inserted it between the plate resistor of a 1-N-5-G and the volume control (IRC, A21-250) a 250,000 ohm potentiometer in the grid circuit of the following tube. In other words the filter merely replaced the coupling condenser between the two tubes. The frequency response of the amplifier alone is shown in curve "C". Insertion of the filter modifies this to curve "D". However, the pronounced dip at 300 cycles per second, and the gradual rise which follows renders this curve entirely useless for our work. Finally the potentiometer was bridged with a 21,000 ohms resistor which, in parallel with the 250,000 ohms of the potentiometer gave a good approximation of the 20,000 ohm termination for which the filter values were computed. The result is shown in curve "E" and is satisfactory in every respect.

In conclusion we are led to the assumption that the impedance of the copper oxide meter rectifier, varying as it does with frequency, produced an effective termination for the filter which departed considerably from the nominal 20,000 ohms stated on the meter, and secondly, that the performance of these filters depends greatly on their proper termination.

. . . .

Yours very truly,

LAKE SHORE MINES LTD.

Z. E. G.