# SEISMIC RESEARCH PROGRAM
# ROCK BURST PROBLEM
# LAKE SHORE MINES

Report No. 3
April 15 - August 15
1940

Ernest A. Hodgson

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# Table of Contents

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## Appendixes

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Two reports dealing with the seismic research program being carried out in collaboration with Lake Shore Mines have already been presented. The first was entitled "Seismograph Installation, Lake Shore Mines, Kirkland Lake", and dated January 31, 1940. The second, entitled "Seismic Research Program, Rock Burst Problem, Lake Shore Mines", is dated April 15, 1940.

Amendments to the second memorandum, correcting chiefly some of the statements as to geological conditions and mine operations, were kindly prepared, at the request of the Observatory, by Mr. Robson at Lake Shore Mines. These appear as Appendix I to the present account of the work.

The two earlier reports present a complete record of the work up to the middle of April last. The present memorandum is designed to bring the detailed account to August 15, 1940.

## 1. Résumé of Progress: April 15 - August 15, 1940.

At the date of the second report, Mr. Gibbs was just returning to Kirkland Lake, after two weeks spent at Ottawa in building an amplifier, in consulting catalogues and in making contacts with various manufacturers and their agents. He was hoping to find the laboratory room well advanced in construction at Lake Shore Mines. It was expected that the surface seismograph (installed Dec. 19, 1939, at Lake Shore and brought back to Ottawa by Mr. Gibbs about April 8 for some alterations) would be ready to ship to Kirkland Lake in two or three weeks. In the meantime the seismograph, constructed by Mr. Hollinsworth and used in the mine during March, was to be continued in operation at the surface station at the mine in order that the program of accurate timing of the bursts might not be interrupted.

The laboratory was completed shortly after Mr. Gibbs returned to Lake Shore on April 20. A progress report on the laboratory, prepared by Mr. Gibbs, and submitted to Mr. Todd on June 10, is presented (without the illustrative record samples) as Appendix II. The construction was carried out as recommended in the previous report except that no gas service was installed. It was felt that the need for such equipment is so slight that any work requiring it can be done in the mine shops. Supplies for constructing a mine seismograph were ordered promptly and were received without undue delay. The testing equipment for the laboratory could not be ordered until extended correspondence with various manufacturers had indicated what might be available for use with 25 cycle current. All such equipment for which need has so far arisen has now been ordered and most of it has been received. The laboratory should be in full operating condition in the very near future.

Owing to circumstances over which no one has any control, there have been many unexpected delays in obtaining instrumental equipment. For example, the synchronous motor, required for the alterations in the surface seismograph, was requisitioned by the Observatory on April 9. Because of unusual business conditions due to the war, this motor was not received until June 9. The final machine work and testing of the seismograph were thereupon promptly completed and the instrument shipped to Kirkland Lake on June 27. The first record was made at Lake Shore Mines July 2-3, since when recording has been practically continuous.

Thus, the Hollinsworth seismograph was held on surface until July 2. (It has since been returned to Ottawa for use in experimental work.) In the meantime Mr. Gibbs completed another mine seismograph, building an amplifier and related equipment and using a commercial Esterline-Angus recorder, which was obtained with a minimum of delay (May 16). After a period of testing and adjustment on the surface, this seismograph was placed in a specially prepared position on the 2950-foot level in the mine on June 10. The outfit has operated in this position continuously from that date to the present. Figs. 1-3 show the details of the installation on the 2950-foot level; at the same location first occupied during the March experiments by the Hollinsworth seismograph. The site was improved, however, by scaling off all loose from the face of the drift and building a small cement pier in intimate bond with the wall. This makes a much better mounting for the pick-up.

As was the case with the Hollinsworth seismograph, the mine records on the new instrument are confused by man-made moises: blasting, tramming, etc. It is believed that, in many cases, the blasts initiate bursts; so that many of the larger offsets at blasting time are probably due to small bursts. During the relatively quiet, off-shift periods the recorded disturbances are few. Typical sections of the records are shown, half size, in Fig. 18.

It is necessary to construct a seismograph which will not record mine noises, but which will record bursts. This can be done if the frequency of the vibrations at the time of a burst differs from the frequencies of man-made noises. If the frequency ranges were known, filters could be constructed to pass only that part of the spectrum desired. Much time has been spent with (till now inadequate) equipment in an endeavour to determine these frequencies; so far without success. This problem must be solved before further work can be efficiently carried on. Proposals to this end are given in Appendix IV (section 3) and in Appendix V (section II-3).

Rock burst research has been carried on since September 1938 at the Frood mine by the International Nickel Co. This work is under the general superintendence of Mr. R. D. Parker, General Superintendent, Mining and Smelting Division, and is administered by Dr. Arthur B. Yates, Chief Geologist, with the assistance of Mr. P. J. Shenon, Assistant Chief Geologist, Mr. H. R. Elves, Geologist, and Mr. A. E. Prince, Testing Electrician.

Close collaboration is now arranged between those working at the Frood mine and the group at Lake Shore. Data are exchanged on amplifiers, etc. and complementing programs are being arranged. In the case of one rather costly project (determination of the frequency of vibration of bursts and blasts) the experiments will be done in both mines and the overhead cost of equipment will be shared. Steps are being taken to calibrate the seismometers and amplifiers used in the two mines, so that the records may be compared qualitatively.

On June 11 last, Messrs. Parker, Yates and Shenon visited Lake Shore Mines for a conference on geophysical methods of studying the rock burst problem. A report on this conference appears herewith as Appendix III. It was then arranged that such exchange visits, back and forth, should be made at suitable intervals in the future. On July 30-31, Gibbs and Hodgson visited the Frood mine for a conference on recommendations for a continuing program. The memorandum in this connection, presented by Messrs. Yates and Shenon to Mr. Parker, appears as Appendix IV of this report. Of the recommendations then made, all were approved by Mr. Parker except that of making one of the two proposed, three-component seismograph stations an affiliate of the international seismological network. No decision on this point has as yet been made, pending further conversations.

The Ontario Mine Operators Association has appointed a special Committee on Rock Bursts with Mr. R. D. Parker as Chairman. This committee has arranged a visit by Mr. R.G. K. Morrison of the Nundydroog Mines, Mysore State, India. Mr. Morrison is an authority on rock bursts, which he has studied in India, in South Africa and in Canada. He has been in Canada, engaged on this commission, since late June and will be here until the end of September. The writer had the benefit of several long conversations with Mr. Morrison at Lake Shore Mines in late July.

A report on the rockburst research at Lake Shore Mines was presented by the writer at the Annual Meeting of the Royal Society of Canada at London on May 20. At that time, Prof. E. S. Moore of the Department of Geology, University of Toronto, expressed an interest in the investigation and kindly made available, to the present research program, data from a series of tests on the strength of various samples of Lake Shore rock, studied under his direction some years ago at Toronto by Mr. C. Godefroy. He stated that he would be glad to try to arrange any cooperation which might be desired from the Department of Geology. At present the work has not proceeded far enough to permit the formulation of definite problems which could be presented for solution with the aid of the University's trained personnel and special equipment. Similar tentative offers have been received from the Department of Physics of the same University. It is likely that, as the work proceeds, special problems will arise which can be submitted to these organizations best qualified to deal with them.

On his latest visit the writer arrived at Lake Shore Mines on July 17, remaining there until August 6, except for the visit to Sudbury on July 30-31 in company with Mr. Gibbs. His time was spent in organization and in study, details of which are given later in this report. At the conclusion of the visit, a report was prepared by Hodgson and Gibbs for presentation to Mr. A. L. Blomfield, Managing Director of Lake Shore Mines. This memorandum outlines recommendations for continuing the work. It is given in full as Appendix V. A memorandum of the costs, to July 12, 1940, prepared at Mr. Blomfield's request by Mr. Gibbs and presented at the same time, appears as Appendix VI. The recommendations were discussed with Messrs. Blomfield and Robson on August 6 and were agreed upon, substantially as outlined.

It is to be noted that Mr. E. W. Todd resigned his position as Superintendent at Lake Shore Mines on June 22 and that, since that time, Mr. A. L. Blomfield, Managing Director of Lake Shore Mines, has been in charge. Mr. Blomfield has indicated that the program of rock burst research is to continue on the same basis as before.

The memorandum presented to Mr. Blomfield on August 6 suggested (section II, subsections 8 and 9) that detailed geological studies be made in the mine after all bursts. It also recommended the appointment of a junior assistant to Mr. Gibbs. In the discussion on August 6, it was decided that, instead of such a junior assistant, a geologist, Mr. Howard M. Butterfield, be appointed to take care of the geological side of the work and to collaborate with the geophysicist, Mr. Gibbs, in a combined attack on the rockburst problem. This was accordingly arranged.

Mr. Butterfield, a graduate mining geologist with considerable experience, has for some time been engaged in back fill research at Lake Shore Mines. He has been interested in the rock burst problem, both directly from the standpoint of his back fill studies and indirectly through the assistance which he has been regularly giving Mr. Gibbs since the geophysical work began.

2. Alterations to the Surface Seismograph.

The surface seismograph, installed at Lake Shore Mines on December 19, 1939, has given some trouble, due largely to the fact that it was designed to be independent of power supply interruptions. That is to say, the lamp was supplied with power from a battery floated on a charging line and the drum drive was arranged as a pendulum clock. Further trouble began to develop due to deterioration of the two mirrors used in the light path. It was decided to return the instrument to Ottawa for the following changes:

(a) Substitution of a synchronous motor drive for the unsatisfactory pendulum clock.

(b) Re-design of the optical system to use a new type lamp and to avoid the use of two mirrors and a prism in the light path.

(c) Provision of change gears to permit a choice of speeds of 30 mm/min. or 60 mm/min.

The equipment was packed by Mr. Gibbs before he left Lake Shore Mines on April 3 and was received at Ottawa on April 8. A requisition was made on April 9 (Order No. 1604) for a synchronous motor (Type KYC-22RC 110v. 25 cycle; 1500:1 reduction, 1 r.p.m., code Bdalzcftai) to be obtained from the Bodine

Fig. 1

Set-up of Seismograph on 2950-foot Level, as of June 10, 1940, seq.

Fig. 2

Steel Seismograph Case

Left (top): Control Switches and Power Pack

Left (bottom): Amplifier and Lamp for Moisture Control

Right: Esterline-Angus Meter and Moisture Control Lamp

Fig. 3

Set-up of Seismograph on 2950-foot Level, as of June 10, 1940, seq.

Fig. 4

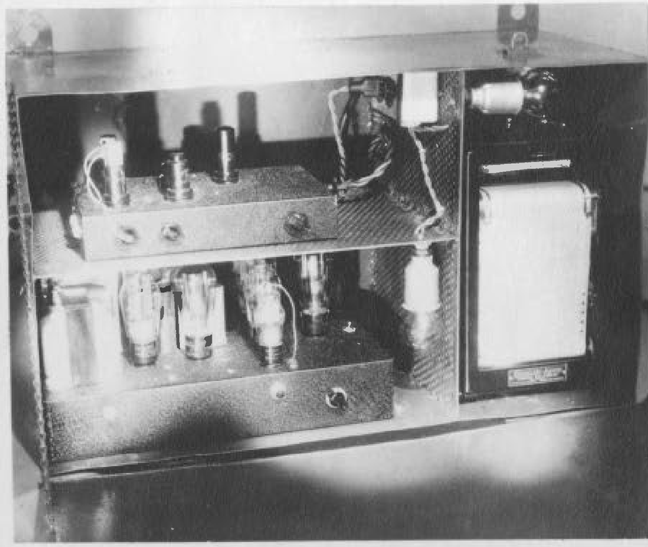
Surface Seismograph

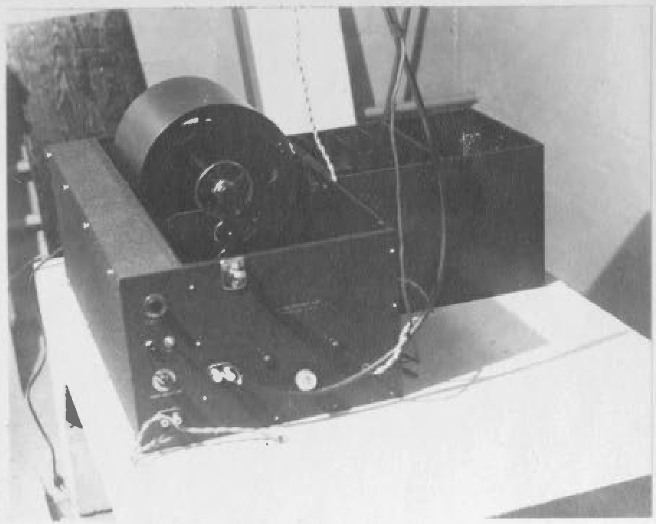
Showing Added Case for Accommodation of New Optical System

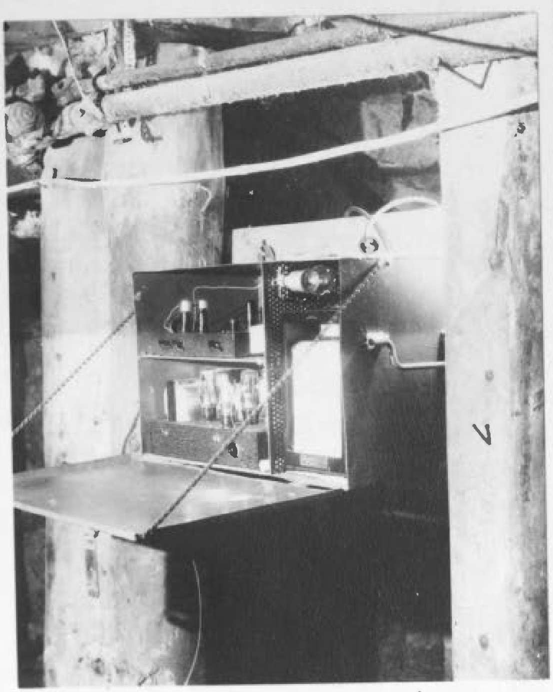
Fig. 5

Surface Seismograph

Showing Synchronous Motor Drive and Change Gears







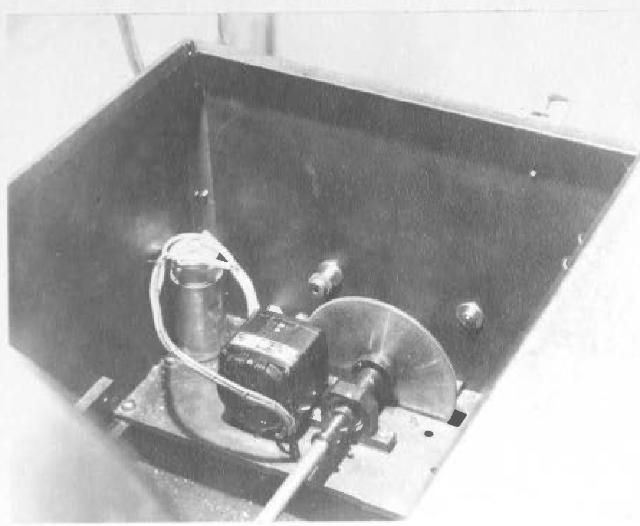


Fig. 6

Plan of Laboratory

Fig. 7

South End

Fig. 8

S W-Corner

Fig. 9

S E-Corner

Fig. 10

N W - Corner

Fig. 11

N E - Corner

Fig. 12

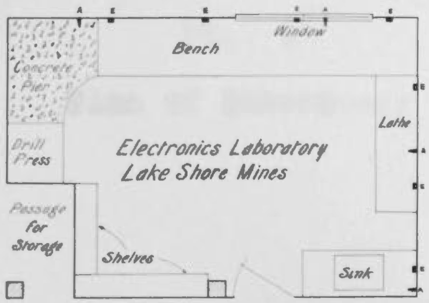
Rock Outcrop
Under SW-Corner
Forming Foundation
of Instrument Pier

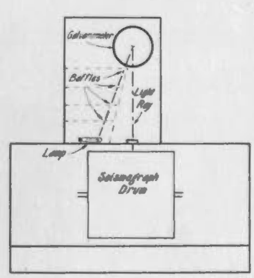
Fig. 13

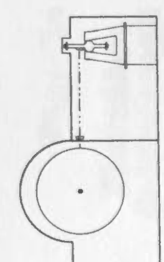
Plan of
Seismograph Box

Fig. 14

Elevation of
Seismograph Box


Window
Bench
Concrete Pier
Lathe
Drill Press
Electronics Laboratory
Lake Shore Mines
Passage for Storage
Shelves
Sink


Galvanometer
Baffles
Light Ray
Lamp
Seismograph Drum



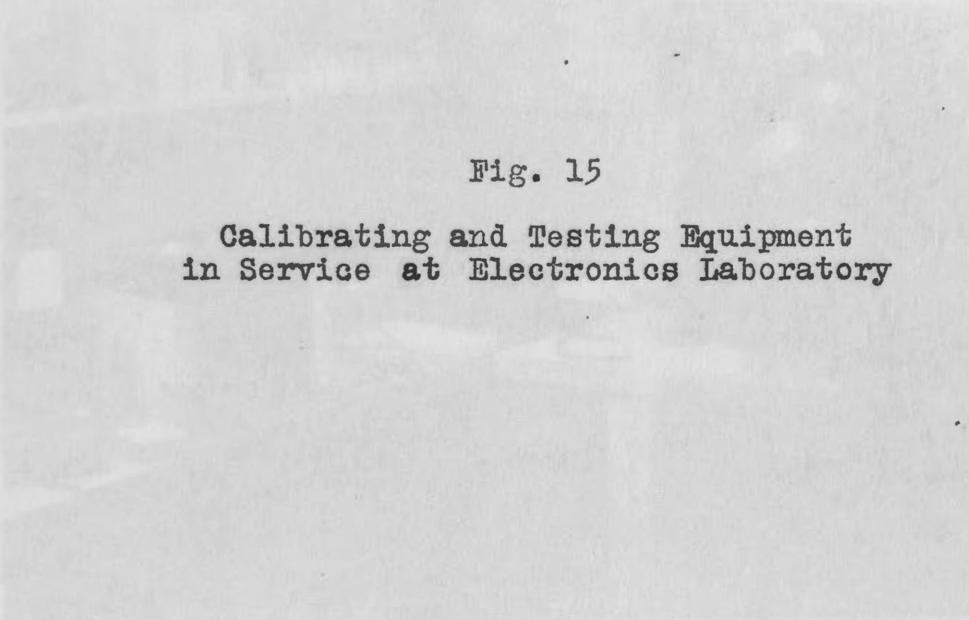


Fig. 15

Calibrating and Testing Equipment
in Service at Electronics Laboratory

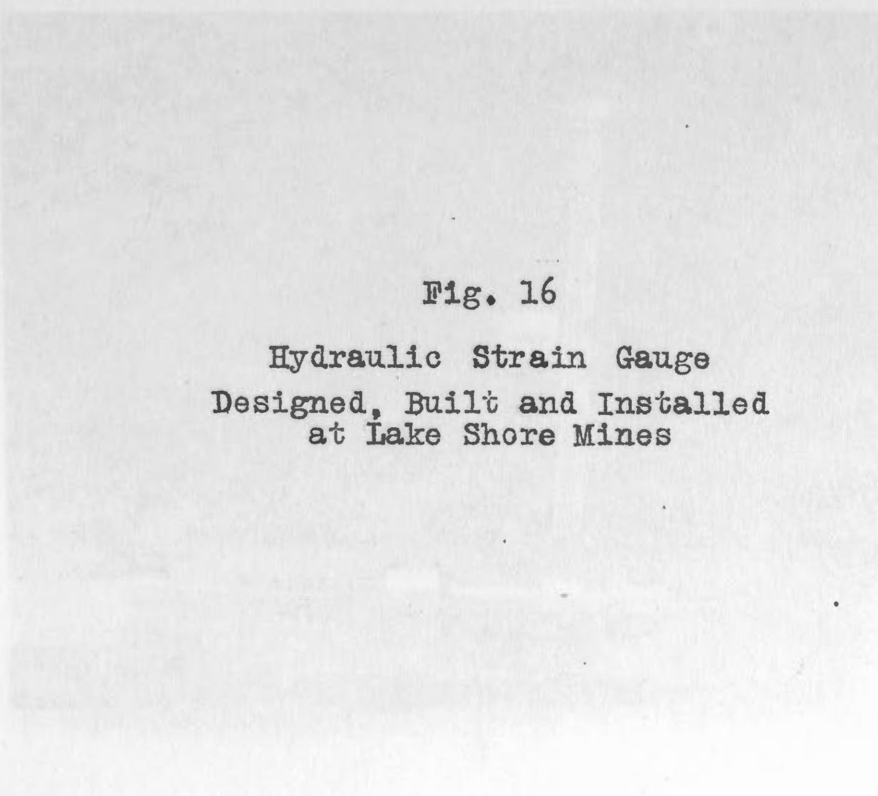
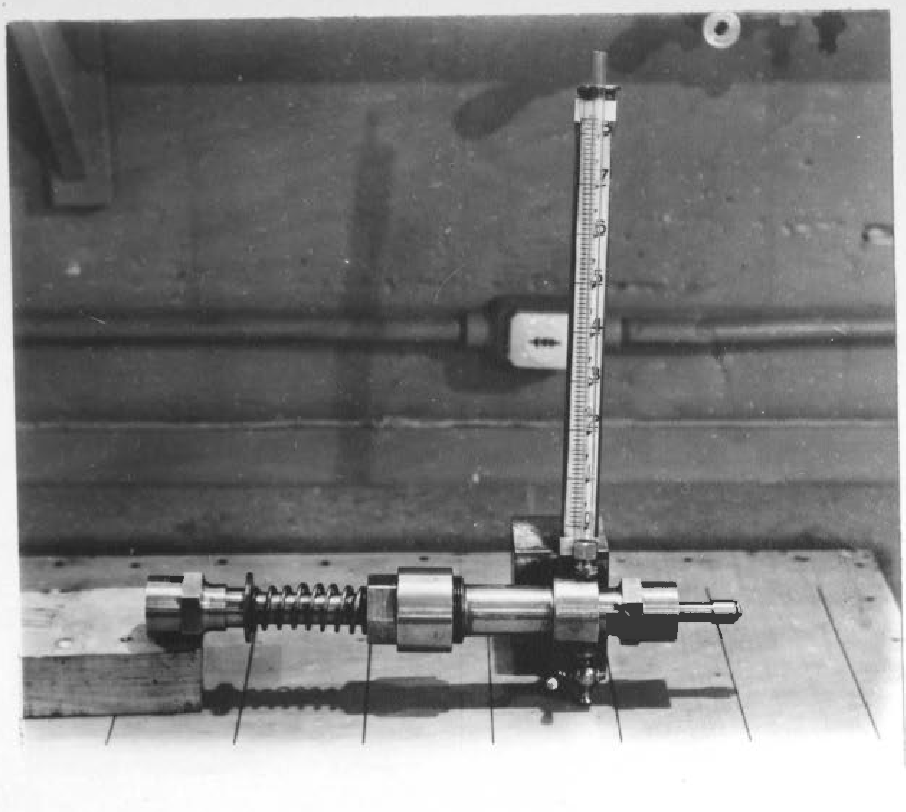


Fig. 16

Hydraulic Strain Gauge
Designed, Built and Installed
at Lake Shore Mines



Electric Co., Chicago. The motor was not received until June 9, a delay which kept this seismograph out of commission much longer than had been anticipated. In the meantime the pen recording instrument made by Mr. Hollinsworth for use in the mine during March, was operated on surface at Kirkland Lake, the accurate timing equipment being used. As the paper speed is only 8 mm/min. instead of 30 mm/min., the timing of bursts was not quite as accurate as had been the case with the Heiland equipment, but the recording of bursts and blasts was excellent.

While waiting for the motor, the optical changes were made. A new lamp, suggested by Mr. Gibbs, was tried out and found to give excellent results. The lamp which had previously been used was the standard type, made specially to the order of the Dominion Observatory and used at all Canadian stations (Canadian General Electric, Single filament No. 117, 36 watt, 10 volt, T-14). This lamp was required to run at full rating, or even a little over, in the case of the Lake Shore seismograph, to provide sufficient light to permit the use of standard-speed seismograph paper. As a result, the filaments were bowed out of shape. Variations in voltage while in operation caused them to so change their shape that the light path through the slit varied sufficiently to prevent coverage of the galvanometer mirror, with consequent loss of record. The lamps burned out frequently, which required that they be replaced. This was a difficult operation for an unexperienced operator and resulted in further record interruption. Moreover, the lamps cost slightly more than a dollar each.

The new lamp (Canadian General Electric, pre-focussed photo exciter, 4A, 8.5v.) costs only fifty cents and is made in large quantities for the motion picture industry as a precision product. Replacement requires merely the insertion of a new lamp with no adjustments. The new system eliminates the use of two mirrors and a prism in the light path, thus increasing the available light, so that the lamps need never be run at full rating and will therefore have very long life. They have proved so satisfactory that adaptors have been made for the lamp sockets at all the Canadian seismograph stations and the new lamps are being used throughout the service.

The new optical system on the Kirkland Lake instrument locates the lamp at the rear of the recorder case. The power supply is furnished through a Thordarson transformer from the 110v. 25 cycle service wires. The light beam passes back through a series of baffles in a new light-tight metal case to the galvanometer, mounted on a weighted base independent of the case. After reflection at the galvanometer mirror, the beam passes through the cylindrical lens now mounted in a hole cut in the rear of the old case. The focussed point of light falls on the rear of the drum. The illustrations given show the details of this arrangement. See Figs. 4-5 and 13-14.

The gear system could not be designed until the synchronous motor was received on June 9. It proved to be quite simple to arrange as shown in Fig. 5. A friction clutch was added at the drum, so that inadvertent turning of the drum by hand, without having pulled out the connecting gear at the outer end of the threaded shaft, would not damage the gears in the motor. Using a choice of the two gears provided, at the outer end of the motor shaft, yields 30 or 60 mm/min. as required for the paper speed.

The final machine work was completed by Mr. Christenson and the instrument turned over to Mr. Hollinsworth for re-wiring on June 18. Test records were run at Ottawa June 22-26 and the instrument shipped to Kirkland Lake on June 27. It began operation at Lake Shore Mines on July 2 and has been in practically continuous operation since that time.

Some experimenting has been done in an effort to improve the recording of the rapid excursions of the light spot during a burst. If one uses sufficient light for recording such excursions, the regular line is too dark and the sheet tends to fog. Accordingly, the writer, while at Kirkland Lake in July, arranged an opaque screen on the cylindrical lens, which cuts off most of the light from a very bright spot while that spot is at rest. As soon as movement occurs, the full recording power of the light comes into use. As bursts record symmetrically about the zero position and as the zero position of the Heiland seismograph does not wander, the result is very satisfactory. A sample seismogram showing a recorded burst appears as Fig. 17. It may be noted here that a ferrotype plate has been supplied to the Lake Shore station. The ferrotyped sheets are less trouble to handle and take less filing space.

The length of the optical arm of the new system is only about .6 of that previously in use. The magnification is thus cut in proportion. However, experience shows that this is not a disadvantage as all bursts record on the new system.

The Heiland Research Corporation supplied the design of a battery-operated amplifier for use with the present equipment. Such an amplifier was constructed by Mr. Gibbs and proved quite satisfactory, except that it shorted the timing impulse to the galvanometer so that all time marks were lost. Pending the design of a semaphore timer to be placed in the light path in lieu of the impulse to the galvanometer, the use of the amplifier has been discontinued. It does not seem desirable to use it, since the primary object of the installation is to time the bursts and the present arrangement provides quite sufficient amplification for that purpose.

The power supply at Lake Shore Mines (since April 30, 1940) is the Hydro system. The frequency control is excellent as the sample record shows and interruptions are few and of short duration. Of course, when such interruptions do occur, the timing of bursts is consequently discontinued for the interval; the drum ceases to revolve and the light goes out. Except for this drawback, the modified equipment is very much more satisfactory than the former design. In justice to the Heiland Research Corporation, which designed the original equipment, it must be said that most of their difficulties arose from the specification, laid down in the order, that the instrument was to be made independent of power supply interruptions.

3. <u>Construction of the Electronics Laboratory</u>.

One of the recommendations made in the memorandum to Mr. Todd on March 6 last (Report No. 2. Appendix I, section VI) was that an electronics laboratory be constructed on the west side of the south end of the Accommodation Building. The suggestions there made were approved and work was begun on the laboratory on April 1.

Mr. Gibbs furnished rough specifications for the room before leaving Lake Shore on April 3. On his return on April 20, construction was well under way. Although all work had not yet been done, he was able to move into it on May 15. Painting was finished about June 10, since when the laboratory, as a room, has been practically complete.

Space for the laboratory was found in the north-west corner of a large basement room at the south end of the Accommodation Building. See Fig. 6 . It is 12' x 18' with its long axis north-south. A corner somewhat less than 4' square is cut out of its south-east corner to provide passage way to other storage room in the basement. The west wall is the outer basement wall of the building. It is of concrete. The north wall is a basement partition wall of cinder blocks. The other walls are of frame with Ten-test panels inside and out. The ceiling is also of Ten-test. All walls together with the floor and ceiling are painted. A re-inforced concrete block is built on the rock outcrop shown in Fig. 12 and furnishes a solid instrument pier in the south-west corner of the laboratory. Figs. 7 - 11 show the room from various point of view.

Electrical outlets and compressed air jets are placed at convenient intervals around the walls. A sink is provided, with hot and cold water supplied through a convenient mixing tap. Electric lights and the bench outlets are fused inside the room and a throw-out switch is installed near the door. A company telephone connects through an automatic switchboard to the other instruments throughout the offices and other mine properties.

A description of the laboratory was prepared by Mr. Gibbs for his report to Mr. Todd on June 10 which appears herewith as Appendix II.

It was found that the west (outside) wall of the laboratory leaked badly after heavy rain. This was reported to Mr. Blomfield on Aug. 6 (Appendix V, section II-1). Repairs were immediately undertaken and waterproofing was finished on Aug. 8. The laboratory room as now completed is most satisfactory, furnishing every facility needed for effeciency and convenience.

4. Laboratory Equipment.

The previous section describes the laboratory as a room, together with its services: water, electricity, compressed air, and telephone. The present section deals with the equipment. This has come from three sources and is the property of Mr. Gibbs, Lake Shore Mines, and the Dominion Observatory.

Mr. Gibbs had a good deal of electronics equipment which he has gradually purchased from time to time and which, when he came to Canada in March, was in storage, partly at Cambridge, Mass., and partly at Los Angeles. He offered to use this equipment in the present work, provided the mine would pay the transportation charges. This they agreed to do. In addition to a small but well selected electronics library (to which he has since added) and a typewriter, the equipment includes an oscilloscope, a Wheatstone bridge, ammeters, voltmeters, etc., and a large and varied stock of condensers and resistances. Also included with the shipments was a fine supply of tools, end wrenches, box wrenches, pliers, etc. All these came to him in three shipments, the last of which was received May 29.

In addition to parts and supplies (tubes, transformers, vibration pick ups, meters, etc), required for the construction of the mine seismograph and similar equipment, the mine furnished an excellent electric soldering iron and a most satisfactory "Delta" drill press with a supply of drills, reamers, etc. The latter was received early in June. It appears in place in Fig. 7 . An order was placed on May 20 for a South Bend lathe with grinder, vise, and accessory tools. This equipment has not been received as yet. The latest word on the order is that it will be shipped on September 1. There is very great need for the lathe and its accessory items and it is hoped that they can soon be made available.

It was felt that some of the more expensive testing equipment comes under the classification of instruments imported for scientific purposes. The instruments are of no use to Lake Shore Mines except for the purposes of the present research. They are thus on a par with the seismograph purchased in 1939. These were purchased by the Dominion Observatory with the understanding that Lake Shore Mines would re-imburse the Observatory for the expenditures incurred and that the latter would agree to leave the instruments at Lake Shore for at least ten years or longer if circumstances should require it. A list of the equipment so ordered together with details of the arrangements made, is given as Appendix VII. These instruments were ordered on July 3 and the last shipment was received at Lake Shore Mines on August 15.

As soon as the lathe and its accessories have been received, all the construction and testing equipment for the laboratory for which need has so far arisen will be in place. With the exception of supplies for experimental units to be constructed, this should suffice for all experiments now contemplated.

Before any of the laboratory equipment had been received, Mr. Gibbs secured three rubber stamps and a supply of special marking ink. All items received have been listed and all larger units have been stamped as the property of Zack E. Gibbs, The Dominion Observatory, or Lake Shore Mines, as the case may be.

5. Experimental Work to August 15.

The experimental work for the period covered by this report has been confined to:

(i) Design and construction of one strain gauge.

(ii) Design, construction and tests of a mine seismograph.

(iii) Frequency tests in the mine.

These may be briefly reported on as follows:

(i) Strain Gauge: The strain gauge, constructed recently at the Lake Shore Mines workshop, consists of a heavy brass cylinder with an internal diameter of one inch. This is closed at one end by a piston working through a packed sleeve. The other end opens into a glass tube at right angles to the brass cylinder. The ratio of areas of cylinder and tube has been tested and found to be 12:1. This is expected to be sufficient magnification. The liquid proposed for use in the gauge is a coloured light oil. The gauge has not yet been set up in the mine. A serious objection to the present design is that it lacks a recording system. See Fig. 16.

Steps are being taken to follow the recommendations made in the report of August 6, to design and construct ten recording gauges to be operated in the mine at strategic points to be selected by the geological department.

(ii) Mine Seismograph: A mine seismograph has been designed and constructed by Mr. Gibbs and has been in practically continuous operation on the 2950-foot level since June 10. The designing of this equipment has been progressively accomplished through solutions of a series of problems which may be discussed briefly as follows:

(a) Power Supply Frequency Problems: The frequency of the power supply at Lake Shore Mines is 25 cycle. Nearly all commercial testing equipment required for the laboratory is designed for 60 cycle. It was a matter to be decided, once and for all, whether equipment should be selected and designed for 25 cycle operation or whether converters should be used to change the supply to 60 cycle.

The correspondence required to settle this point was responsible for the delay to the end of June in ordering the General Radio equipment for the laboratory. It was finally decided to adapt all equipment to either 25 cycle or to battery operation. The oscilloscope belonging to Mr. Gibbs was originally designed for 60 cycles. It was remodelled to be used with 25 cycles. The power pack and amplifier for the mine seismograph were designed for 25 cycle operation and built early in May.

(b) Seismograph Design: The pick ups for this instrument were the Heiland geophone and the DP-1 Brush vibration detector purchased by Lake Shore Mines for use in the March experiments. The recorder selected was a commercial, 5 milliampere, Esterline-Angus meter. This instrument was received promptly, on May 16. It uses a paper chart run normally at 3 in/hr. but capable of a variety of speeds for experimental purposes. Registration is by means of ink, using a special pen. The power pack and amplifier were built by Mr. Gibbs. Test of this instrument on the surface revealed the fact that voltage fluctuations in the power supply affected the overall magnification to an extent which precluded comparability of the records. A voltage regulator was therefore designed and built by Mr. Gibbs. It has given excellent results.

The amplifier and meter were originally used with the DP-1 pick up. The combination worked quite well until about the end of June when it suddenly failed. Examination showed that moisture had affected the crystal of the DP-1, so the unit was returned to the manufacturers to be repaired. Incidentally, the difficulties met in trying to arrange for this work in the United States has so delayed the repairs that the unit has not yet been returned.

With the DP-1 out of commission, the Heiland geophone was installed. The results were not at all satisfactory. Amplification was much too low. The geophone and the amplifier were not impedance matched. A matching transformer (Hammond No. 910) was tried with highly gratifying results. The full gain of the amplifier could not now be used without the record line being too much disturbed by the mine noises. This final arrangement has continued to date, the installation being on the 2950-foot level where a special pier was constructed on solid rock for the pick up location. See Fig. 1-3 . The power pack, amplifier and Esterline-Angus recorder are housed in a specially constructed steel box as shown in Fig. 2-3. Sample records are shown in Fig. 18 . They show clearly that small bursts probably occur during blasting, that they certainly occur at intervals when the mine is not on shift and that comparatively large bursts do not go off scale on this seismometer. The gain is linear for about half the full scale and then diminishes rapidly. For example, the bursts marked as such are perhaps ten fold more severe than the heaviest bursts occurring during blasting time.

Experiments at the Frood Mine show some promising results. All bursts occurring there are plotted on an empirical vertical scale designed to show integrated total intensity and with a horizontal time scale. The resultant curve, extending over some months, shows a distinctive pattern after and before large bursts. If the records could be purged of all noise records and confined to bursts alone, it is believed that this pattern would become sufficiently distinct to permit approximate prediction of large bursts. Purging the record would be possible if the vibration frequencies of blasts and bursts differ materially.

(iii) Frequency Problem: To make the records of the seismograph useful, it is necessary to prevent the recording of blasts; and, as stated above, this can be done if blasts and bursts differ in frequency. Tests have been made in the mine in an endeavour to determine these frequencies. A head set and an oscilloscope were arranged in multiple from the output of the amplifier. It was thus possible at the same time to see the record being made on the Esterline-Angus meter, to see the wave form of disturbances on the oscilloscope, to hear the mine noises directly with one ear and to listen through the ear phone with the other. This, or similar experiments have been tried by various operators both at Lake Shore and at Frood Mine, but the results have not been satisfactory so far as frequency determination is concerned. Recommendations for other methods of using the oscilloscope are given in Appendix IV and in Appendix V. Recommendations for use of a seismic prospecting outfit are given also in the same reports. These recommendations have been approved and steps are being taken to carry them into effect.

6. Plans for the Immediate Future.

In addition to the proposed strain gauge program mentioned above plans for the immediate future call for a new set-up of the testing equipment in the mine, for frequency tests by several methods, for tentative velocity tests, and for experiments to detect ultra-sonic vibration. These may be briefly outlined.

(a) <u>New Location for Mine Seismograph</u>: An excellent location for the mine seismograph has been found in a long crosscut on the 3075-foot level. This crosscut runs north from the drift on No. 2 vein for about a half a mile. It was an exploratory working and is not now in use. The seismograph will be set up there in the near future, as soon as Mr. Gibbs has built an amplifier which can be operated on batteries, there being no power supply in this crosscut.

(b) <u>Velocity Tests Proposed</u>: When the seismic prospecting outfit is on hand tests will be made to see whether changes in pressure appreciably affect the velocity of propagation of the elastic waves due to small blasts. If they do it will be desirable to obtain an outfit permanently. A second hand outfit of this kind may be purchased from Root Petroleum Co. for about $1400 U.S., but it is likely that it would be found preferable for Mr. Gibbs to build one. Six track galvanometer assemblies have been quoted by Heiland at $425. U.S. Seismometers may be purchased at $150 each and a recording camera could be built. Recommendations on this matter cannot be made until after tests have been run with the Leet outfit, being rented for frequency tests.

(c) <u>High Frequency (Ultra-Sonic) Vibrations</u>: It is believed that, prior to bursts, there occur high frequency vibrations which, if they could be recorded, would furnish a means of burst prediction. This work will be undertaken as soon as possible. In the meantime two high frequency pick ups have been purchased from the Brush series. These are known as the VP-1 and VP-5. These, together with suitable filters and matching transformers, will be tried with the equipment set up in the long crosscut mentioned above.

Dominion Observatory,
Ottawa, Canada,
August 15, 1940.

Ernest A. Hodgson.

Fig. 17

Section of Record
Surface Seismograph
Showing Burst

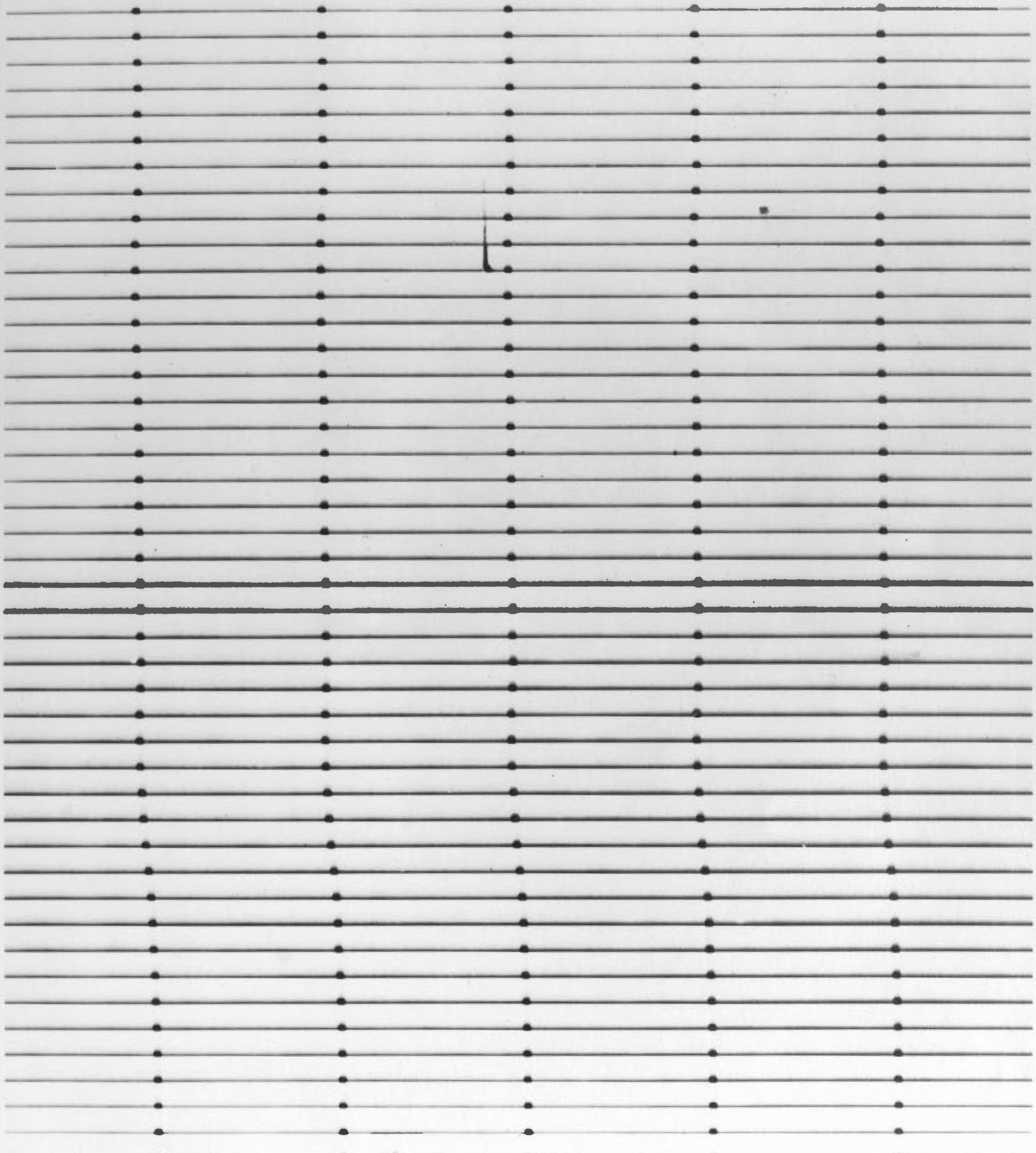


Fig. 18

Sections of Record

Esterline-Angus Meter

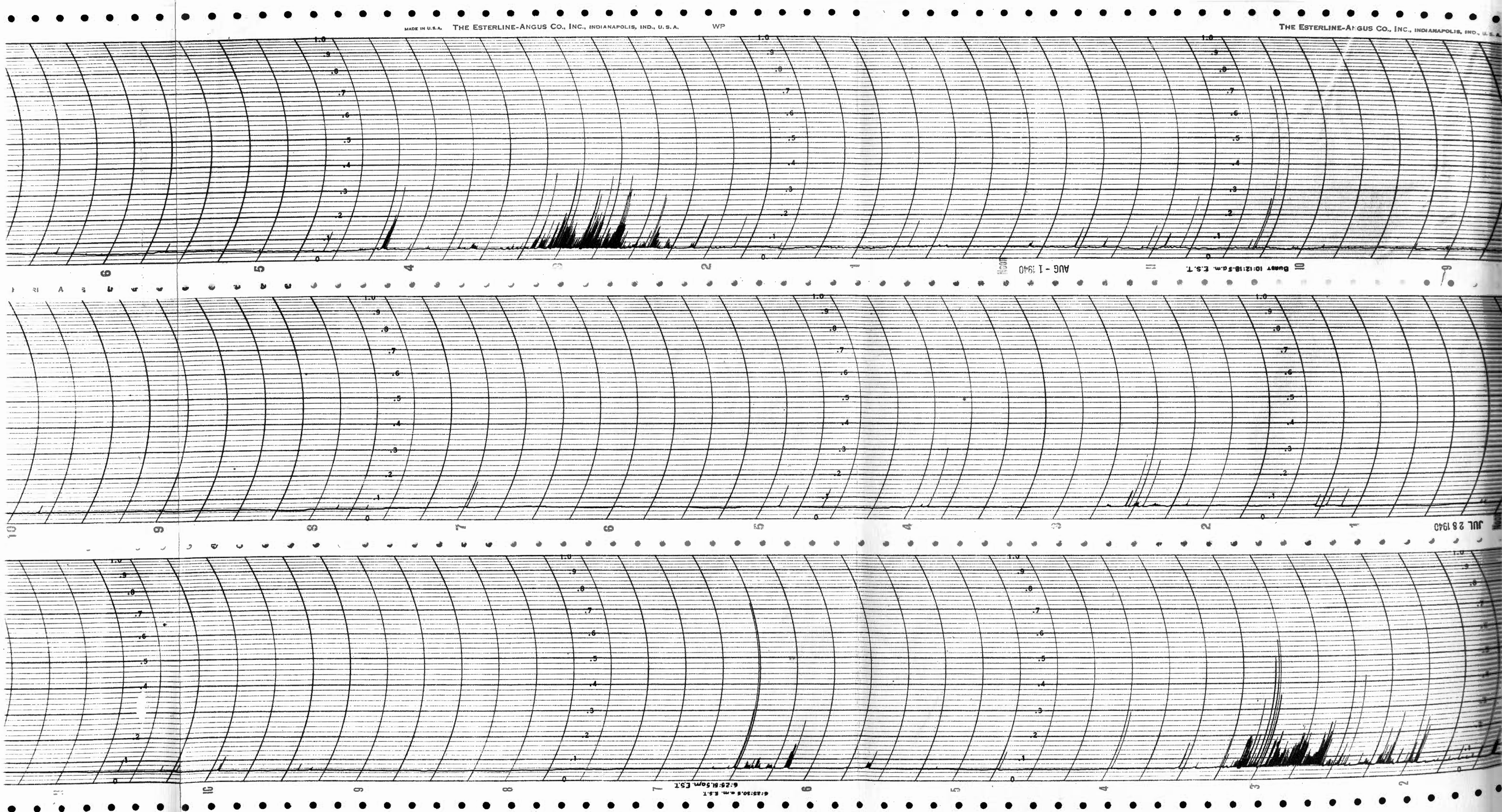
(half-scale reproduction)

Note: Large burst on upper section and on bottom section.

Blasting period on same sections.

Small bursts during off-shift period, as shown in the centre section.

Small bursts occurring during the blasting period.



MADE IN U.S.A. THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A.
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THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A.

## APPENDIX I

### Revision of the Report of April 15, 1940.

***

Under date of April 15, 1940, a report was presented by Ernest A. Hodgson showing the progress of the seismic research at Lake Shore Mines for the period January 31 - April 15, 1940. The report bears the title "Seismic Research Program, Rock Burst Problem, Lake Shore Mines".

This report was submitted to Mr. E. W. Todd, then Superintendent of Lake Shore Mines, with the request that it be critically read by those officers of Lake Shore Mines best fitted to suggest amendments. The amended draft was received at Ottawa on Friday, June 21.

No changes were suggested in the introductory paragraphs; but, as might have been expected, many were indicated for Section I - Geology of Kirkland Lake Area and Lake Shore Mines. Amendments to Section II - Development - were also quite numerous, up to the end of Subsection 1, Part c (page 6). Thereafter the corrections were few and scattered.

It seems best, therefore, in reporting the revised draft, to present in its entirety pages 2 - 6 inclusive as amended by Lake Shore officials and to tabulate the remaining items, locating each by page and line references to the original report. This is accordingly done as follows:

(1) <u>Revised draft of pages 2 - 6 beginning with Section I</u>.

I. <u>Geology of Kirkland Lake Area and Lake Shore Mines</u>:

According to Robson[2] "the productive veins of the Kirkland Lake district lie within a belt of metamorphosed tuff, conglomerate, and greywacke, which occupies a synclinal trough in the old Keewatin basement". In the vicinity of Kirkland Lake, numerous granitic offshoots, chiefly syenitic types, have intruded the older sedimentary rocks in an area situated to the north of the central axis of the syncline. The intrusions occur in the form of dikes and small bosses, which together make up the greater part of the ore zone. This syncline is narrow in the vicinity of Kirkland Lake -- about two miles wide -- and extends for about 100 miles in a direction roughly east-west. That the depth of the ore body would probably be found to be very great was suggested some years ago by Todd[1].

The ore bodies at Lake Shore were deposited in pre-ore fault zones. There are two main veins, designated as the No. 1 or south vein, and the No. 2 or north vein. These veins lie roughly parallel and about 400 feet apart at the surface. No. 2 vein is 2,800 feet long from boundary to boundary of the Lake Shore property. The outcrop of the veins has a strike roughly N.60°E. The dip varies, according to Adamson(8), "from about 75° to the south, down to the 1200-foot level, to approximately 87° also to the south, for 1,800 feet below this horizon". There are also several important diagonal veins. The plan of these veins at the 2200-foot level is shown in Fig. 1. The ore bodies are thus subsequently-mineralized, pre-ore, overthrust faults. These faults were caused by pressure from the southwest.

The mine has been developed from a series of shafts on a line running approximately at right angles to the veins at about the centre of the Lake Shore property. It is to be noted that, when the mine was first opened, only the south or No. 1 vein was visible on the surface, the north or No. 2 vein being concealed beneath Kirkland Lake, which has since been filled by tailings from the mine.

An important difference between the east and west sections of the mine is shown in Fig, 2. From a point roughly 200 feet west of the line of shafts to the eastern boundary of Lake Shore property lies a porphyry mass which has not been invaded by other intrusives. It has, however, been subjected to post-ore, cross faulting of considerable magnitude as shown in Figs. 1 and 2. The displacement of both veins at the extreme east end of the property is 600 feet, the eastward continuance of the veins being thrown up into the Wright-Hargreaves property. To the west, the intrusives are in smaller masses, tongue-shaped in horizontal section. Post-ore cross faulting is here less pronounced. The more important faults are indicated in Figs. 1 and 2. These cross faults are clearly due to tension. As between the two principal veins, cross faulting is more pronounced on No, 1. A large, pre-ore, diabase dike occurs near the western boundary of the Lake Shore property as shown in Fig. 1.

In addition to the post-ore cross faulting, strike faults are encountered, although, with few exceptions the displacement along them is not great. These dip at a lower angle than the principal veins (as little as 30°) and have a strike slightly more to the north. Tension cracks were developed in some parts of the foot-wall of the south vein, and thus provided channels in which ore was deposited.

Their presence in any part of the development results in increased width of drift and stope.

The north vein is much the more productive of the two larger ore zones. This is due to the fact that it is much more crushed than is the south vein. At various horizons, branching vein structure has resulted in the formation of parallel ore bodies as indicated in Figs. 3 and 4. High grade ore bodies as much as 70 feet in width are found on this vein, particularly in the fractured zone at its junction with the diagonal vein. (See Fig. 1). Because of the more widespread fracturing of the rocks in the west end of the mine, this section has, in general, larger ore shoots than has the east end. A model of the north vein as seen from the west boundary, from the 3075-foot level to the 4075-foot level, on a scale of 20 feet to one inch, is shown in Fig. 5. Important ore shoots were found in both the south and diagonal veins towards the east end of the property.

To sum up: the principal fact to note, from the standpoint of rock burst study, regarding the geology of Lake Shore Mines is that the north vein, particularly in the western half of the mine, is much more crushed and fractured than is the south vein. The vein-fracture pattern is made up of several parallel fractures with diagonal breaks joining them, resulting in the formation of roughly diamond-shaped blocks. This structure persists, not only in the larger masses, but throughout the blocks of these masses, and is apparent in both cross section and in plan. A well developed system of jointing results in weak walls, particularly in the north vein where crushing has been more pronounced. When the ore is mined, particularly if the rock is porphyry, small angular blocks are formed along the walls and, if unsupported by backfill or timber, the sloughing will extend for quite a distance into the walls of the ore body. When the walls are predominantly basic syenite, larger lenticular shaped slabs are formed. They are bounded by smooth surfaces coated with chlorite and other secondary minerals, resulting in treacherous stope walls which require careful attention. Finally, it is to be noted that, in general, the rocks in Lake Shore Mine are to be classed as hard and brittle. The jointing and the numerous contacts of various types of rocks, particularly in the west end of the mine, are features which tend to result in the building up of stresses which are released by rock bursts of various types.

II. <u>Development</u>: By the term "development" is meant that work done on a mine which admits the miners to the stopes or working faces of the ore body and which will permit the transportation of ore, waste, filling and other materials. The development at Lake Shore Mines will be discussed briefly in order that an index may be placed on record to serve in the case of later reference to various mine locations. With regard to nomenclature, it is to be noted that serial numbers indicate the chronological order of development; as, for example, No. 1 and No. 2 veins as previously noted. Shafts Nos. 1 ~~and~~ to 6 were developed in the order indicated. A drift is indicated by a preceding number of one or two digits, as required, to indicate the level, followed by a two digit number indicating the order of development and followed again by E or W, indicating the direction of the drive, e.g. drift 3908W indicates a drift on the 3950-foot level, it being the eighth drift to be opened on that level, and it was driven in a westerly direction.

(1) Shafts and Hoists: Six shafts have been developed at Lake Shore Mines. These lie roughly on a line which runs at right angles to the veins and about the centre of Lake Shore property. Shafts 1, 2, and 3 were sunk in the early days of development. No. 1 begins at the surface and goes to a depth of 4,500 feet in two stages; the first from the surface to 2,200 feet the second offset at the 2000-foot level where the hoist is located.

No. 2 is an inclined shaft, at 18°, extending to the 200-foot level, from what was once a peninsula on the north side of Kirkland Lake. Railway terminals are adjacent to this shaft. A timber framing plant, timber storage yard, and timber treatment plant are located at its entrance. The fire hazard is thus kept far from the mine proper and the passage of timber and other construction materials into the mine is facilitated.

No. 3 shaft extends from the surface to 4,000 feet in one stage. Because of the close proximity of this shaft to the north vein zone, a portion of the ore body had to be left in place. There was thus a great deal of valuable ore tied up in the shaft pillar and the crushed nature of the rock made the use of the shaft a serious hazard. It has therefore been abandoned for hoisting purposes and is now used as the main upcast airway for ventilating the mine. Large fans in this shaft provide the up-draught.

No. 5 shaft begins at the surface and extends to a depth of 4,000 feet in one stage. The construction of this shaft and the equipment used in it are described in great detail by Adamson(8). This shaft was sunk 70 feet through mill tailings impounded in what was formerly Kirkland Lake. The description of the work done is most interesting. In spite of the location, the water seal is so effective that no water of any consequence enters the mine. It may here be noted that very little seepage occurs anywhere in the mine. It may be classed as a "dry" mine; but, nevertheless, there is enough water present that the air in the mine is very moist and in many places the walls are wet.

Shafts 4 and 6 extend from the 3950-foot level to lower horizons of the mine. Shaft No. 6 is temporarily bottomed at 4750 feet while No. 4 shaft is being extended below the 5325-foot level.

For the purposes of this article it is sufficient to note here that:

(a) The line of shafts lies roughly N.30°W. as shown in Fig. 1. (The entrance to No. 5 shaft lies farther to the north along the line from No. 1 to No. 3 and a little west. It is 125 feet north and 250 feet west of the collar of No. 3 shaft. It is thus 80 feet in the foot-wall of the north vein on the 200-foot level and 600 feet in the foot-wall on the 3950-foot level.)

(b) The hoisting machinery is situated on the surface in the case of No. 5 shaft and at the 3575 and 3825-foot levels in the case of No. 6 shaft.

The shaft dimensions are approximately 17 feet by 13.5 feet divided into five compartments as shown in the left half of the drawing in the lower left hand corner of Fig. 6. In each of the sections marked "skip" runs a combination cage and skip operated by the hoist situated on the 3575-foot level, and used for transporting both men and ore. The large compartment on the left of this same section of the drawing is for a larger cage, used for carrying supplies into the mine and for raising mine equipment for servicing, as well as for moving men at the beginning and end of a shift.

This cage, about 12 feet by 6 feet, which is operated by the hoist situated on the 3825-foot level, is built like a large freight elevator. It has three decks, all of which can be loaded at once. It can carry a gross load of 45,000 lb. The cage alone weighs 13,500 lb.

(2) Pg. 7, L. -5*.

Change to read:

(j) The shaft is steel framed and lined with pre-cast concrete slabs. It is fireproof throughout.

(3) Pg. 8, L. 7.

Change varies to vary .

(4) Pg. 8, L. 12.

Change spelling to gunite .

(5) Pg. 8, L. -10.

Change all to most of making the line read; "It is to be noted that most of the timber . . . ."

(6) Pg. 9, L. 23.

Change eight to twelve.

(7) Pg. 9, L. 27.

Change all working to certain making the line read: "Current for electrical blasting is carried to certain stopes."

(8) Pg. 12, L. -12.

Change Squared-set to Square-set in the section title and again in the last line on the page.

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* A minus sign in the line reference indicates that the counting is done from the bottom of the page.

## APPENDIX II

### Progress Report on Rock Burst Laboratory

### Prepared by Mr. Gibbs and submitted to Mr. Todd

### June 10, 1940

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Construction of the Rock Burst Laboratory in the south end of the staff house was completed May fifteenth. However, the space was actually put into service nearly a month before. Benches and shelves were installed, a lead-lined sink built, and a concrete block for solid support of instruments cast. The walls and ceiling were painted gray and the cement floor surfaced with a brick red stain. Ten electrical outlets were provided around the room and four compressed air valves located strategically. Five lights were placed in the ceiling. All electrical circuits were brought out to a single master switch by the door. By opening this master switch on leaving the laboratory, all electrical apparatus is disconnected and possible danger from fire eliminated. Also, in case of emergency, all circuits can be killed at once.

Heavy machinery has been ordered for the laboratory. The ten inch South Bend lathe has not yet been delivered but the Delta Drill press is installed and working. Tools, meters, instruments and apparatus belonging to myself have been brought from Cambridge and Los Angeles and all of the items have been inventoried and marked for identification.

Certain testing instruments have not yet been ordered from the General Radio Co. These are to be brought in through the Dominion Observatory for scientific purposes if customs formalities will permit.

Immediately on my return from Ottawa work proceeded on construction of an instrument for use underground in place of the one loaned in March by the Observatory. An Esterline Angus recording meter was purchased and an amplifier designed to work with it. In effect this amplifier causes the meter to record the amplitude of any disturbance, regardless of frequency. Provision is made in this amplifier for attachment of any one of the four different vibration pick-up devices, or for the use of a pre-amplifier in case a pick-up unit is required more than fifty feet away from the recorder. Records are for the most part made with the Brush DP-1 crystal pick-up. Record VI shows the result of using a high quality Brush P-1 crystal microphone. This unit was laid on the recording pier near the box containing the other pen seismograph. It is interesting to note that the sound of the operation of the time relay is plainly recorded. Walking and talking on the upper floors of the staff house is also picked up with ease. Record VIII shows the tremendous output from a special crystal mosaic. After construction certain flaws became apparent (see Record III). Also the need for a well regulated source of direct current power was recognized. Consequently parts were ordered and a voltage-regulated power supply constructed. A comparison of the output voltage of the regulated power supplies is shown on Record VII.

When the amplifier was put into operation it became apparent that we had a means of measuring the relative intensity of ground disturbances. The routine blasting both in Lake Shore and in Teck-Hughes mines was easily seen and at the same time certain large amplitudes were recorded. By correlation it was shown that these were either very large blasts or small strain bursts. Further indication showed a large number of instances where small bursts were coincidental with the first of a group of blasts (See Records III and IV). This would seem to indicate that the blasting acted as a trigger to release existing strains in the rock. Several small bumps not connected in any way with blasting give a clue as to the relative energy involved in each case.

The apparatus, which has until now only been tested on the surface, has been mounted in a steel case and installed on the 2900 foot level today.

Respectfully submitted,

..........................
Zack E. Gibbs.

Kirkland Lake,
Ontario,
June 10, 1940.

## APPENDIX III

### Report of Conference at Lake Shore Mines June 11

***

**Library**

A complete bibliography of papers and reports covering rock bursts and allied subjects has been compiled and libraries of rock burst literature are being assembled by the Ontario Mine Operators Association at Toronto and at some of the mines.

**Investigations**

Critical parts of mine workings have been mapped in great detail to determine the disposition of rock types, faults and joints in an endeavour to determine if there is any correlation between these structural features and the locations of rock bursts. It has been found that, in general, rock bursts are confined to the more brittle or friable rocks and that major structural features influence their location, as for example, intersections of vein or fracture systems, major irregularities in ore body outlines, close spacing or parallel ore bodies, and the presence of many closely spaced pre-existing joints and fractures. The object of this work is to furnish data that will aid in the planning of mining methods and proper mining sequence to control, in so far as possible, the occurrence and severity of rock bursts.

Engineering and geological records of rock bursts have been kept for a number of years as a basis for statistical analyses which has led to a better understanding of the contributing causes of the phenomena. Charts, plans and sections have been prepared to show the location, time, frequency of occurrence, extent of damage, relative intensity and sequence of bursting. From these charts is obtained an understanding of the space relationship of bursts to the physical condition of the mine as a whole. Study of this graphic data also aids in the predetermination of critical areas.

Many attempts have been made by means of various micrometer bars, extentiometers and gages to measure small movements within the walls of various mine workings to ascertain if there are indications of movement within the elastic limit of the rocks that might indicate areas within which unusual stresses are being built up to produce rock bursts. Thus far it has been found that slabbing along the walls and differential movement along small joints vitiate results. Some work has been done and further work has been planned to determine temperature changes in areas known to be undergoing increasing pressure, in the belief that the rate of temperature increase may give a measure of the accumulating stresses that cause rock bursts and thus furnish a basis for predicting their occurrence.

Apparatus has been constructed and installed in several places in two mines for the purpose of recording vibrations in the rock structure set up by stress releases. The immediate object of the work is to correlate these vibrations with subsequent rock bursts and to attempt to give adequate warning of forthcoming bursts. Enlightening data has been obtained with reference to the time pattern of the minor readjustments preceding major movement and it is hoped that eventual results will be consistent enough so that reliance may be placed in their interpretation. A specially designed seismograph has been purchased and put into continuous operation in coordination with the Dominion Observatory of the Department of Mines and Resources. Dr. E. A. Hodgson, Dominion Seismologist, is working in close cooperation with the technicians employed by the mines for this special purpose and is devoting considerable time and energy to the problem.

A very well equipped laboratory supervised by specially trained scientists has been set up to develop and construct instruments for use in this investigation. New types of extremely sensitive electronic apparatus, much of it especially designed and constructed, has been applied to the problem, and while it is too early to cite specific examples, sufficient encouragement has been attained in the short time in which these methods have been in use to hold out the promise of valuable contributions to the safety of deep mining operations.

## APPENDIX IV

International Nickel Company of Canada, Copper Cliff, Ontario
Memorandum of Meetings with Dr. Hodgson and Zack Gibbs
July 30th and 31st, 1940.

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1. It was agreed that we should continue the low-frequency recording, and that the Inco instrument should be redesigned. There was considerable discussion of the type of amplifier best suited to the job and it was agreed that a circuit and arrangement which would result in a linear relation between alternating voltage input and recorded output is most suitable. It is also recommended that the amplifier be so designed that its sensitivity can be varied by calibrated control. These matters were discussed between Gibbs and Prince, who will interchange designs for mutual checking and agreement before construction. It is felt that there is a possibility of getting some valuable information in regard to predicting bursts, if we can get a long enough base-line of observations.

2. The matter of recording ultra-sonic or high frequency vibrations (which may occur in the rocks even before the lower frequency cracking and snapping) was also discussed. It is not definitely known that these vibrations do occur; but, if they do, it is felt that they will probably give a better basis for predicting trouble than do the lower frequency vibrations. For this reason it was agreed that we should design and construct an amplifier incorporating a proper filter to eliminate all vibrations below say 10,000 c.p.s., provided with a properly matched pick-up, such as the VP-1 and an Esterline-Angus recording meter. Such an instrument would cost about $460.00. This would have to be in addition to the one now operating on the lower-frequency vibrations, for it is felt that this record should not be interrupted and that the two should go along together and the results plotted side by side.

3. Inasmuch as little is known about the actual frequencies of the small snaps and bursts or of the larger rock bursts, various means of determining or measuring these frequencies were discussed. The most accurate way of getting this information is by means of a recording seismograph. Various attempts have been made to obtain one of these instruments but the cost seemed prohibitive in every case. Mr. Gibbs has access to one belonging to L. Don Leet of the Harvard Seismological station, but inasmuch as Leet is in Texas, Gibbs would

have to go to Cambridge to get the outfit together, make the necessary changes to adapt the equipment for this particular job and bring it into Canada. The rent of the outfit will be $500.00 per month in U.S. dollars, and the expense of making the necessary changes, including Gibbs' trip to Cambridge, together with exchange and custom duties, will probably be another $500.00; so that the total cost for use of the instrument for one month will be about $1,000.00. It is suggested that this cost can be split between Inco and Lake Shore.

The instrument can also be adapted to make some seismic velocity measurements, which it is felt will be necessary to get a start on a scheme of compiling velocity-pressure data for measuring stress conditions.

Gibbs cannot get away from Lake Shore for 3 or 4 weeks and it will probably take about 2 weeks to get the outfit together in Cambridge so that it will not be available for use for about 6 to 7 weeks. It is recommended that this be done, so that accurate measurements of the frequencies involved can be obtained, for it is obviously impossible to properly design equipment to distinguish the records of blasting from those of rock bursts without having this data.

4. Two other schemes were discussed that would give some idea in regard to these frequencies: (a) building an amplifier with a filter which would cut out the range of blasting frequencies, as estimated by other observers, and see if bursts are recorded and not the blasts. If they are, then their frequencies would be either appreciably higher or lower than the frequencies rejected by the filter. Filters could then be arranged in the circuit to determine whether they were higher or lower and would probably give some idea of their limits. It was agreed this is a poor substitute for the seismograph. (b) the use of the cathode-ray oscilloscope. The general idea is to impress a series of known frequencies on the instrument and provide a scale for each frequency setting of the instrument. Then, by superimposing these scales on unknown frequencies, they could be estimated within a limit of, possibly, 5 cycles per second. This is also a poor substitute for the recording seismograph but will afford a quick and cheap method of getting a rough idea of the ranges of frequencies involved.

5. The matter of the feasibility of installing one or more seismographs at Frood was discussed. The question was raised as to whether or not such an installation would determine the location of the many bursts that occur, presumably in the hangingwall, and which are not located within the workings of

the mine. Hodgson and Gibbs think that by the use of two properly-designed, 3-element seismographs, with synchronized recording, this could be accomplished. The approximate cost of such equipment would be about $5,000.00. If it is desired to make one of these stations an affiliate of the Eastern Seismological Association (co-operating in a program of studies on bursts, blasts and nearby earthquakes in north-eastern U.S. and eastern Canada) the additional cost for the necessary timing equipment will be approximately $1,500.00. In that event, this station would be included in the periodical reports and Inco would have the benefit of specially trained supervision. A station of this kind is now in operation at Kirkland Lake, and such a station at Frood would be at an optimum distance position in the present co-operative net-work.

It is felt that the results to be obtained by the installation of the two stations will justify the expense and their installation is recommended. The extra cost of making one of these a co-operative station with the international association would provide a means of correlation and interpretation of results not otherwise obtainable. Such co-operation would be of material benefit; but, of course, this is a matter of policy.

*

A.B.Y.

P.J.S.

# APPENDIX V

## Rock Burst Research Program
## Lake Shore Mines
## Progress Report and Memorandum Recommendations
## August 5, 1940

***

The latest detailed report previously presented on the progress of the rock burst research at Lake Shore Mines is dated April 15, 1940, and is a complete presentation of the work up to that time. The present short memorandum will sketch very briefly the progress since then, only so far as will suffice to make clear the recommendations which it seems desirable to make with reference to further work. A complete account will be prepared in the near future, placing on record the details of the work subsequent to April 15. This memorandum will appear as an appendix to that report.

The writers visited Frood Mine July 30-31, and discussed the various common problems with Messrs. Yates and Shenon. At the conclusion of that discussion, a memorandum was prepared, submitting various considered recommendations to Mr. Parker. It is assumed that a copy of that memorandum has been submitted to Lake Shore, to be considered in conjunction with this report. A copy will also be prepared as an appendix to the next detailed account of the work, subsequent to April 15.

I. <u>PROGRESS REPORT - April 15 to August 5, 1940</u>.

(1) <u>Delays Due to Abnormal Conditions</u>: Progress has not been as rapid as was expected, largely due to abnormal conditions over which no one has any control. Most of the purchases have had to be imported from the United States, with consequent delays due to new export regulations and the general disruption of normal business on account of the war. Even where equipment was ordered in Canada, delivery has not been made promptly. As a result, the laboratory still lacks some essential material now long past due. This has been promised for the near future. It is hoped that the laboratory will be fully equipped within the next week or so, with all the testing instruments ordered to date. These should suffice our present needs.

(2) <u>Surface Seismograph</u>: The recorder of this instrument was reconditioned and remodelled at Ottawa. The drive was

changed from clockwork to synchronous motor, with greatly enhanced performance as a result. The optical system was changed, eliminating two mirrors and a prism. A new type lamp was also adopted. The records are now much clearer and more legible. This instrument is used in the research program for accurate timing of bursts.

(3) New Mine Seismograph: A new mine seismograph has been constructed and has now operated for some weeks. The pick-up at present in use is a Heiland seismometer. The amplifier was designed and constructed by Mr. Gibbs. The power source employed is the 25 cycle A.C., with special voltage regulation. The recorder is a commercial, 5 milliampere, Esterline-Angus meter with a normal paper speed of 3 in. per hr. A variety of speeds is available for testing purposes.

The equipment is installed at present on the 2900-ft. level. All bursts and blasts, together with man-made noises (hoist, fan, tramming, etc.) record, so that, during shift periods, the record is an integrated register of all audible mine noises, including bursts. To make these records of value, the instrument should be moved to a position in the mine less disturbed by man-made noises. Filters should also be provided, designed to exclude all noises except bursts. This requires that the frequencies of the various noises and that of the bursts should be known with reasonable accuracy.

(4) Frequency Problem: As indicated above, the present most pressing problem is the determination of frequencies. Various methods have been tried without success and some are now proposed which, it is hoped, will yield the required information. It was suggested at Frood that the frequency of bursts is from 20-40 cycles, and that of blasts from 40-80 cycles. The experimental data on which this conclusion of a supposed difference is based were discussed at the Frood conference on July 31. It was concluded that the evidence was not sufficient to warrant the conclusion and that other, experimental, means would have to be employed. It was also agreed that the question is of fundamental importance and that steps should be taken as soon as possible to obtain the data required. Recommendations to this effect will appear later in this memorandum.

(5) Strain Gauges: A single, strain gauge has been built and calibrated at Lake Shore, but has not yet been installed and operated. It consists of a pressure chamber filled with coloured oil and a small-bore glass gauge giving a magnification of about 12 times. The gauge, as at present designed, does not record. It must be read at intervals.

After discussion with Mr. Morrison, it was decided that, to yield data of practical value, it will be necessary to provide a recording mechanism. It was also decided that the present design is too heavy and too expensive. A design for a cheaper and self-recording gauge is now receiving attention. It is felt that several, ten if possible, of the gauges should be installed in strategic positions to be recommended by the geological staff.

(6) Amplifier Design: A good place for the installation of the mine seismograph seems to have been found in 3052 X-cut. Unfortunately, A.C. power is lacking there. Thus, battery-operated amplifiers will be required. It is proposed to design an entirely new amplifier for this purpose, which can be used interchangeably with the pick-up and recorder. The extra amplifier will make the outfit much more flexible and its construction is cheaper than the wire which would be required to carry A.C. into the X-cut.

There is some question as to whether the gain of the amplifier should be linear (or exponential). That is to say, whether successive equal steps of input voltage from the pick-up should be delivered to the meter as amplified, but equal, steps on the record. This has the advantage that one can read relative intensities directly from relative displacements on the meter. The disadvantage lies in the fact that, if the gain be sufficient to record small bursts with ease the recording of the larger bursts would be limited by the width of the record paper. If, however, the gain were exponential, then large amplification could be had for small bursts but increasingly-smaller amplification would apply for increasingly-larger bursts. Thus, all will record, but a scale would have to be used to determine comparisons of magnitude. The important point is that, until the last week or so, testing equipment has been lacking for calibrating the amplifiers precisely. This is now on hand and is being used in the present construction work. It has shown up certain inaccuracies in previous design which are now being corrected.

## II. RECOMMENDATIONS.

(1) Waterproofing of Laboratory Wall: The laboratory is most satisfactory and, when the new instruments are all received, well equipped. There is one fault, however, which should be adequately corrected at once. The west wall leaks badly. On Sunday, Aug. 4, the writers returned to the laboratory after an absence of a few hours, to find the bench and floor flooded by an unexpected and heavy rain. Valuable testing equipment in use and in place on the bench was standing in water. It is urged that adequate waterproofing be undertaken as soon as possible.

(2) Interim Frequency Determinations: In addition to other interim tests for frequency, recommended at the Frood conference (the use of arbitrarily-selected filters, and of celluloid scales on an oscillograph), the writers propose to endeavour to determine the frequency of blasts by placing an opaque screen over the oscillograph front to cut off the oscillations due to general mine unrest. A blast will thus give a single set of turning points above and below such a screen. Using film or photographic paper of tested optimum speed, a strip can be placed above the screen directly on the glass face of the tube, but shielded by an opaque screen which can be snatched away.

With the equipment set up in 3052 X-cut, the observer could stay in the mine through the blasting period. When a blast occurs he could see the turning points below the central screen and could adjust the sweep frequency and vertical amplification to optimum values. Then, knowing that another blast would occur soon, he could remove the top shield, wait till a blast showed below, and then remove the film.

He could then impress 25 cycle frequency for an instant, photographing the resulting wave form on another strip of film. This would calibrate the sweep frequency. He could then record with his other data his impression of the magnitude of the blast concerned. This operation could be repeated a number of times during the blasting period and should yield data of value in determining whether blast frequency varies and, if so, within what limits.

To obtain burst frequency in this way is out of the question at Lake Shore, where bursts occur at such irregular and widely-spaced intervals. At Frood, where more numerous small bursts occur, the method might be used to test the frequency of bursts.

(3) Adequate Frequency Determinations: To determine frequency for both bursts and blasts, the conference at Frood decided that it is necessary to recommend the use of a seismic recording outfit. The Frood memorandum outlines the fact that such equipment can be obtained at Cambridge, Mass., and recommends that Mr. Gibbs be sent to Cambridge to assemble the outfit (which he constructed and operated for Dr. L. Don Leet of Harvard, which is not being used at present, and which can be rented for $500. for one month or $900. for two months).

The cost of having Mr. Gibbs go down, assemble the equipment and bring it here, together with the rental for one month is estimated at $1,000. It was recommended that this work be undertaken jointly by Frood and Lake Shore and the expense shared. The writers support this recommendation with the understanding that, before he leaves for this work, Mr. Gibbs is to complete the battery-operated seismograph and leave it installed and operating in the 3052 X-cut while he is away.

(4) Velocity Determinations: In the memorandum presented to Mr. Todd on March 26 (Section B, p. 10), it was recommended that velocity determinations be made to discover whether velocity-pressure variations could be detected in the west pillar at Lake Shore. If (and when) the Leet seismic outfit is here, it is proposed to make test measurements of velocity in the west pillar. If these tests show that further work along this line is warranted, a special camera would have to be built for normal operation over a period of time. What further recommendations would be made in this connection would depend on the results of these tests.

(5) <u>Supersonic Vibrations</u>: It is suspected that, previous to a burst, slight, high-frequency, vibrations may be suddenly released from time to time within the strained rock. If these exist and if they can be recorded, it will be comparatively easy to build filters to exclude all other noises in the mine. A statistical study of such vibrations would probably indicate the imminence of a burst. It is recommended that, as soon as possible, Mr. Gibbs build the necessary amplifier and filter equipment to test for the existence of such vibrations and, if they exist, that a systematic recording of them be undertaken.

(6) <u>Strain Gauges</u>: It is recommended that a self-recording strain gauge be designed and that ten such instruments be built and installed in those positions at Lake Shore to be recommended by Mr. Morrison and Mr. Robson. In view of the fact that these gauges should not be very expensive and that their records will be required as soon as the mine seismograph has been perfected and placed in operation, it is urged that this work should be undertaken without delay. When installed, a regular system of service and recording should be instituted and carried out systematically.

(7) <u>Temperature Measurements</u>: It is suggested that a simple, non-recording, thermometer of thermo-couple design be constructed by Mr. Gibbs and installed in a deep diamond drill hole in some section of the mine where, in the opinion of the mine staff, the program of mining is likely to be changing the pressure fairly rapidly at the point selected. Such a gauge should be read at regular intervals and the readings plotted.

(8) <u>Systematic Investigation of Bursts</u>: It is important that the transient data on rock bursts should be compiled regularly. When a burst occurs (large or small), the vicinity should be examined by the geological staff and all observed data made a matter of record. This work is now being done, of course, but the writers do not know of a regular compilation of data, correlated with the seismograph records and arranged for systematic study. Were such a series carried on regularly and the results available constantly to both geologists and geophysicists, it is highly probable that significant trends and laws would, in time, suggest themselves to those interested in the research.

(9) Assistance: Much time is lost by Mr. Gibbs in inspection and other details in connection with this work. This time could be much better employed in the specialized work which he alone can do. As time is a matter of considerable importance in arriving at deductions, it would appear to be a matter of economy were a capable assistant to be assigned to this work. It would require some one capable of adjusting equipment in regular use and should be confined to some man alone, in order that he might be adequately trained. It is suggested that such an appointment would be in the interests of efficiency and economy.

(10) Conference with Mr. Morrison: It is understood that Mr. Morrison proposes to return to Lake Shore in September. The Frood men have expressed a wish to time their next exchange visit so as to be here about the time Mr. Morrison's survey is finished. It is felt that a session of this kind would be most valuable and it is suggested that, if circumstances permit, such a conference be arranged.

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Lake Shore Mines,
Kirkland Lake, Ont.
August 5, 1940.

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Ernest A. Hodgson.

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Zack E. Gibbs.

## APPENDIX VI

### Memorandum to Mr. Blomfield
### Summary of Costs to July 12, 1940

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Kirkland Lake, Ontario,
August 6th, 1940.

Mr. A. L. Blomfield,
Lake Shore Mines, Ltd.,
Kirkland Lake, Ontario.

Dear Mr. Blomfield,

As requested by you sometime ago Mr. Gibbs has had an analysis made of the costs of the surface seismograph (274-11) and the seismic research program (274-12). These are tabulated to July 12th; but, since that date, purchases on account of the research program have been delivered and others are pending, making added expenditures for this program totalling approximately $3000 more. Hence, the total for this research comes to a little less than $7000. Exact figures for these outstanding items are not available yet as we do not know whether duty will be levied.

With regard to the estimate previously given to Mr. Todd placing a maximum for research at $25,000, it is to be noted, that this did not include Mr. Gibbs' salary. Consequently, $1400 should be deducted from the total (274-12). The surface seismograph is a different project and is also not to be included.

The present total expenditure and immediately pending liabilities in the case of the research program is, therefore, about $5,500. The other expenditures required for this program for the year outlined, ending March 31st, 1941, will not exceed the estimated maximum.

Respectfully submitted,

..................................
Ernest A. Hodgson.

..................................
Zack E. Gibbs.

July 12th, 1940.

- LAKE SHORE MINES, LIMITED -

Cost of Seismic Research to June 30th, 1940

| | 274-11 | 274-12 |
|---|---|---|
| Wages and Salaries | $ 129.15 | $1,490.50 |
| W. C. B. | 2.23 | 45.38 |
| Vo. Record (Invoices) | 952.72 | 1,227.22 |
| Supplies | 8.66 | 185.25 |
| Supplies Handling | .31 | 6.06 |
| Shops Expense | 51.43 | 47.56 |
| Shop Orders | 877.33 | 586.86 |
| Cash | | .54 |
| Petty Cash | | 33.70 |
| General Charges | 22.25 | 266.57 |
| | $2,044.08 | $3,889.64 |

## APPENDIX VII

### Laboratory Equipment Ordered Through the Dominion Observatory

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Some of the testing equipment required for the laboratory is clearly of a scientific rather than commercial nature. It thus comes under the same classification as the seismograph purchased last year for use on the surface at Lake Shore Mines. An agreement exactly similar to that outlined at the bottom of page 4 and the top of page 5 of Report No. 1 (January 31, 1940), was drawn up in a letter from Hodgson to Gibbs dated June 20, 1940. This was approved by Mr. Blomfield in a letter to Mr. Stewart dated June 25.

The equipment so ordered becomes the property of the Dominion Observatory, but is to be retained at Lake Shore Mines for the purpose of this research "for at least ten years or longer if conditions require".

The instruments covered by the above agreement were ordered from the General Radio Co., Cambridge, Mass., on July 3 (Order No. 2750). They were received in two shipments, the second of which reached Lake Shore Mines on August 15.

The following items of equipment were so purchased:

| | | |
|---|---|---|
| I. | Two (2) Variacs (200-CMH) at $21.50 each | $43.00 |
| II. | One (1) Impedance Bridge (650-A) | 175.00 |
| III. | One (1) Beat Frequency Oscillator for 25 cycle operation (713-BM) | 575.00 |
| IV. | One (1) Output Power Meter (583-A) | 95.00 |
| V. | One (1) Microvolter (546-A) | 80.00 |
| VI. | One (1) Sound Level Meter (759-A) | 195.00 |
| VII. | One (1) Sound Analyser (760-A) | 260.00 |
| | Total = | $1423.00 |

This gives the total in U.S. dollars. The cost laid down at Kirkland Lake is increased by exchange, customs, sales tax, and express.

The Type-numbers, in brackets in the above tabulation, are taken from General Radio Catalogue K (1938). In order that the Variacs might be used at Lake Shore Mines where the power supply is 110 volts, 25 cycles, it was necessary to order them for 220 volts, 60 cycles. The Beat Frequency Oscillator chosen is adapted for 25 cycles, the cost being $90. greater than would have been required for 60 cycles. The other equipment is battery operated and hence not affected by the frequency of the power supply.

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