SEISMIC RESEARCH PROGRAM
ROCK BURST PROBLEM
LAKE SHORE MINES

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On January 31, 1940, a confidential report was presented on: "The Seismograph Installation at Lake Shore Mines, Kirkland Lake". Section 8 of that report deals with the subject: "Further Rock Burst Research Proposed". As there indicated, the month of March was to be devoted to a study of records made in the mine itself, with tentatively-arranged equipment assembled at the Dominion Observatory.

To assist in this work Mr. Zack E. Gibbs was recommended by the writer at the request of Mr. E. W. Todd, Superintendent of Lake Shore Mines. The continuation of the research beyond March 31 was to be dependent on the conditions found and on the adoption of a further agreement.

The equipment was assembled at the Observatory, largely through the efforts of Mr. V. E. Hollinsworth, about a nucleus consisting of two commercially-built, vibration detectors, purchased at our request by Lake Shore Mines. On the arrival of Mr. Gibbs at Ottawa on March 1, this equipment was tested and mounted for use in the mine. It was shipped to Kirkland Lake on March 7 and operated there by Hodgson and Gibbs from March 13 to March 29 inclusive. A report on the observations up to and including March 26 was prepared for Mr. Todd and presented on March 27.

After describing the equipment used and the data obtained, the writers pointed out the limitations discovered in the tentatively-assembled equipment, outlined the problems which would have to be met to affect an improvement, and recommended a continuing program which would require a year or more to carry through. The estimated cost of this program was "not less than $15,000 and not more than $25,000". A necessary preliminary to such a program was declared to be the establishment of an electronics laboratory at Lake Shore Mines, to equip which would require not less than $3,000. A copy of the above memorandum is given as an appendix to the present report.

On March 29 Mr. Todd arranged an interview with Hodgson and Gibbs and agreed to the proposals as a coordinated whole. Mr. Gibbs was engaged to carry on the work at the mine under the general supervision of the writer, with the collaboration of those members of the Observatory staff directly interested.

There was, of course, no need of any mention of the conditions in the mine in the memorandum to Mr. Todd. Those conditions, however, require careful consideration in the planning of the continuing program. Fortunately, several more or less recent papers, listed at the end of this report, describe the mine and its neighbours in some detail. From these and from observations made during his stay at the mine, the writer has endeavoured to prepare a condensed analysis, stressing those details which most affect the program to be adopted.

This analysis has been written for the information of various officials, some of whom are not familiar with mining operations or terminology. Explanations of these have thus seemed to be in order. The report is designed to place in ordered form the outlook of the investigators, themselves just beginning to understand something of the locale of their problem. To that extent, it may be considered a progress report to date.

I. Geology of Kirkland Lake Area and Lake Shore Mines:

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". 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. Dougherty(4) indicates that the ore zone occupies a depression in the batholith; and that, while the horizontal distance along the present erosion surface to the exposed part of the batholith is short, the depth of the deposits, proven by mining and drilling to extend more than a mile, "is certain to extend many thousands of feet deeper". 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.

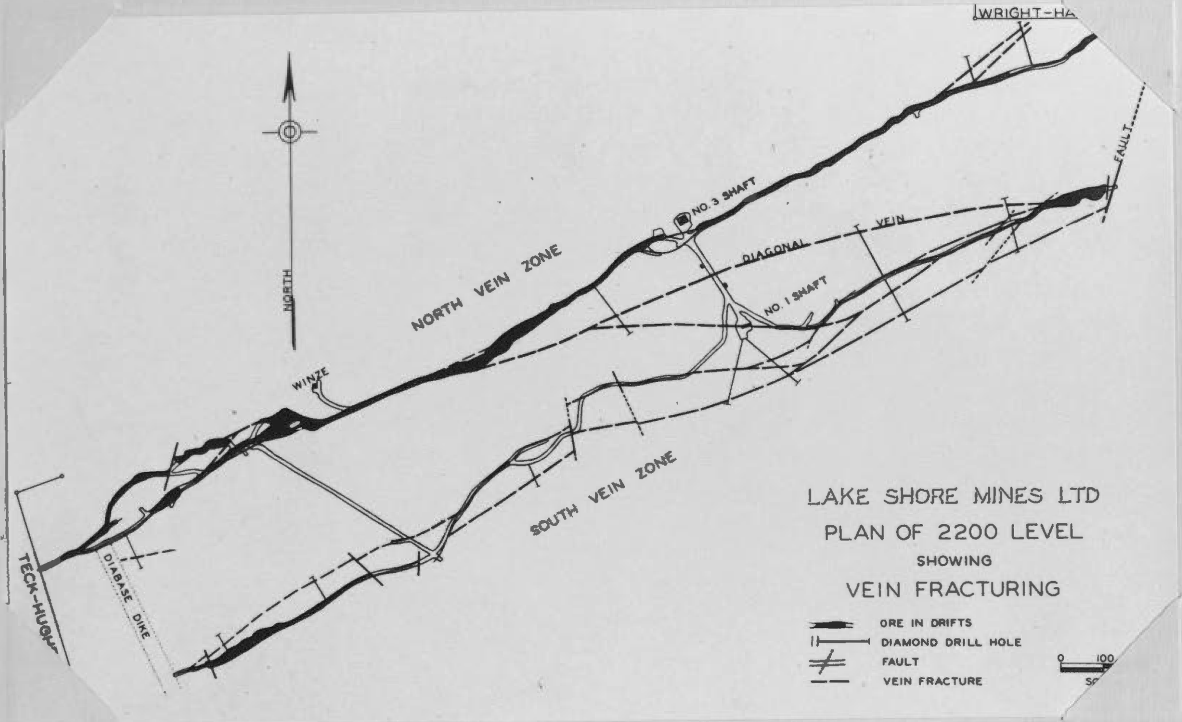

Fig. 1. Plan of 2200-foot Level

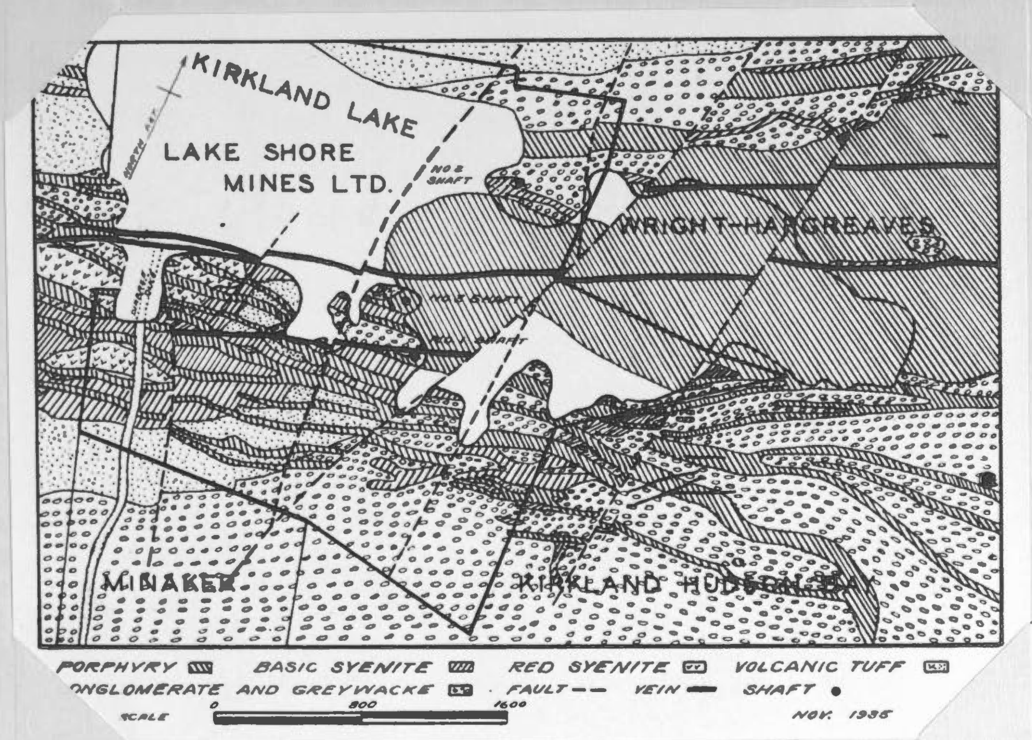

Fig. 2. Surface Plan Showing Distribution of Rocks

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 the south vein at the extreme east end of the property is 600 feet, the eastward continuance of the vein 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. In the west end of the mine there are no displacements on these faults at depths greater than 1,000 feet. 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 of even later age are common. These dip at a lower angle than the principal veins (as little as 30°) and have a strike slightly more to the north. They have been mineralized as were the principal veins, but do not carry gold. Their intersections with these veins make it difficult to follow the ore bodies in developing the mine. 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, intermediate veins appear 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

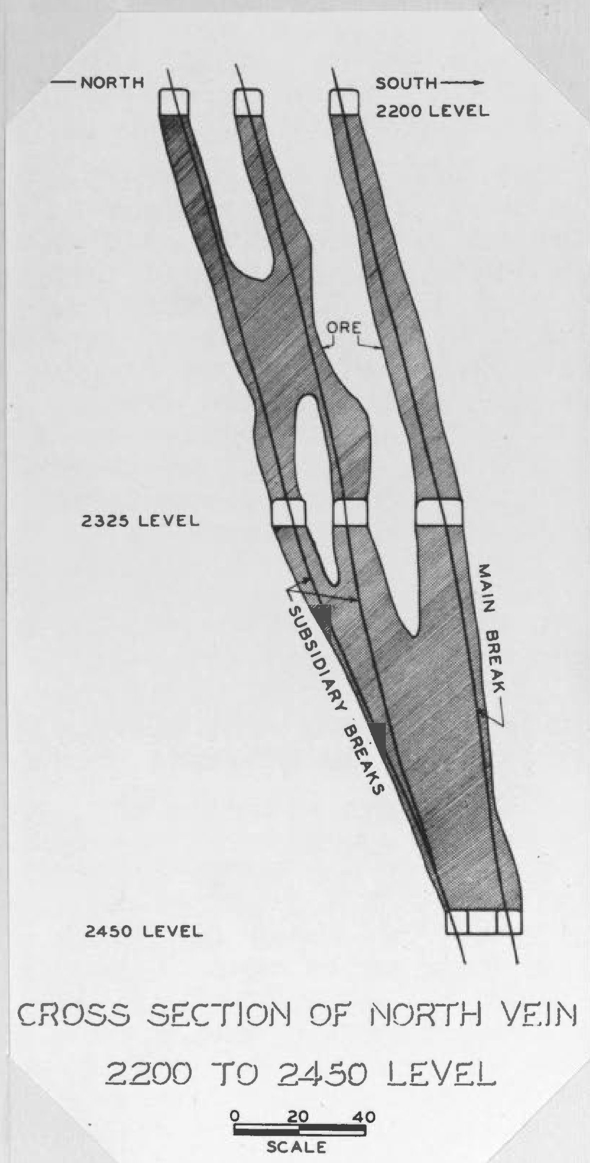

Fig. 3. Cross Section of North Vein
2200 to 2450-foot Levels

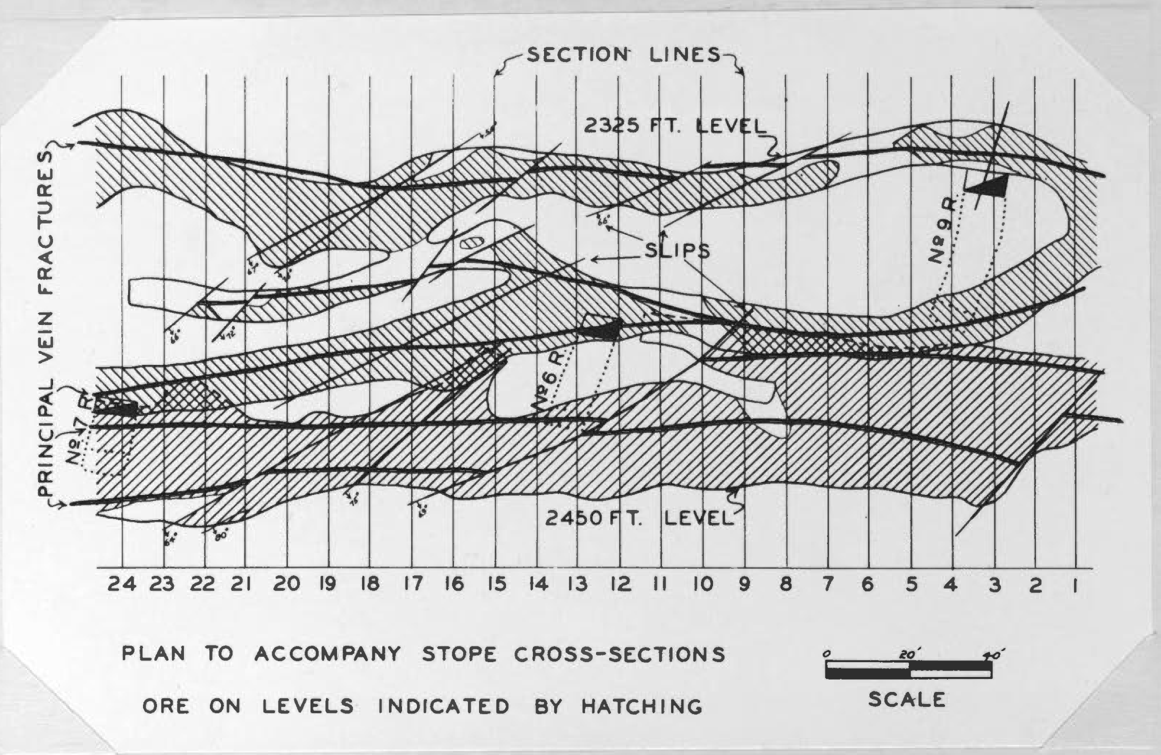

Fig. 4. Fracturing on 2325 to 2450-foot Levels

junction with the diagonal vein. (See Fig. 1.) Because of the broken nature 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. The diagonal vein is more crushed than the south vein, but there has not been much displacement in the direction of its strike. An important ore shoot was found at the extreme east end of the south vein at its junction with the diagonal vein.

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 is much more crushed and fractured than is the south vein and that the west end of the mine has been faulted and jointed more than has the east end. The entire fault system 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 down to small hand specimens, and is apparent in both cross section and in plan. This jointing results in weak walls, particularly in the north vein where crushing has been more pronounced. If the rock is porphyry, large masses are liable to slough off the walls and backs of stope and drift. If the rocks are syenite, their fracture faces are smooth and likely to be mineralized with chlorite and other secondary minerals, which results in treacherous stope walls. 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. Development: 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 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 end of the mine concerned, e.g. drift 3908W indicates a drift on the 3950-foot level; it being the eighth drift to be opened on that level in the west end of the mine.

(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. It was found that, since the dip of the veins changed from the surface indications, this shaft reached rich north vein areas at a depth of about 3,000 feet. There was thus a great deal of valuable ore tied up in the shaft pillar and the crushed nature of the rock, much of it being shabby porphyry, 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 is now the only shaft used for traffic into or out of the mine below the 200-foot level. It begins at the surface and extends to a depth of 4,025 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 the bottom of the mine. Shaft No. 6 is now being extended below 5,300 feet, on which level the cross cut is at present being driven.

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 3825-foot level in the case of No. 6 shaft.

(c) The shaft compartment is approximately 17 feet by 13.5 feet and is 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 small hoist, thus designated, for transporting men and ore. The large compartment on the left of this same section of the drawing is for a larger hoist called a cage, used for carrying supplies into the mine and for raising mine equipment for servicing. It is sometimes used for moving men at the beginning and end of a shift. This cage, about 12 feet by 6 feet, 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

Fig. 5. Model of West End
Lake Shore Mines
3075 to 4075-foot Levels

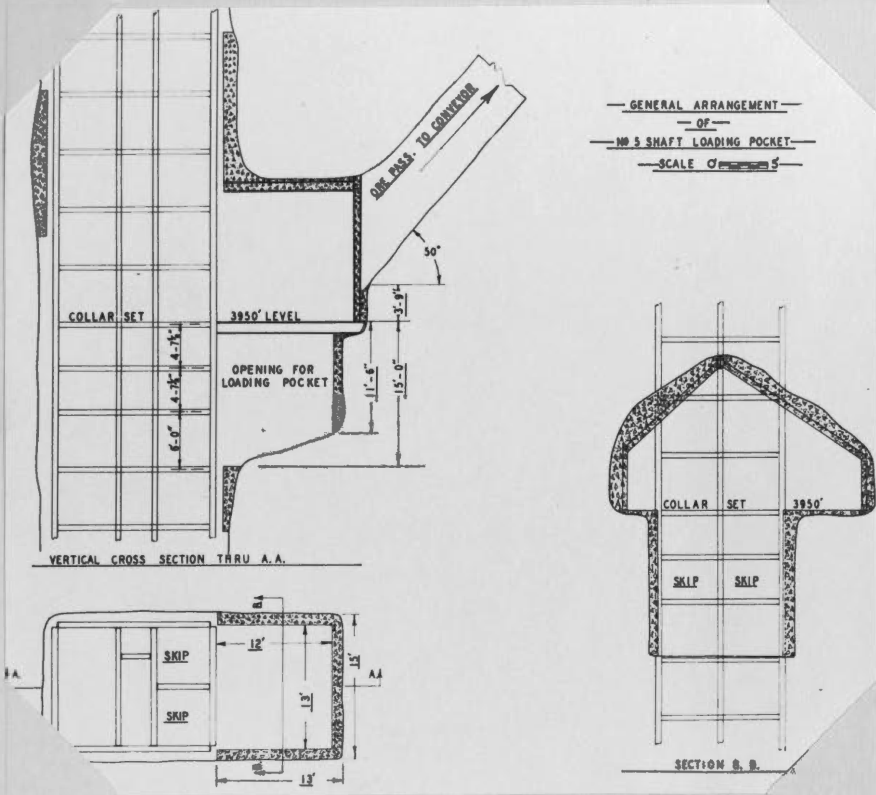

Fig. 6. Loading Pocket on 3950-foot Level

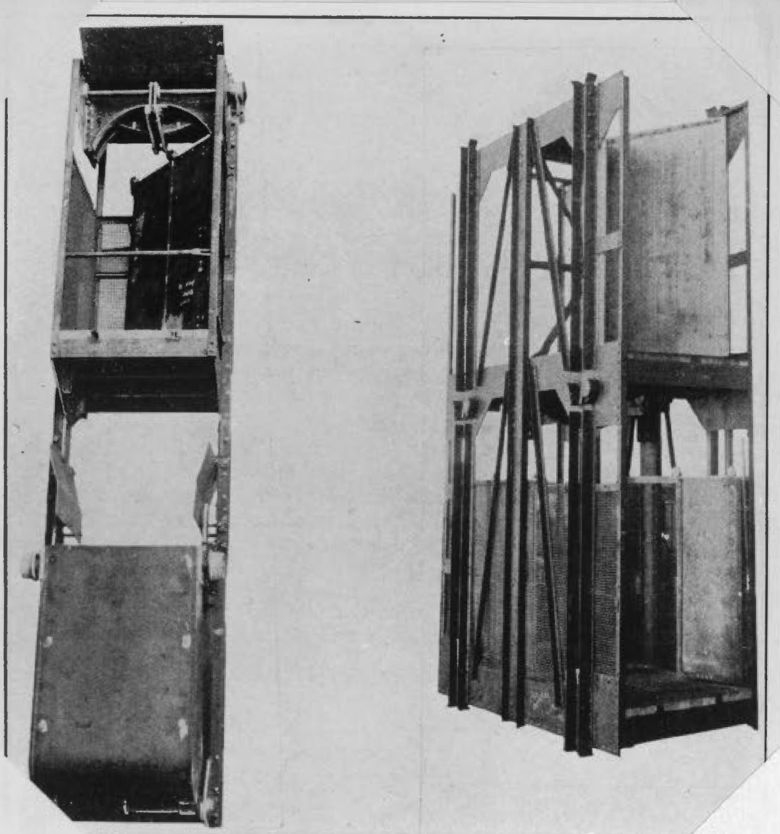

Fig. 7. Skip and Cage

weighs 13,500 lb.

The space between skips and cage is provided with ladders by means of which men may climb in or out of the mine, and also provides space for the armoured electric cables which are dropped vertically down the shaft in the space reserved for them. The air and water pipes are also carried down this same compartment. A picture of the skip, with man space above and ore bucket below, is shown in Fig. 7, at the left.

(d) The cage is run at 1,800 feet per minute. The skip runs at 2,000 feet a minute when carrying ore, or 1,500 feet a minute when carrying men.

(e) Stations are cut into the rock at intervals of 200 feet down to 2,200 feet, and 125 feet from there to the bottom of the mine. A cross section of one of these stations is shown in Fig. 6.

(f) A buzzer system is used by the attendant on skip or cage to signal the operations required to the hoist operator on surface. Telephones link all levels, surface, and hoistmen.

(g) The electric wires fed into the mine through the shaft are led off through trenches below the station floor at each elevation and carried to a switch room at which point all wiring on that level is controlled.

(h) The collar of No. 5 shaft is at an elevation given by Adamson[8] as 1,051.03 feet.

(i) The skip and cage make routine service trips at shift change hours, but are engaged in hoisting ore and waste and in lowering supplies throughout the entire shift time. One can be carried from level to level or up to the surface only when the trip can be worked in by the hoist attendant.

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

(k) While the mine is to be classed as "dry" the air is very moist and in many places the walls are wet. Such water as does collect is led into sumps and pumped out of the mine.

(2) Drifts and Equipment: At each level, cross cuts are run to connect all shafts and the two principal veins. These cross cuts are 17 feet wide and 8 feet high for a distance of 100 feet from No. 5 shaft and thereafter are 7 feet wide and 7.5 feet high. The dimensions of the cross cuts var~~ies~~y somewhat. The above figures are the minimum. If loose rock is encountered, the walls or back may slough off and the cross cut be thus made larger. When completed, all loose rock is scaled off and, where necessary, the walls are protected by a cement surface put on by a spray (~~gunight~~ gunite).

On reaching the principal veins, drifts are run along these to the boundaries east and west. The drifts are a minimum of 7 feet wide and 7.5 feet high. The dimensions are again subject to change due to loose rock, the drifts becoming much wider at some points, especially in the north vein and in the west end for reasons already noted.

Since the drifts are run through the crushed rock of the veins, they must be timbered at many points. Two types of timbering are illustrated. Fig. 8 shows a pin support used where the walls are good and the backs loose. Fig. 9 shows more complete timbering using posts. In this latter illustration one should note that the lagging on the back is placed longitudinally and that the ends of the cross beams carry V-shaped pieces which up-tilt the outer rows of lagging. If the drift becomes subjected to pressure, it tends to close in. Placed in this way, the lagging rides up and continues to hold the back. Sometimes the pressure is very great and squared timber, more than a foot square, placed crosswise of the drift, is crushed by end pressure alone as shown in Fig. 10. This particular timber is located at the point marked C in Fig. 22. It is to be noted that ~~all~~ most of timber used throughout the mine is treated with zinc chloride.

In the west end of the mine, additional cross cuts have been provided connecting the drifts on the principal veins. These are known as safety cross cuts. Their location on the 2950-foot level is shown in Fig. 22. In these cross cuts, at dangerous points, special circular steel sets have been placed as shown in Fig. 11. The particular set shown is situated at the point marked B in Fig. 22. These sets are made of 65 lb.

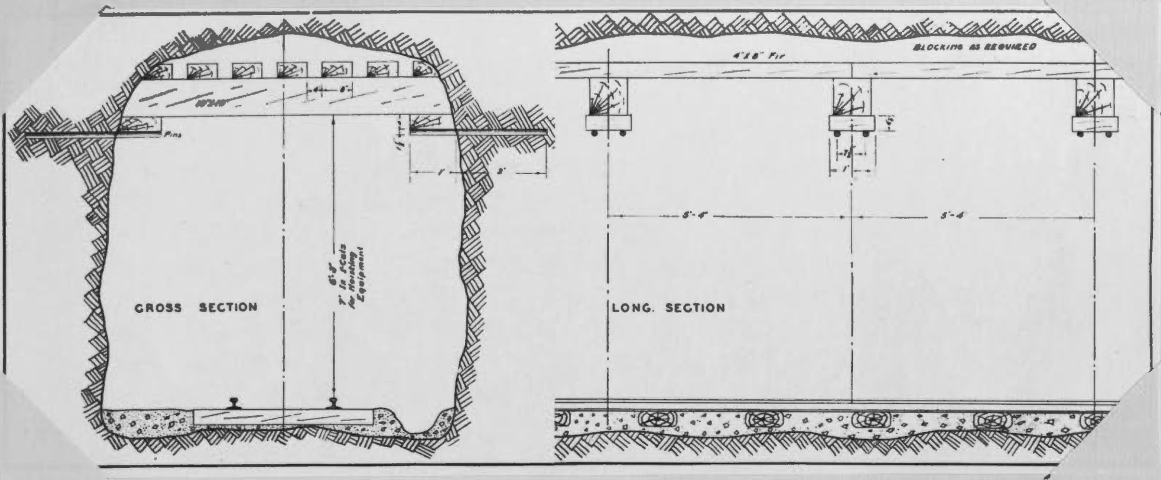

Fig. 8. Pin-supported Timbering

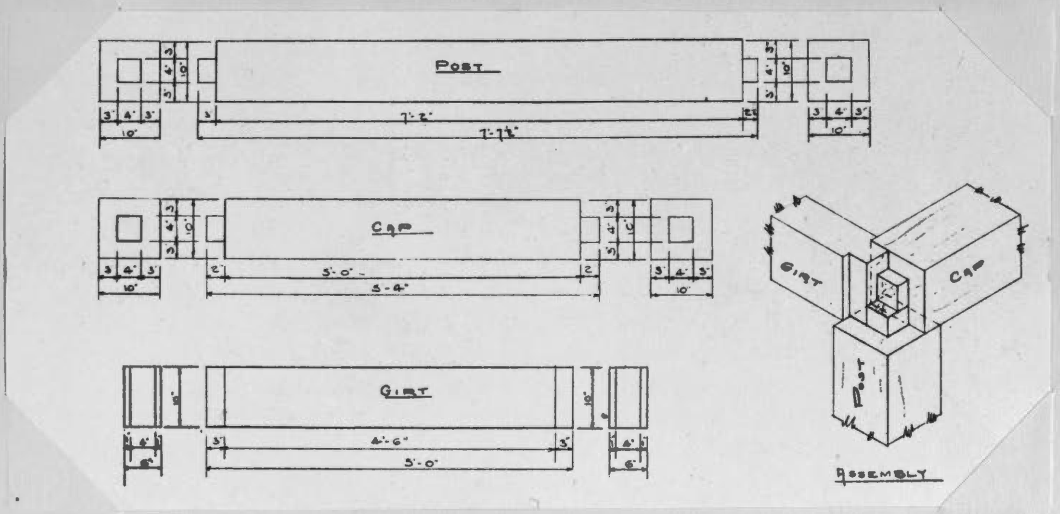

Fig. 9a. Cribwork Details

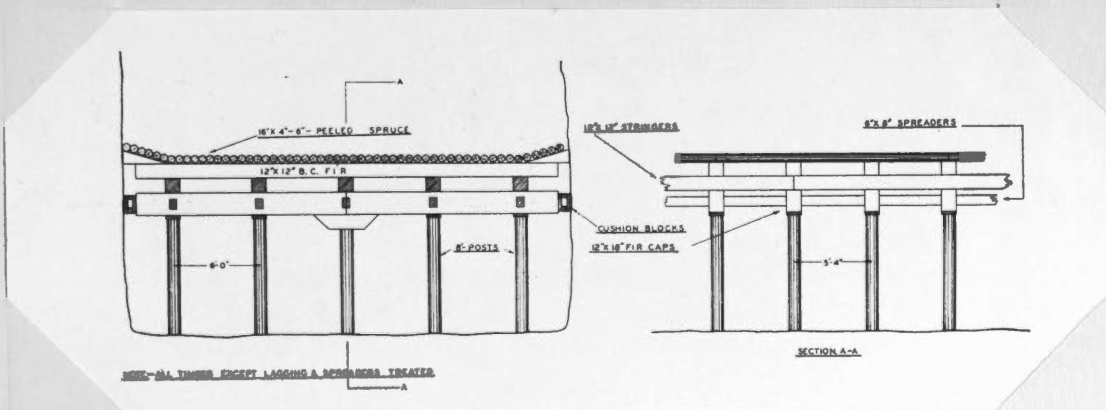

Fig. 9b. Drift Timbering

Fig. 10. Beam Crushed by End Thrust in 2950-foot Level

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Fig. 11. Circular Sets in 2950-foot Level

11

Fig. 12. Model of Ore Passes
4325 to 5450-foot Levels

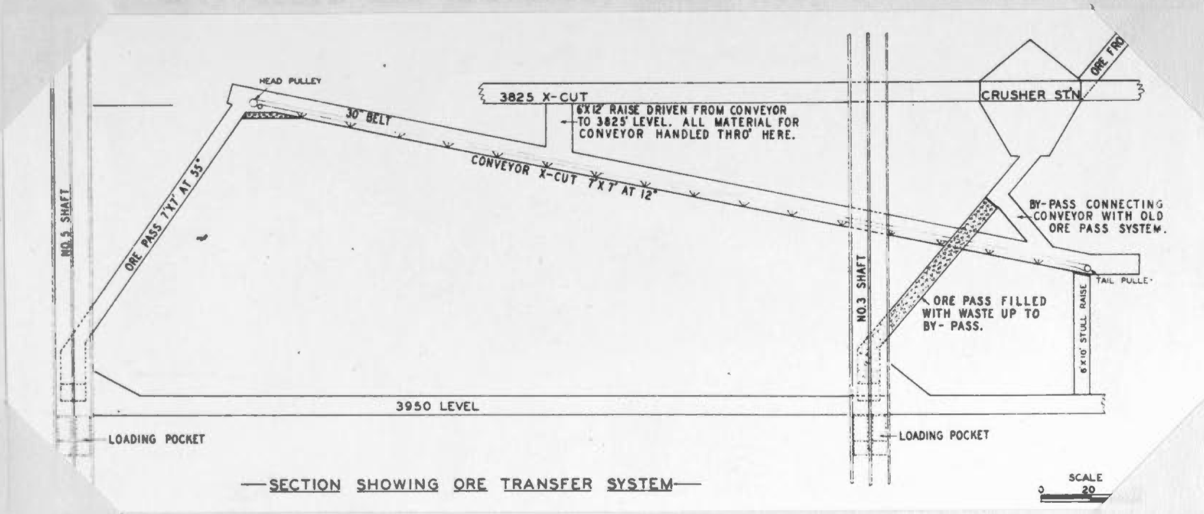


Fig. 13. Crusher and Ore Transfer
3825 to 3950-foot Levels

rails, bent with the ball to the inside and covered with 16-foot round lagging treated with zinc chloride. About a foot of sand is placed above the lagging. In case of a burst, these sets do not completely crush. They afford a measure of protection for anyone in them at the time of a burst and hold a way open for escape. More than 1,500 feet of these sets are now in use.

The drift is held at a slope of 0.5 percent, up as one moves out from the cross cut. This slope thus favours the heavy ore transportation. Rails are laid in all cross cuts and drifts. The standard gauge is 24 inches, using 35 lb. rails. The trucks are of three sizes 24 cu. ft., 45 cu. ft., and 100 cu. ft. The largest have eight wheels, each equipped with Timkin bearings. The locomotives are storage battery type and in two sizes. The larger type weighs 3 tons. Charging stations are situated on the cross cuts at each level.

Air lines and water pipes are carried through all drifts to service the drills when mining begins. The drifts are not lighted. All miners carry very efficient, diffuse-beam, electric lamps with Edison storage-batteries. These lamps burn continuously for ~~eight~~ twelve hours. They are returned to the charging and servicing station on the surface when the men leave the mine. The cross cuts are, for the most part, lighted. Current for electrical blasting is carried to ~~all~~ certain working stopes.

At various points in the cross cuts, as required, heavy doors are provided, which help to control the ventilation system. The air in the mine is remarkably good and free from dust; but, as previously noted, is quite damp. The temperature varies little from day to day and month to month. The yearly range is said to be only 2° to 3° F. The writer did not note any appreciable difference in temperature at the different levels below about 4000 feet.

(3) <u>Ore and Waste Passes</u>: To remove the ore and waste from the mine, ore and waste passes have been run between the various levels at the cross cuts. These dip at an angle of about 50° and change direction at intervals to assist in controlling the falling rock. Fig. 12 shows a model of a typical lay-out of such passes to be developed below the 4325-foot level. The model of the illustration was constructed by the geological division. Only the

coloured parts have so far been completed.

Such passes have a diameter of about 6 feet by 9 feet and are, of course, unlined. They are protected at the loading levels in the cross cuts by gates. Ore is dumped from the trucks and passes to crushers, which are situated at the 1400, 2000, 2700, and 3825-foot levels. The rock is crushed to pass 5.5 inch openings in a protecting grid or grizzly. Ore being passed through the chutes is sprayed to prevent dust. As drilling is done with water fed through the drill rods, there is little cause for dust in this mine.

For example, at the 3825-foot level the construction is as shown in Fig. 13. The ore from the crusher is carried up the slightly-inclined conveyor on a belt. It then falls into the ore pass, which is inclined at 55° -- not much above the angle of repose for crushed rock. At the bottom of this pass, its flow is controlled by a special gate of heavy chains terminating in 15-lb balls as shown in Fig. 14. This gate was designed by Mr. D. L. Cramp, Superintendent of the Mechanical Department. It permits the closing off of a moving chute of ore with certainty and remarkable precision.

The ore below the chute passes into a measuring pocket which contains just enough to fill the ore compartment on the bottom of the skip (see Fig. 7). When the ore ceases to flow into the measuring pocket, the Cramp gate is lowered onto the top of the now stationary ore in the chute. The measuring pockets, one for each skip, appear in Fig. 15. The door at the base of the measuring pockets is controlled by compressed air. The cylinders are clearly shown in the illustration. The skips run in counterbalancing fashion, one going up as the other goes down.

A skip being in position below its pocket and the Cramp gate down, the operator admits the air which opens the lower gate. As the ore discharges from the pocket, the Cramp gate closes off the flow in the pass above. The skip, having been loaded, is hoisted to the surface to a position above a great hopper. The ore discharges into the hopper by gravity and is conveyed by a moving belt to the mill. Ore can thus be carried to the surface by the two skips with ease and rapidity and with practically no hazard to the operators.

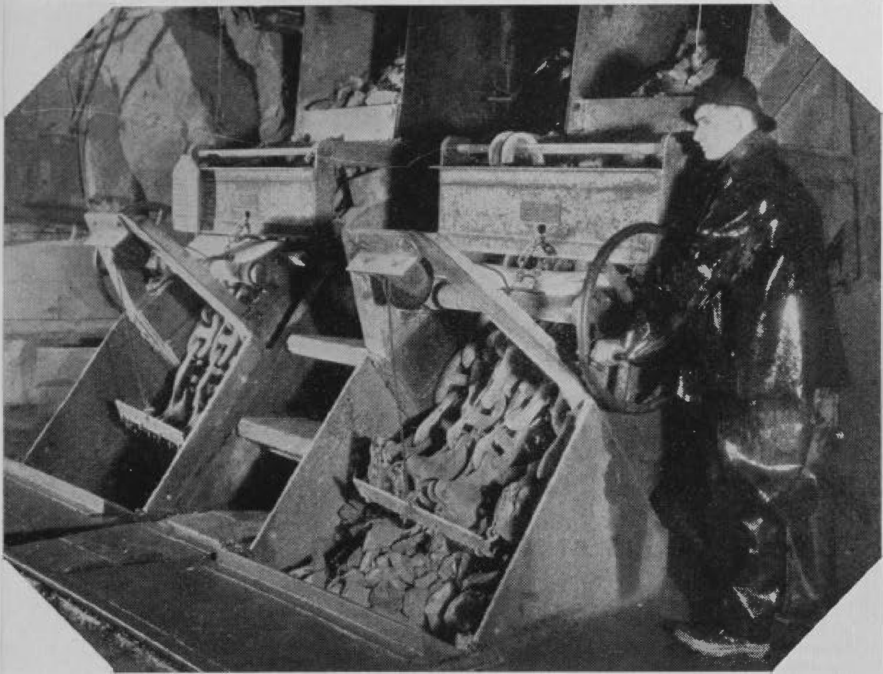


Fig. 14. Loading Pocket on 2950-foot Level Showing Cramp Gates

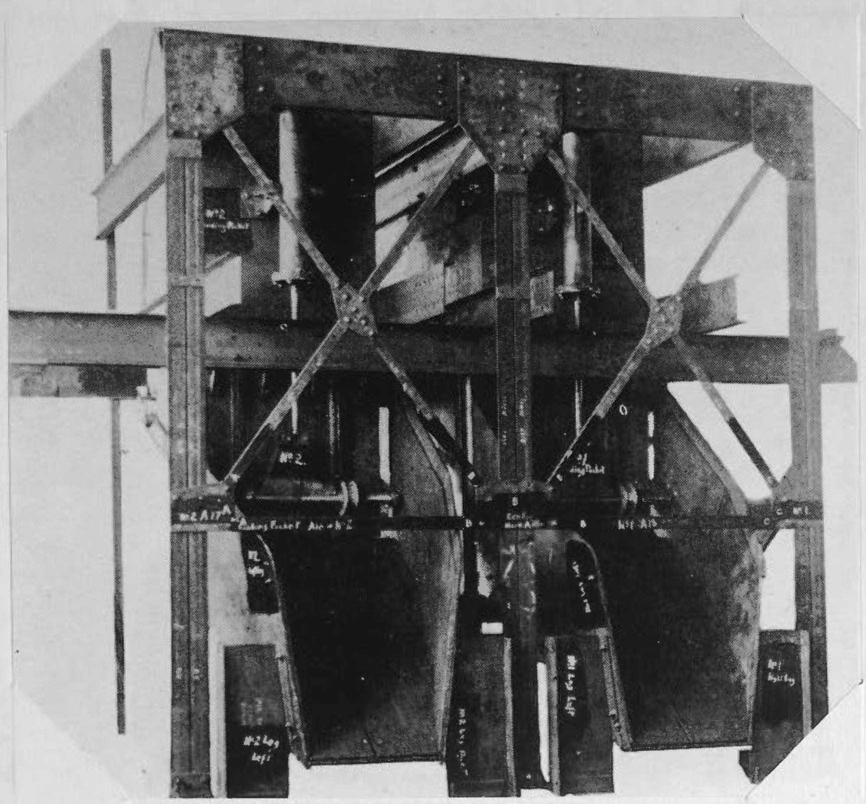


Fig. 15. Loading Pocket at Discharge Bins

In addition to the waste rock and ore which is taken out of the mine, filling is taken down, by means of passes similar to those used for moving the ore and waste. Some of the filling used is rock, some sand, and some cement, as will be noted later in discussing the mining operations.

III. Mining Methods: Before describing the mining procedure followed at Lake Shore, it seems best to list the methods used and explain briefly what is meant. Ore is mined from a working space or stope. If the excavation proceeds from below it is called overhand stoping; if from above, underhand stoping. Practically all stoping at Lake Shore Mines is overhand. That is to say the section of vein lying between two drifts 125 feet apart is mined from the lower of the two drifts.

To mine a section of vein, vertical holes called raises are driven upward from the lower drift to the upper at regular horizontal intervals. If driven from the top down, such a vertical hole is called a winze. The back of the lower drift is then mined down until a 16-foot cut has been put through from raise to raise just above the lower drift. Timbers are then put in and covered with lagging (flooring, whether round poles or plank) through which openings are left for ore chutes and manways. These are timbered and lined. To a depth of 8 feet, the lagging is covered with crushed ore and waste. A working chamber or stope has thus been formed, terminated at each end by a raise and running horizontally from raise to raise. It is the full width of the vein and has a working height of 8 feet above the rock covered lagging over the lower drift.

To continue this stope, various methods are possible. It may be continued by:

(1) Shrinkage stoping
(2) Stull stoping
(3) Horizontal cut-and-fill, open stoping
(4) Horizontal cut-and-fill, square-set stoping
(5) Open rill stoping
(6) Square-set rill stoping.

These methods may be briefly described as follows:

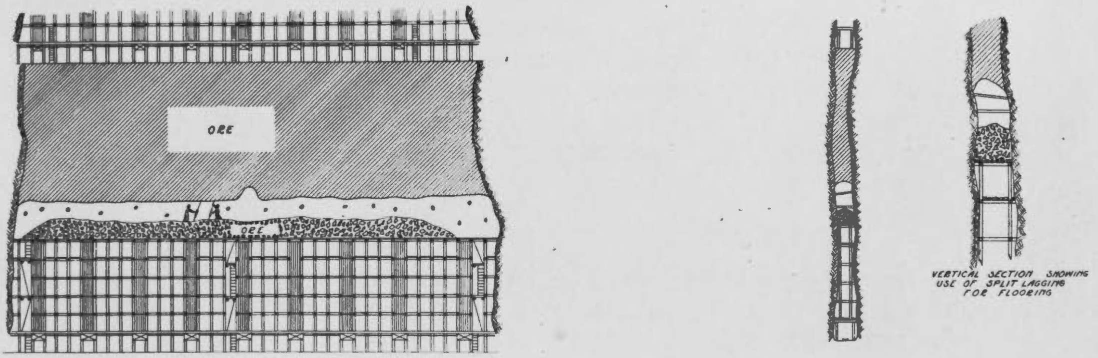
(1) Shrinkage Stoping: Broken rock occupies about 60 percent more space than ore in place. If, therefore, the miners break down the back and breast of the stope, passing out about a third of the broken rock to go to

the crushers, and keep raising the timbered ore chute and man pass as the working level rises, the broken rock will continue to fill the cavity up to the working height; and, if the walls are firm, the miners could emerge at the upper drift, leaving the entire section full of broken or "shrinkage" ore. If this were all the walls required to provide a safe working stope, the miners could thus safely finish the entire section; and, afterwards, draw out the broken ore from below without entering the stope. This method is called shrinkage stoping. It has not been used in Lake Shore Mines below 1,600 feet.

(2) Stull Stoping: A good English-French, technical dictionary defines a stull construction as pont de travail, which makes the idea quite clear. A stull construction consists of posts with cross beams and a lagging cover at the level needed. If it were outside a building we should describe it as a scaffold. A stull fill does more than afford a working platform however, for the cross timbers are wedged from face to face of the stope as a rule and thus give some support to the walls. The stope, so mined, is simply timbered as the miners work upward, the rock being taken out as mined, after which the timbers are removed. For an illustration of a stull stope see Fig. 16.

(3) Horizontal Cut-and-fill : Open Stoping: This is illustrated in Fig. 17. As the name implies, the stope is carried upward by a series of horizontal cuts put through from raise to raise beginning in the back of the lower drift. As each step upward is taken, the ore chutes and man ways are timbered up, waste rock and sand being passed in, by way of the raise, from the upper drift.

(4) Horizontal Cut-and-fill : Square-set Stoping: This method is similar to the one above except that permanent timbering of carefully jointed cribwork or square-sets is put in as the stope is mined out. Such sets are very strong and are wedged into place as the work progresses. Each succeeding section is tied to those below and to the side, so that a rigid wooden block affords continued protection to the miners in the stope. As the successive layers of cribbing are added, they are filled with waste rock and sand passed down the raise from the drift above. The timber remains in the stope. Fig. 18 illustrates horizontal cut-and-fill stoping with square-set



Longitudinal section.

Vertical section.

Fig. 16. Stull Stope

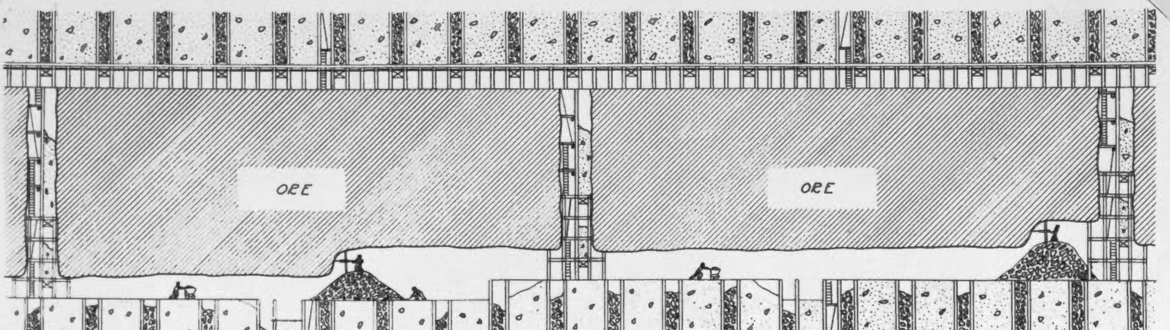


Fig. 17. Horizontal Cut-and-fill: Open Stope

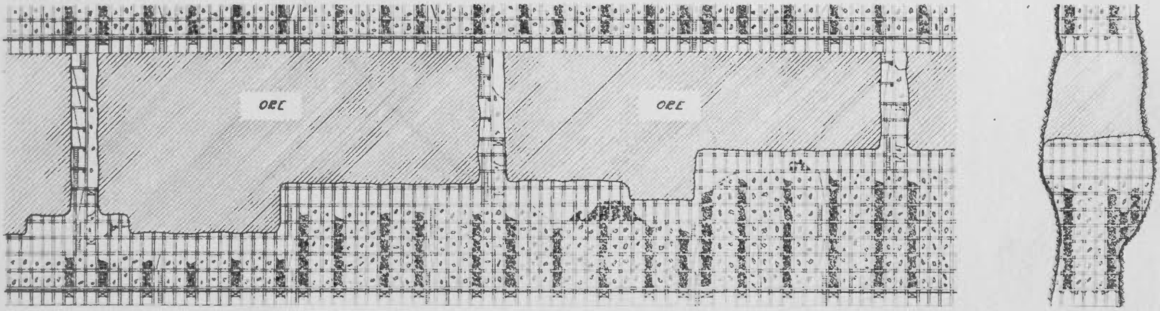


Fig. 18. Square-set Horizontal Cut-and-fill Stope

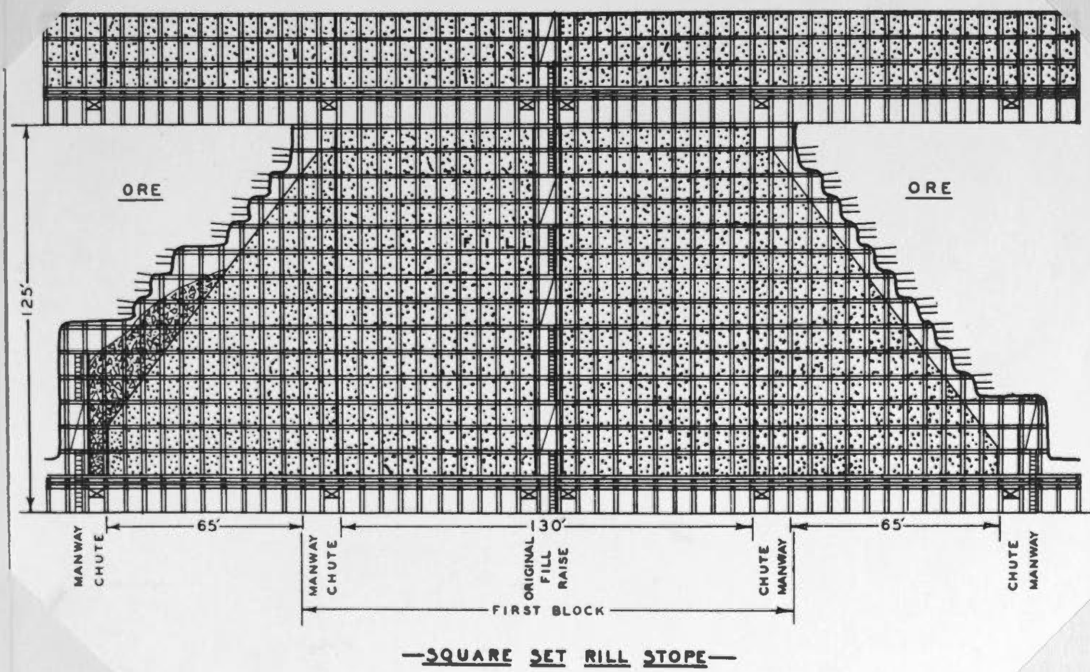


Fig. 19. Square-set Rill Stope

cribs.

(5) Open Rill Stoping: The drawback to the horizontal cut methods in a deep level mine is that as one approaches the upper drift a long horizontal pillar* of ore is left which is subjected to enormous lateral pressures as can be seen on reference to Fig. 10. This sill pillar or floor pillar is thus liable to burst with disastrous results to men and to the workings. To avoid this and carry the cut forward, horizontally as well as vertically, recourse is had to rill stoping in which a cut is taken off the inside edge of the raise at an angle which makes the raise wider at the bottom than at the top. Thus, the men work from a sloping pile of fill lying at its angle of repose as dumped down the raise. This method is known as open rill stoping.

(6) Square-set Rill Stoping: By this method, the stope is carried forward as successive rills, filled with square-set cribbing as the work progresses. The procedure is shown in Fig. 19. The successive rills are filled with waste and sand as completed. Each raise is thus mined as a rill, cut from below with the fill held back on its lower level by its own weight on the angle of repose and on the upper part of the raise by lagging nailed outside the last square-set erected, wedged if necessary from the working face until the square-set in the new raise is in place. This is the method now in general use in Lake Shore Mines. The rill is never carried more than 16 feet forward of the advancing fill. The cribbing goes in as the rock comes out.

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* Note: The term "pillar" is rather loosely used to indicate any volume of rock or ore with more or less definite, if perhaps only partially defined, physical boundaries (air-rock, air-ore, ore-rock). For example, in Fig. 22, the section of waste rock between the two drifts at the point marked E is a pillar. In Fig. 20 and 21 we have, in plan and elevation respectively, a section of ore 1,000 feet high and 100 feet long, of varying thickness and cut quite through at every drift; yet this mass of ore as a whole is the "west pillar". If the ore in Fig. 18, for example, be considered by itself it is a pillar even though it be part of the west pillar. If it is reduced by horizontal cutting until decidedly longer horizontally than it is wide vertically, it would be referred to as a sill pillar or floor pillar.

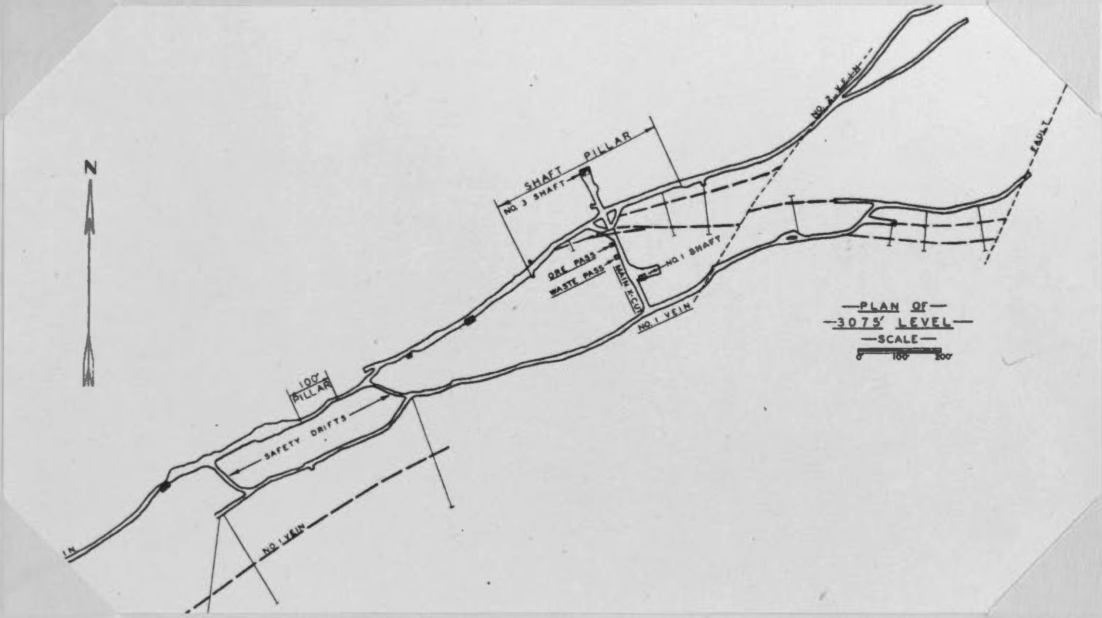


Fig. 20. Plan of 3075-foot Level
Indicating Shaft and West Pillars

see fig. numbered 8

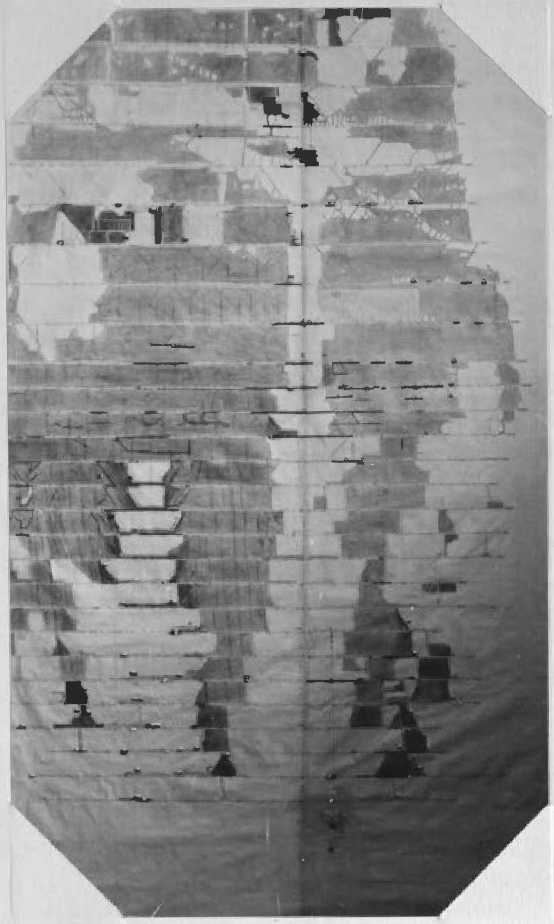


Fig. 21. Elevation of No. 2 Vein, West End

IV. Mining Procedure at Lake Shore Mines: As previously stated, practically all mining at Lake Shore is overhand. In the upper levels, shrinkage stoping and stull stoping were used; but, as the mine was developed to deeper levels, the horizontal cut-and-fill methods came into use. There are some shrinkage stopes in the upper levels from which the shrinkage ore has not as yet been recovered.

As the mine went below the 2000-foot level, rock bursts became more frequent and more severe, and square-set rill stoping was adopted. At the present time, experiments are being carried on with horizontal cement plugs immediately over the lower drift. Such cement plugs are the full width and length of the stope and 8 feet deep. In some cases they they are reinforced with tension cables and iron rods. Such plugs will, it is hoped, relieve some of the pressure on the stope walls until it has been mined out.

In the west end of the mine, the veins were not mined out for a distance of 100 feet from the cross cuts. About the centre of the west end, another section of vein 100 feet wide was left. These sections are referred to respectively as the shaft pillar and the west pillar. (See Fig. 20) Raises at the boundary and at the sides of these pillars provided four working faces or stopes which could be carried forward away from the pillars until they met at the centre. Fig. 21 shows, in elevation, the present conditions on the north vein in the west end of the mine. The shaft pillar and the west pillar are shown with the mined out sections, now packed with fill, lying between. The west pillar is now being mined from various levels. As it is taken away, the last ore-in-place in this area is taken out and the vein walls are supported only by the fill and the inherent strength of the wall rock. Mining in No. 1 vein is carried on, in general, in advance of No. 2 as the former is in the hanging wall of the latter.

V. Rock Bursts in the Kirkland Lake Region: Informative papers on this subject have recently been published by Christian(5), Robertson(6), and Robson et al(7). Valuable contributions to the same subject are given in earlier papers by Robson(2) and Weldon(3). Some brief excerpts from the papers referring to Lake Shore Mines may here be given. It is noted that:

(1) The governing factors affecting the incidence and severity of rock bursts are:

(a) Type of rock and its properties.
(b) Depth of workings, other conditions being equal.

(c) Dip of the ore body and rock structure.
(d) Mining methods and speed of operations.

(2) It has been found that:

(a) Bursting occurs in many instances at the time of, or closely following, blasting.
(b) Complete extraction of ore is desirable, and the leaving of small pillars, whether of ore or waste, is to be avoided so that a gradual and uniform subsidence of the hanging-wall may take place.
(c) Horizontal pillars are a menace and must be avoided, or removed as soon as possible.
(d) Mining out a remnant from two directions is not good practice, regardless of the form of the triangle established.
(e) Steep rills avoid the formation of horizontal remnants and hence are least susceptible to bursts.
(f) Long rills, extending from level to level, and advancing in the direction of unmined ground, are less susceptible to bursts than those mining out a remnant.
(g) The method of mining vertical cuts in short sections is useful in particularly heavy ground, but is higher in costs.
(h) Bursts at either side do not transfer through the shaft pillar, nor in most cases do they occur close to it.
(i) No bursts have occurred in the vertical pillars formed by the Teck-Hughes boundary line and the diabase dyke.

(3) Rock bursts types may be listed as:

(a) Strain bursts affecting the face of workings only.
(b) Pillar bursts where a volume of rock bursts in a more or less localized part of the mine.
(c) Crush bursts where larger sections of the mine burst and settle.

(4) The mechanism by which, it is supposed, the large stresses are built up is known as doming. As a section of ore is taken out of a stope the rock in the walls

with or without partial support of crib and fill, is called upon to hold open the workings. The face of the rock is generally in the crushed region of the vein and has little strength. The stress is supported by the rock behind, which acts as an arch or dome, spreading the stress to the pillar edges. As the workings increase in size, the dome changes in dimension and the stress per unit area on the pillar increases. If this stress exceeds the bursting strength of the pillar a rock burst results. Doming takes place in the hanging wall at lesser depths than in the foot-wall.

In the upper part of the mine, there was some displacement of the veins along a strike fault which gave a displacement to the south of as much as 90 feet in the case of the most prominent strike fault. In this area, therefore, the upper workings are over a solid base in the foot-wall of the vein. The doming caused by the upper workings is thus not carried on downward to the lower levels. This type of fault does not extend below the 1600-foot level.

(5) The location of rock bursts in the various workings at Lake Shore Mines is given by Robson(7). He also gives a description of some of the larger bursts and shows the effect of these bursts on timbering and on the circular steel sets.

(6) The methods in use to prevent bursts have been and must, of course, continue to be improvements in mining technique, including careful attention to the speed of mining. To reduce the hazard, the shifts are reduced to two of eight hours each, operating from 7 a.m. to 3 p.m. and from 7 p.m. to 3 a.m. Blasting, except for small shots for various purposes, is carried out at the end of the shift, with all men withdrawn from the mine. The blasts are fired electrically from the shaft station, the stopes being fired in order beginning with those farthest out. As bursting takes place during or after blasting, as a rule, the mine is left empty except for a few isolated workmen during the off-shift hours.

VI. <u>Adaptation of Research Program to Mine Conditions</u>:

Throughout the foregoing description of Lake Shore Mines care has been taken to include all observed data which would have some bearing on the adaptation of the research equipment or program which will have to be made in order to meet the conditions in the mine. Some of these may be specifically mentioned as follows:

(1) Equipment will have to be operated in very moist air but little or no special precautions need be taken against dust.

(2) Operational noises and electrical disturbances in the vicinity of the cross cuts which may affect recorders are likely to be caused by: hoists, charging stations, hoist machinery for No. 6 shaft, ventilating fans in No. 3 shaft, ore and waste discharges and fill runs, crushers, annunciator and telephone systems, locomotives and trucks with ore and supply loads, water pumps, chute blasts to loosen ore.

(3) Operational noises and electrical disturbances in the drift regions which must be considered are: drilling, discharge of ore from chutes in the stopes, discharge of fill into stopes, transportation equipment, water pumps, popshots for timbering and placing drills, blasting.

(4) Equipment must be made in units which can be lifted by one man and loaded into trucks so as to clear all timbering and permit of unloading at its destination.

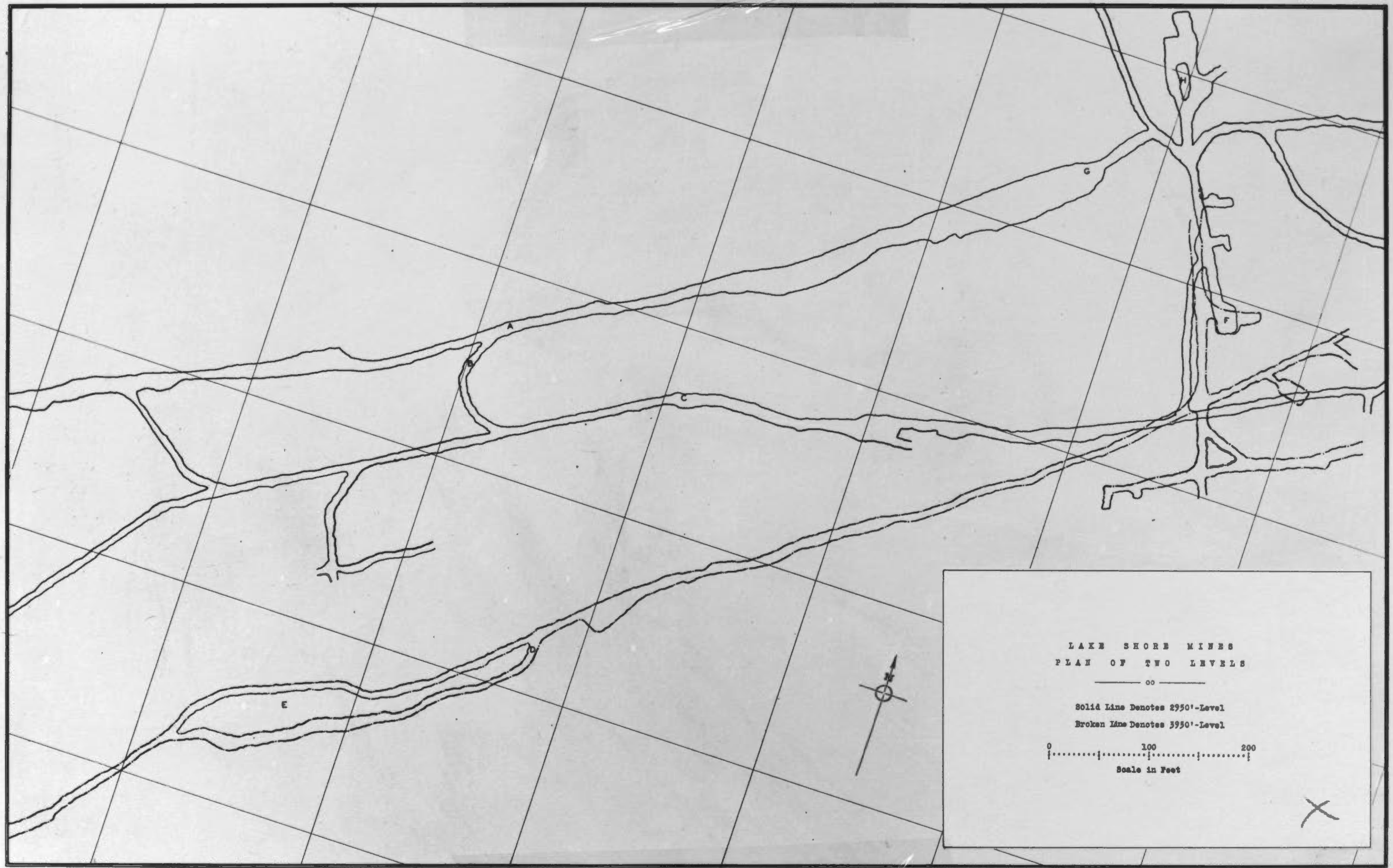
(5) Locations for seismic equipment, which will be placed for the most part in the west end of the mine, must be on solid rock. This will mean scaling into the walls and providing cement lined recesses for the units. The units for this reason also must be compact as possible. Equipment must be placed in such a way as not to obstruct traffic through the drifts.

(6) Locations should not be in the west pillar but as close to it as possible in the drifts.

(7) Programs must be designed to require as few trips up and down shaft as possible, since this is time consuming.

(8) If it is decided to have surface recording at a later date, the difficulty of getting electric cable down to the detectors will be largely one of expense. The shaft compartment provides easy access to every level.

(9) Equipment should be battery operated if possible, as the only electric service to the stopes is for blasting and this cannot be used for amplifier supply.


LAKE SHORE MINES
PLAN OF TWO LEVELS
Solid Line Denotes 2950'-Level
Broken Line Denotes 3950'-Level
0 100 200
Scale in Feet
N
A
B
C
D
E
F
G
H

(10) To avoid using mine trucks, a light service truck should be provided which can be lifted from the track if necessary and which is for the use of the research group only.

(11) Temperature conditions do not present a problem for seismic equipment and are favourable to studies on temperature effects within the pillars due to changing pressure.

(12) Since all workings are interconnected, it should be possible to record with seismometer and microbarograph at the same location and obtain some indication of the position of a burst from the time interval between the elastic wave through the rock and the shock wave through the air.

VII. Location Data for Use with Appendix Report: In the appendix report, reference is made to locations of the equipment in the mine. This is explained graphically in Fig. 22, which shows on the same location grid the two levels concerned: 2950-foot and 3950-foot.

The cross cuts are readily located. No. 3 shaft is at H, and No. 1 shaft at F. The drift, 2901W, begins at G. A barrier at this point shut off through traffic, as this drift is considered unsafe for regular service, but permitted the observers to pass into the drift as far as A, where a closed barrier prevented passing. The first set-up of the instruments, as shown in Figs. 9 and 10 of the appended report, was at A.

On the 3950-foot level, the drift, 3908W, begins at D. The drift, normally in use, was here temporarily closed by a tight barrier to the east and a partial barrier some twenty or thirty feet further in. The set-up shown in Fig. 11 of the appended report was at D. Access to the set-up was gained by walking around the waste pillar, E.

The circular steel set shown in Fig. 11 of the present report is at B and the beam crushed by end thrust shown in Fig. 10 is at B.

Copies of two daily records with the equipment used in March are given as Figs. 23 and 24 of the present report. Fig. 23 shows the last record made at the position A (2901W), March 19-20. The pick-up used was, in this case, the crystal detector. The very considerable amount of operational noise is quite evident, especially during the blasting periods from

2 to 3 p.m. and from 2 to 3 a.m. No known strain bursts are recorded. The need for a wave filter, to prevent blasting records from obscuring possible mine noises, is apparent.

Fig. 24 has been copied from one of the later records made at D (3908W) of Fig. 22. This was made March 24-25 -- Easter Sunday. No mining was carried on that day and the difference in the records is clear. The sharp offset at $7^h36^m55^s$ p.m., March 24, was a small but sharp pillar burst in the stope above 2901W, about 100 feet east of the point A of Fig. 22. This burst was followed by three others which were smaller. The time recorder of the mine seismograph was out of order for this record but the exact time was determined from the record of the surface seismograph. The absence of all tremors other than the bursts shows that, in addition to the filter, a change must be made in the frequency of the detector or else the amplification must be increased, or both.

If mine noises other than bursts were present during the period of the record for March 24-25, they could not be detected by the equipment employed.

<u>CONCLUSION</u>: The present report, together with the appended re-report as presented to Mr. Todd on March 26, brings the account of the research to date. The work on an electronics laboratory was begun April 2. Mr. Gibbs came to Ottawa on April 4 and has remained here to date. He has been making contacts with manufacturers and agents of various supply houses and has completed an amplifier which he will use, together with a commercial recorder about to be purchased, to make a further study of the possibility of mine noises.

He plans to return to Kirkland Lake on April 17 going via Toronto where he will visit various supply houses and making a side trip from North Bay to Sudbury on April 20 to consult with Mr. A. B. Yates at Copper Cliff who has had considerable experience with strain gauges. Arriving at Kirkland Lake, he expects to fit up the electronics laboratory which should be completed by then and to proceed with the various studies planned.

On his return from Kirkland Lake on April 4, Mr. Gibbs brought back the Heiland recorder of the surface seismograph. This will be modified to use alternating current instead of the unsatisfactory pendulum clock. The optical system will also be changed. It is expected that the modified equipment will yield much better surface records at Kirkland Lake. In the meantime the equipment used in the mine during March is being operated at the surface station until the regular recorder can be returned.

REFERENCES

1. TODD, E. W. : "Kirkland Lake Gold Area." Ontario Department of Mines, Vol. 37, Part 2, Toronto, 1928.

2. ROBSON, W. T. : "Lake Shore Geology." The Canadian Mining and Metallurgical Bulletin, No. 287, Montreal, March, 1936.

3. WELDON, Leslie S. : "Mining Methods and Practices at Lake Shore." Ibid.

4. DOUGHERTY, E. V. : "Some Geological Features of Kolar, Porcupine, and Kirkland Lake." Economic Geology, Vol. 34, No. 6, Lancaster, September-October, 1939.

5. CHRISTIAN, J. D. : "Rock Bursts at Teck-Hughes." The Canadian Mining and Metallurgical Bulletin, No. 331, Montreal, November, 1939.

6. ROBERTSON, A. F. : "Rock Bursts at Wright-Hargreaves." Ibid., No. 332, December, 1939.

7. ROBSON, A. T., ADAMSON, J. C., and SELNES, W. E. : "Rock Bursts at Lake Shore Mines." Ibid., No. 333, January, 1940, (Excellent rock burst bibliography)

8. ADAMSON, John C. : "Construction and Equipment of No. 5 Shaft at Lake Shore Mines, Limited." Canadian Mining Journal, Vol. 61, No. 1, Gardenvale, January, 1940.

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

Ernest A. Hodgson.

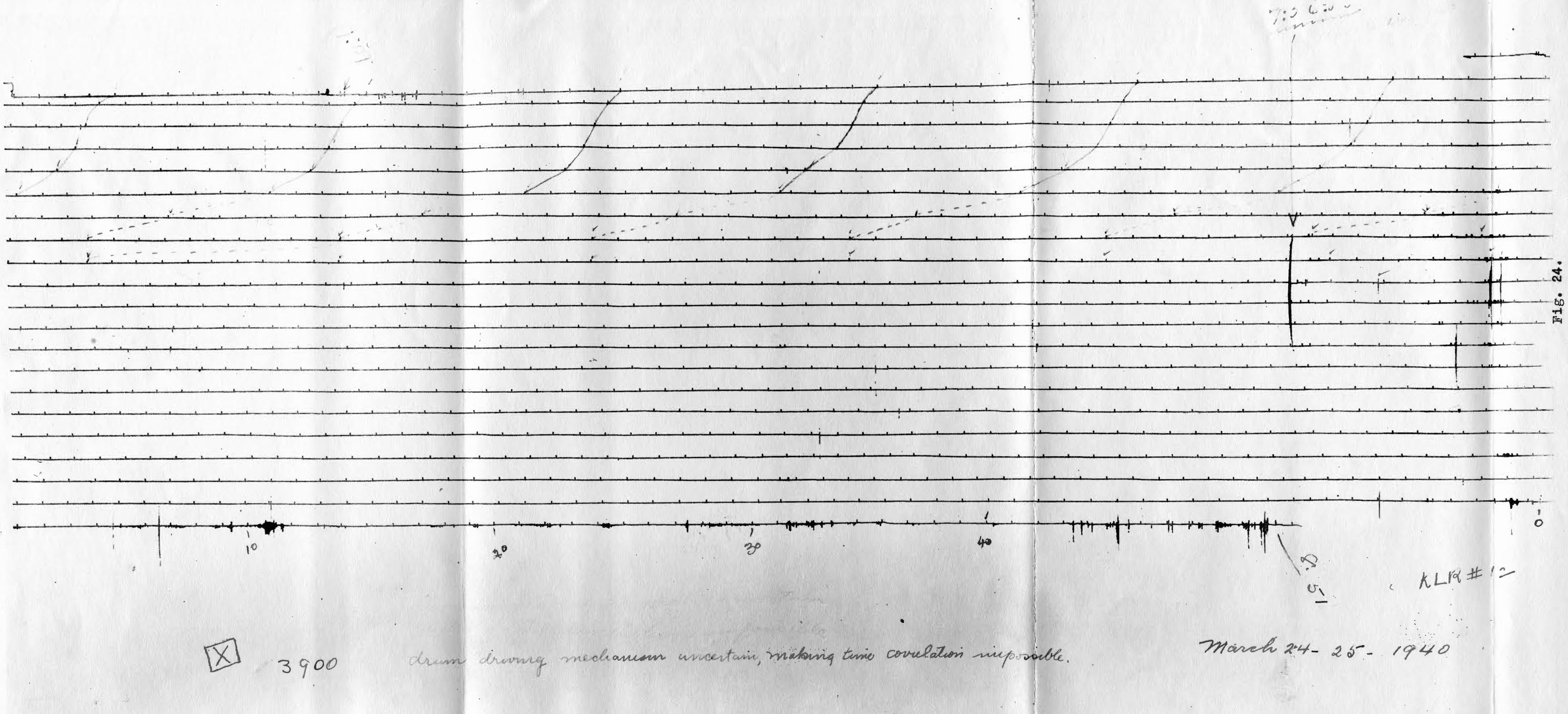
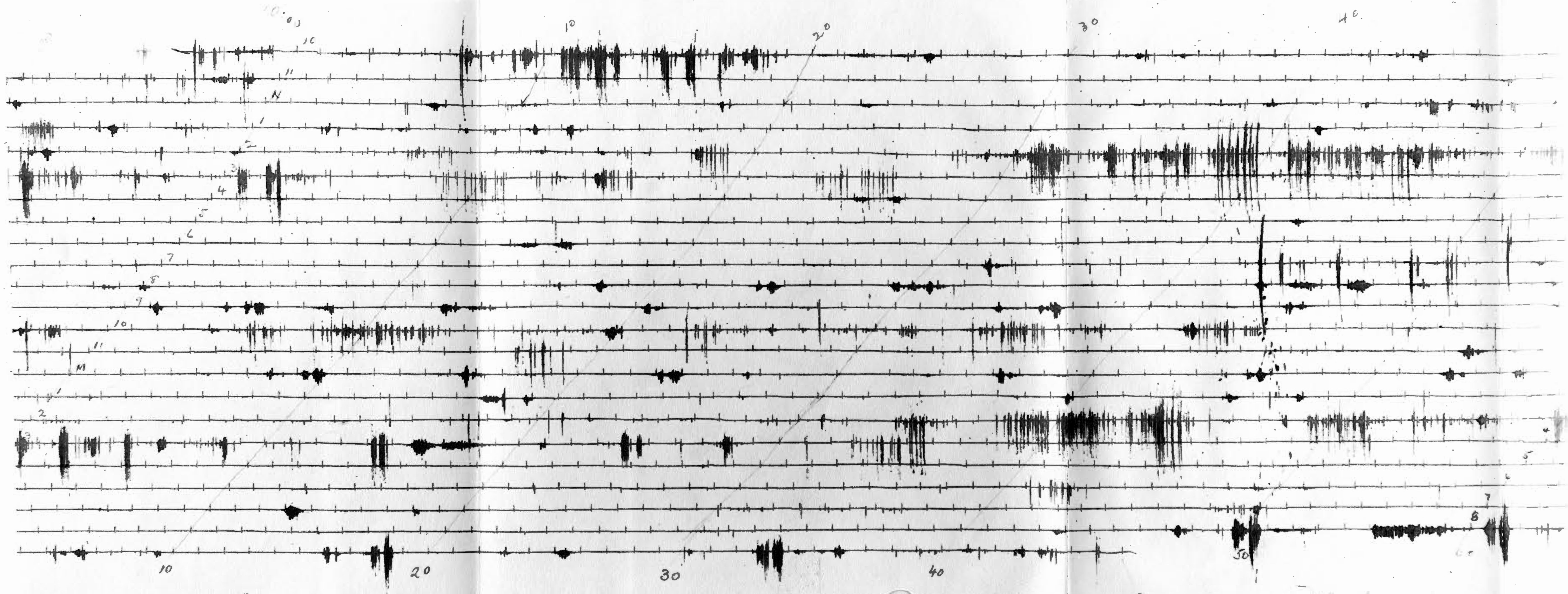


Fig. 24.
Mine Record: March 24-25, 1940



X

2900

Mar 19- 20 - 1940

Clock correction (-4 min/day

Drum correction +15-4=+11 min/day.

March 19-20, 194

KLR. #7

(17)

Fig. 23.
Mine Record: March 19-20, 1940

P R O G R E S S   R E P O R T

ROCKBURST SEISMIC RESEARCH

LAKE SHORE MINES

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ROCKBURST SEISMIC RESEARCH
LAKE SHORE MINES

The following report describes the nature of the instrumental equipment, designed and used during March, 1940, in seismic research on the rockburst problem at Lake Shore Mines. It indicates the data thus obtained and tabulates the deductions drawn therefrom. The difficulties at present foreseen, which lie in the way of further investigation, are reviewed and the possible means of overcoming them briefly examined. Finally, the writers propose what may be termed an interim experimental program, which should require a year or more to carry through and which is designed to solve the problem of the most suitable equipment to detect and record the physical data upon which, it is hoped, rockburst prediction may be based.

I. <u>Initial Program Planned and Equipment Provided</u>: The aim of the program undertaken during March has been that of determining, if possible, the nature and occurrence of mine noises which might, by their chronological pattern, indicate that a pillar under examination is in danger of bursting. As nothing was known as to the vibration frequency of such noises, two frequency ranges in detectors were provided. A Heiland geophone (Fig. 1, right) was purchased for the purpose of covering the frequency range from about 20 cycles to 75 cycles. The interior construction of this geophone is shown in Fig. 2 and Fig. 3. A Brush crystal detector (Fig. 1, left) was selected to cover from about 1 cycle to a little above 5,000 cycles.

The amplifier for use with the above detectors was built by Mr. Hollinsworth of the Dominion Observatory staff for another purpose but was loaned to this investigation through the courtesy of the Dominion Astronomer and Mr. Hollinsworth. The amplifier was designed to have a linear amplification over the combined range of both detectors, but had not yet been tested and modified by experiment when pressure of time led to its being taken over for this work. The amplifier appears in Fig. 4.

The recorder was built at the Observatory under the direction of Mr. Hollinsworth and according to his design. It records

Fig. 1. Brush Crystal Detector and Heiland Geophone

Fig. 2. Interior of Heiland Geophone

Fig. 3. Interior of Heiland Geophone

Fig. 4. Amplifier Unit

with ink on ordinary paper. The pen--a fine-bore, thin walled tube of stainless steel--is clamped near the inner end of its tube. At the extreme inner end, the tube dips into an ink reservoir. About a third of the distance from clamp to writing point, the pen is connected by a rod (horizontal when in operating position) at right angles to the tube. This rod is fastened to the voicecoil of a permanent magnet, dynamic, loud-speaker unit. For details of the pen, see Fig. 5.

The pen is mounted at right angles to the axis of a Milne-Shaw recording drum, which uses a sheet of paper about 10"x19.5" and gives a paper speed of 15 mm/min. To mark time, an alarm clock was fitted with a minute contact, which operates a relay through two No. 6 dry cells. The relay, in turn, supplies current from a single No. 6 dry cell, through a rheostat, to the loud speaker unit of the pen. The rheostat permits the amplitude of the time marks to be adjusted. A small copper oxide rectifier, between the amplifier and the speaker unit of the pen, is arranged so that all mine noises are recorded with a downward mark of the pen. (Whipping of the tube sometimes makes such marks appear on both sides of the line, but only for the more violent disturbances.) The time marking device is arranged to move the pen upwards to mark the minutes. The arrangements of this paragraph were made by Mr. Gibbs after his arrival at Ottawa on March 1. The recording assembly is shown, open, in Fig. 6, and in the covering box in Fig. 7. The entire outfit with the Heiland geophone is shown in Fig. 8.

On being received at Lake Shore Mines, the recording unit and amplifier were mounted in a wooden box as shown in Fig. 9. The amplifier is fitted into the lower shelf, with a forward-opening door. The recorder, box and all, is placed in the top compartment, the door of which opens upward. Two 40-watt lamps are kept burning in the lower section with the amplifier. Holes in the floor of the top half permit the warm air to reach the recorder. It has been found that this is ample protection against the dampness of the mine.

The arrangement in Fig. 9 is as set up in Sec. 8W of 2901W. The crystal detector (or DP-1 as it is usually designated) is shown suspended against the face of the drift. The wall is spalled at all points near this set-up, so the detector perforce, does not rest on solid rock. For this same set-up, the Heiland geophone was set on firmly wedged but loose rock on the face (see Fig. 10). More solid conditions were available in the second set-up in 3908W (south drift). These are shown in Fig. 11.

Fig. 5. Pen Mechanism of Recorder

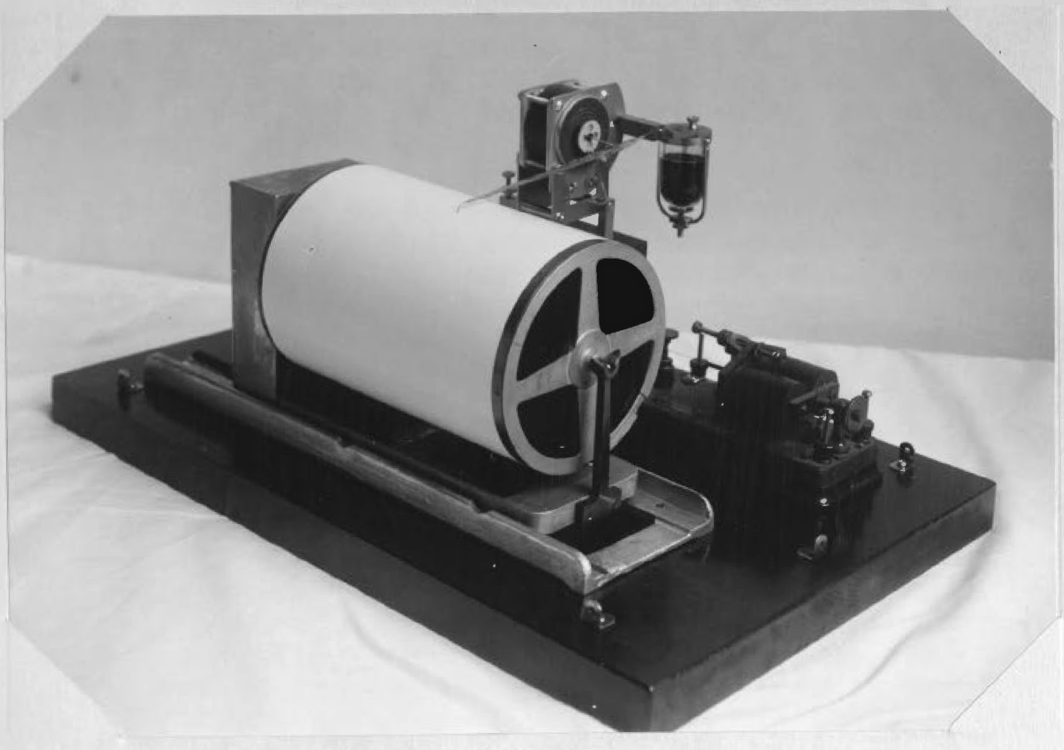

Fig. 6. Recorder without Cover

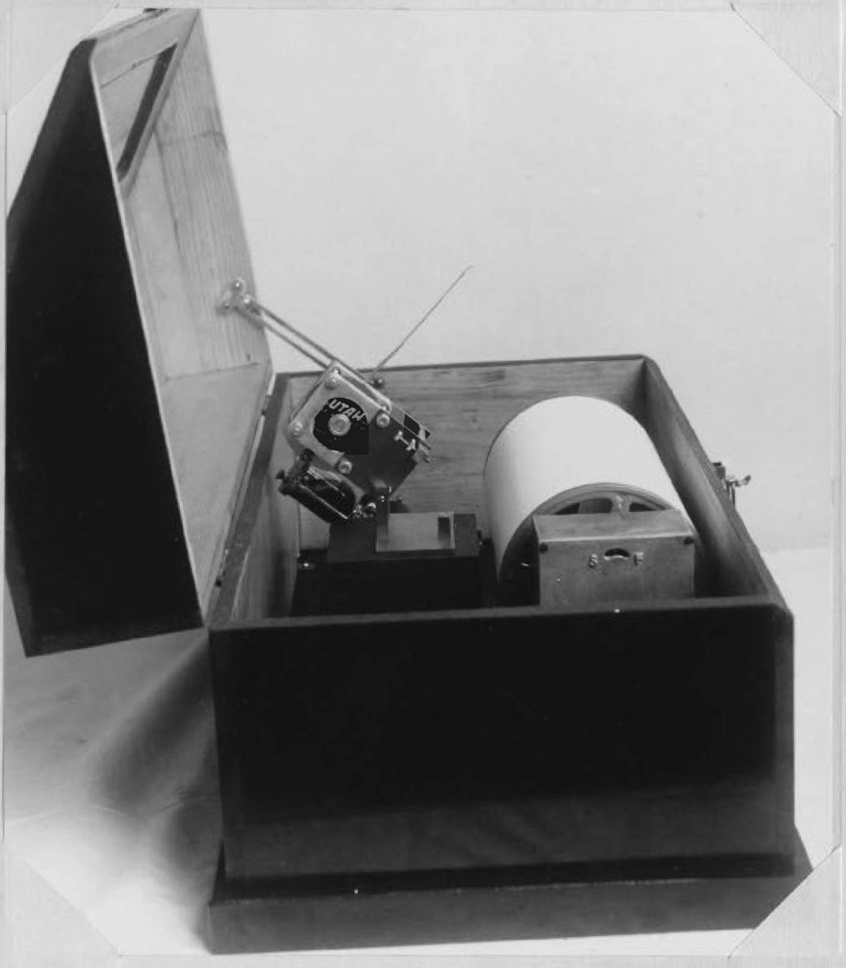

Fig. 7. Recorder with Cover

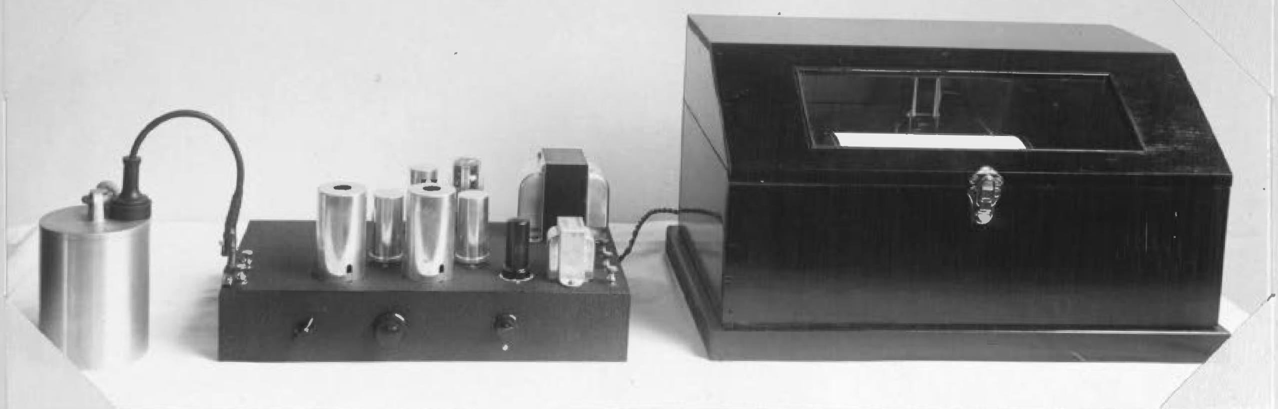

Fig. 8. Assembly with Heiland Geophone Pick-up

Fig. 9. Crystal Detector Set-up on the 2950-foot Level

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Fig. 10. Geophone Set-up on the 2950-foot Level

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Fig. 11. Set-up on the 3950-foot Level

*

*

Fig. 12. Wiring to Set-up on the 2950-foot Level

II. Recording Program as Implemented:

(1) Mine Seismograph: The equipment was received at Lake Shore early, Monday, March 11. It was set up and tested that same morning. The box providing protection from dampness in the mine was designed and built in the afternoon, being delivered early next morning. Tuesday was devoted to fitting the instruments into place and in completing the wiring for recording and heating. Electric current at 110 A.C. was carried in metal sheathed BX cable to a location in the unused south drift about 90 ft. east of 2909 X-cut. Convenience outlets and power switch were installed here to accommodate the recording apparatus and to provide light while working on the instruments.

The instruments were placed in operation Wednesday morning, March 13, using the Heiland geophone. Improper adjustment or the dampness caused the pen arm to rise off the record soon after recording had begun. Drying of the ink at the end of the capillary prevented subsequent recording when the pen returned to the paper later on. As a consequence no record was obtained on the sheet for March 13-14. A good record was obtained for the 24-hr. period terminating Friday morning, the same hook-up being used. Conditions were left unchanged until Sunday morning, March 17, when the crystal detector was installed in place of the Heiland geophone. Good 24-hr. records were removed Monday, Tuesday, and Wednesday.

On Wednesday morning, March 20, the outfit was moved to the east end of 3908W drift. This end of the drift was closed by barricades. Good records were obtained each morning to the date of this memorandum (March 26) using the crystal detector. As installed at first, the detector was supported by wires fastened to a post resting on service pipes on the floor of the drift. The mine captain on this level pointed out that much of the disturbance recorded was due to tremors carried along this pipe at the time muck was being discharged from the stope nearby. The wires were changed Monday morning, March 25, being fastened only to the rock as shown in Fig. 11. The record removed the next morning was quite changed in character, though it must be noted that the operations in the stope had changed and filling had commenced.

On removing the records each day, they are taken to Mr. Adamson's office and there compared with the reports received from the mine captains showing the amounts of explosive used and the nature of the rock blasted. Special reports have also been asked for and received showing the positions and times of all pop shots for timbering and, for one day, the movements of electric trains in the vicinity of the west pillar on the 3950' level. The co-operation of the mine captains and their interest in the investigation have been most helpful.

The difficulties have been experienced in obtaining full 24-hr. runs, except for the first day when the pen ran dry and, at times, when the timing contacts failed to function. The failure of the time marks is not a serious matter, as the times of beginning and ending are entered on each sheet from the corrected watches of the operators. The drum rotates nominally once an hour and its rate is known, enabling time to be identified on the record to within a minute or so. More exact timing is seldom needed, but when required the blasting records on the mine seismograph can be correlated with the accurately timed records of the surface seismograph.

(2) Surface Seismograph: At this point it may be stated that the surface seismograph has been completely overhauled since the writers arrived at Kirkland Lake. The seismometer was found to require adjustment and also the galvanometer and the lamp. The timing circuit has been arranged to operate from a dry cell instead of from the battery supplying the light source. This eliminates any possibility of interference due to the charging generator. The efficiency of the surface installation has been greatly enhanced and serves as a valuable check on the mine instrument.

As it was sometimes impossible to receive time signals, even from NAA, the aerial was taken down and re-wired, the dimensions being changed. The long wire was cut and three insulators inserted at intervals of 66 ft. From the centre of these three insulators an ordinary lamp cord was run to the receiving set. Each conductor of the lamp cord was soldered to one 66-ft. length of antenna. When connected to the receiver as a "half-wave doublet" this antenna affords excellent reception of CHU on 3330 Kc. and reduces the static. By changing the method of attaching the feeders to the receiver, the antenna may be made to operate as a simple capacitive antenna. Knife switches have been mounted on the wall of the radio room to facilitate the change. Operating as an ordinary antenna, the signals from NAA are better than before, due mainly to a better signal-to-noise ratio obtained with the effectively shorter antenna.

The developing bench was found to be much corroded, the galvanizing being destroyed in many places. At our request this was rubbed down and given two coats of gray paint. The paint used was apparently not entirely suited to the conditions or, perhaps, a primer coat of some sort should have been applied, for the new paint tends to blister and turn white if water is left standing on it.

To take care of all the needs now observed at the surface station, the following are hereby recommended;

(i) Top of developing bench to be painted two coats of special waterproof paint. There is a C.I.L. product sold for this purpose.

(ii) The floor of the seismograph room and also the radio room should be sized and painted to eliminate, as far as possible the fine dust which is damaging the mirror surfaces of the seismograph.

(iii) To eliminate radio interference due to the motor-generator set, radio frequency chokes should be installed in the leads from the motor-generator. A grounded shield around the commutator of the generator might also be helpful. The cost of this improvement should run between five and ten dollars

III. Deductions from Data Obtained: The following are the observed results of the short recording program so far carried out with the mine seismograph:

(1)a All blasting and all reported bursts in the region of the west pillar appear to have been recorded by the mine seismograph.

(2)b The crystal detector is more sensitive for both the blasts and for the few small strain bursts experienced during the experimental runs.

(3)c There seems to be no record of any noises in the mine, other than those due to mine operations and to the strain bursts reported. There are a few other shocks which seem to have recorded in the same way as strain bursts and appear on the charts of both mine and surface seismographs. These last are probably small strain bursts not located by the miners.

(4)d So far as the writers are aware no mine noises, as distinct from strain bursts, have been reported in the vicinity of the west pillar since recording began. The mine has not been "talking" or "cracking".

(5)e Dumping of ore or waste rock through the chutes does not seem to have been recorded except at the set-up in 3908W where the chutes were very close. Even here, the recording was unduly aided by the improper attachment of the detector wires as noted on page 3.

(6) The seismograph, when in 2901W picked up small blasts from greater distances than when in 3908W.

(7) The seismograph seems to pick up small blasts from greater distances below it than above it, e.g. the energy of a blast seems to travel more freely upward than downward. When in 2901W, it recorded small blasts in the 5300 X-cut with equal or greater amplitude than when in 3908W.

(8) Rock drills do not affect the seismograph even when operating quite close, e.g. in the stope above 3908W.

(9) Locomotives and trains, even when loaded, do not record unless passing very close. Detailed reports of locomotive operation were obtained for one day only.

(10) Strain bursts give no warnings which can be detected on the slow time scale of the recording drum. The paper speed is only 1/8 mm/min.

(11) Experience indicates that the detector (crystal or geophone type) should be installed on solid rock with no direct connection to timbering, piping, electric services, or tracks.

IV. <u>Limitations of Equipment Used</u>: As previously indicated, the recording equipment was assembled around two commercial vibration detectors purchased at our request by Lake Shore Mines. The amplifier was built for an entirely different purpose by the Observatory and loaned temporarily to this project. Various odds and ends of idle apparatus served, with some modifications, to round out the installation which has served this investigation. The facilities of the Observatory machine shop and carpenter shop have been drawn upon freely to assemble all these into workable shape.

The assembly was the best we could do at short notice and with no definite knowledge of the frequency characteristics we are to measure. It is evident that, whether or not some of the recorded offsets are mine noises as distinct from operational noises, the latter are so large and so constantly present that a clear picture of mine noises alone cannot be obtained with the present set-up.

If it is decided to continue such listening posts in the mine, it will be necessary to build another outfit. The same two detectors can be used to cover the frequency range to 5,000 cycles, but a third unit must be obtained to extend the frequency band up to 10,000 cycles at least. An amplifier must be built which can filter out the operational noises and record only mine noises. This phase of the problem will be discussed later, in detail and with estimates of the cost. At the moment we wish only to make the point that the present assembly has been most informative, showing the general noise level in the mine and demonstrating the feasibility of operating delicate detectors underground, but that, for a regular program, a designed recorder must be developed by experiment.

The present recorder can be left here for a month or two on loan from the Observatory, while other equipment is being built, subject to recall should the recording drum be required in an emergency. If further work is undertaken and when, in that case, the experimental Lake Shore equipment has been brought to operation stage, the present recorder can be returned to Ottawa. It is not recommended that the program with the present assembly be continued except as a stop-gap.

V. Instrumental Difficulties to be Met in New Design:

(1) Listening Post Equipment: One of the instrumental difficulties we wish to discuss at this point has to do with the development of listening post equipment. Such equipment should have a recording unit which can be run at various speeds at will, so that it can be speeded up at certain times of the day when it is desired to get a clear record of the nature and frequency characteristics of certain noises. The difficulties of making such a recorder have been overcome and it is possible to purchase such a commercial unit complete. The amplifier to be used must be provided with filters which will enable the operator to confine the record to those sections of the frequency spectrum which experience may indicate as desirable to explore. Such amplifiers and wave traps can also be purchased commercially.

To make a selection of the various commercial units and then build them into a co-ordinated whole seems to be a better plan than to attempt to build an entire outfit here. It will take less time and, in the long run, be no more expensive.

In this co-ordinated equipment we should have a portable unit, operating on A.C. or batteries as required, with which we could record, with ink on sproket-driven paper charts and with any desired paper speed:

(a) all noises, as to amplitude

(b) the amplitude of noises of segregated bands of specified frequency

or

(c) the frequencies of all noises, regardless of amplitude, thereby identifying the type of sound and, probably, its source.

It is desirable to perfect a single unit at first. When this has been done, it would be possible to arrange to have detectors at various points of a pillar and to locate all the recorders in the office building on the surface. The problems involved are not serious. The most serious phase of such an arrangement would be the expense and trouble involved in providing shielded cable connections from the various detectors to the central recording station. The advantages of such a centralized recording are obvious but it is not to be recommended until all experimenting with a single recording device has been satisfactorily completed.

(2) Time Recording Devices: If it is desired to adopt a research program on seismic velocities, the most serious instrumental difficulty is that of providing time-measuring devices of sensitivity and precision. The total time for a seismic wave to travel 1,000 ft. in a pillar would probably be about .05 sec. The shortest distance of travel which one might wish to measure would be possibly 100 ft. which would require a travel time of .005 sec. Variations in total time, which would be the quantity one would wish to measure for burst prediction purposes, would be thus about .0001 sec. To do this, accurately timed and clearly recorded lines would have to be made photographically on the record at intervals of .001 sec. At present, field cameras used in seismic prospecting provide timing lines at intervals of only .01 sec. Any available camera would thus have to be specially made or we should have to build one. Mr. Gibbs has had experience in making such cameras and could build one to record satisfactorily at this speed. To do this would take several months and involve expense which will be discussed in Section VII.

(3) Strain Meters: If strain meters are to be used in the drifts, the experience of others should be obtained, for in this field a good deal of work has been done. In this event, Mr. Gibbs would wish to consult with investigators at Coppercliff, at Cambridge, and at Washington, before deciding on a type adapted for use in Lake Shore Mines. These strain meters should be in-

stalled at a multiplicity of points, their readings taken regularly and frequently, and the results kept tabulated to date at all times.

For some pillars, the variations in dimensions of the pillar itself could be taken with a constant tension device Mr. Gibbs has suggested, provided it were possible to drill a hole completely through the pillar from stope to stope and from drift to drift. This matter of drilling may be impractical, but, if not, such a gauge would be very informative. It could probably be used to advantage in small pillars.

VI. Laboratory Facilities Required: If any continuing research program is to be adopted with the present men in charge, facilities would have to be provided at the outset for an electronics laboratory. Other things being equal, a small room on the west side of the south end of the basement of the Accommodation Building suggests itself as suitable, since it would be farthest from possible disturbances, electrical or mechanical, and would be convenient for Mr. Gibbs when experimenting at night.

Such a laboratory should be light tight and ventilated. It should be provided with hot and cold water, A.C. and D.C. supply, compressed air, and gas. Tools and measuring devices would also be required, together with supplies. An oscilloscope, frequency standards, etc. would be needed. The cost of an initial, minimum installation of this kind, exclusive of the room and services (water, gas, etc.) required is estimated, on the basis of previous experience, at three thousand dollars ($3,000).

VII. Interim Program Proposed: The following suggestions define what is termed an interim program since, if adopted, they would require a year or more of experimenting until the exactly suitable equipment had been developed for measuring the various physical properties of the rock in the mine, which experience alone can show to be significant and the nature of which can be defined only by experimental work.

At the conclusion of such an interim program, routine recording with, if desired, multiple detecting units and central recording can be undertaken. The interim program might, perhaps, evolve the chronological pattern of the physical phenomena, significant for the purpose of rockburst prediction. Whether it did or not, routine observation would then be indicated and an established routine program adopted.

Five distinct types of investigation are recommended. The details of providing for each of these (from the point of view of the difficulties involved) have been treated in sections V and VI. The present section sketches briefly the proposed method of attack in each case, the equipment required for each, and the estimated cost, exclusive of overhead (laboratory maintainence, salary, etc.)

(A) Listening Post: Experience seems to indicate that, if a single listening post is to be provided, it should be a portable mobile device, which can be set up in turn in various parts of the pillar. Battery operated equipment is indicated. To provide the commercial equipment and parts sufficient for experimental work to proceed, the following items have been foreseen. The difference between the sum of these costs and the total estimated amount quoted in the Conclusion has been carefully considered. It is believed the sum named is sufficient to enable Mr. Gibbs to make up all required equipment in the laboratory which would be needed to complete experimental work in developing a single perfected unit for recording in the mine. This would not, however, provide for central recording at the surface from multiple detectors at various points in the mine.

D.C. Amplifier	$300.00
Esterline-Angus Recorder	328.00
A.C. Amplifier	150.00
Batt. operation eqpt. .	90.00
Extra Crystal Detect. .	80.00
	$948.00

(B) Velocity Measurements: The west pillar is at least 1000 ft. in height, measured along the dip of the veins. If a seismic prospecting outfit were obtained, the recording unit could be set up in some convenient position in a drift midway of the pillar and cables run up and down to four (or six) geophone pickups, sealed in suitable positions at various heights in the pillar walls. Then, each day, when the mine was not working (say at the third hour of the time between shifts) arrangements could be made to have the mine quiet for, say, five minutes.

At this time, a shot of approximately one stick of dynamite would be fired at a selected point in the pillar. A wire would have been run previously from the recording unit to the firing point. This wire would be left in place from day to day. It would serve to record the instant of discharge. The camera would run through about 30 in. of paper per second, recording the arriving tremors in full detail.

Such a record would show to .0001 sec. the travel time from the shot point to each of the geophones and would thus give the times for four (or six) paths through the pillar. By firing at several points, the number and position of the travel paths could be increased by four (or six) for each firing position. The total time involved in which quiet would be required in the mine could be kept within a few minutes. The geophones would remain in position, the recording unit would be sealed up and left ready for operation and the firing lines to each standard selected firing position would be left in place. The work involved in taking a record each day would be very small.

Repeating the shots each day the travel times for each path could be plotted as measured. The shifting of stress from one part of the pillar to another as mining progressed would reveal itself in the relative movements of the plotted travel times for the various paths. Such a composite graph would be most informative.

To purchase equipment for such an investigation would be too expensive to be warranted until experiment had shown the method to be capable of yielding information of value. Prices have been obtained from three different sources from which such equipment could be rented. These are as follows:

(a) Dr. L. Don Leet, Harvard, Mass. Four pick-up equipment, offered for immediate delivery at $500. for one month, or $900. for two months.

(b) Seismograph Service Corp. (S.S.C.), Tulsa, Okla. Six pick-up equipment offered for, presumably, immediate delivery at $800. for one month, $600. per month for three months, and $500. per month thereafter.

(c) Heiland Research Corp., Denver, Colo. Four pick-up equipment offered for "delivery on four week's notice" at $300. per month.

The Leet and S.S.C. offers would be for used equipment in good condition. The Heiland equipment would, apparently, have a new camera; but our experience so far with them would lead us to look with suspicion on the "four weeks" clause. Mr. Gibbs built the Leet outfit and has operated it often in the field. He has also operated S.S.C. equipment. Certainly the Leet camera and, very possibly, the S.S.C. camera would have to be rebuilt to satisfy the time recording accuracy required.

In addition to the above, Root Petroleum Ltd., El Dorado, Ark., has offered their six-track recorder and seven geophones (used S.S.C. equipment now in storage) at "about 20 percent of the original cost". It is believed that this equipment could be rented for about $200. per month, the rental to apply on option of purchase for $2000. to $2500. The seismic prospecting subsidiary of Root Petroleum has been terminated and the equipment is no longer of use to them. It is somewhat obsolete for oil prospecting but would serve very well for mine work if a new camera were built. Mr. Gibbs supervised the original purchase of this equipment for Root Petroleum and operated it for them in Louisiana and Arkansas some four years ago.

If this method of attack is to be undertaken, it is recommended that a rental-on-purchase option from Root Petroleum be sought. Failing that (they have so far offered only to sell outright) it is recommended that Leet's outfit be rented. Then, if the method is adopted for routine operation, the high speed camera, necessarily made for the test runs with Leet's equipment, could be retained and used with the S.S.C. equipment purchased from Root Petroleum.

On the above basis, the following is an estimate of the cost of this form of investigation for the interim program;

Rental . . . . . $200. to $450. per m.	
Blasting cable and geophone cable	$200.00
Transportation 2-way	75.00
Batteries	30.00
	$305.00
Purchase $2,000. to $2,500.	
Transportation	$150.00
Cable	200.00
Batteries	100.00
Total: $2450. to $2950.	

Photographic supplies in either case . . . . $150. per year.

(No allowance made in any of the above for duty, sales tax, or exchange.)

(C) Strain Meters: It is proposed to place these in multiple positions in drifts throughout the west pillar region and also, if possible, in holes bored through some of the smaller pillars. They should also be installed in the east side of the mine. If used, they should be placed in permanent fashion, with every care, and their records read and tabulated at frequent intervals. Depending on the number of such devices used, the estimated cost, exclusive of overhead for this form of study would be from $20. to $30. each, plus cost of tabulation of records into usable form. More units installed would, of course, reduce the cost per unit.

(D) Thermometric Measurements: Instruments for this purpose could best be built by Mr. Gibbs and installed by him at no cost above the overhead except for supplies. One or two experimental stations should suffice for the duration of the proposed interim program. The cost for supplies for a single such station is estimated at $350.00.

(E) Fault Markers: It would involve very little expense for the construction and installation of devices for measuring the amplitude and direction of slow displacements along the plane of all major faults exposed by drifts. These could be designed to involve a minimum of servicing. Some thought has been devoted to this form of study and several designs for such markers have been discussed.

These markers should be installed also in the east end of the mine where faulting is more marked and, presumably, more active. The tabulated results would be obtained at a minimum expense and trouble and should prove most informative. It is recommended that the installation and servicing of such markers be included in any continuing program adopted. The expense, other than overhead, would be purely nominal.

Note: In all the above program, except as noted, it is proposed to confine the investigation to the west pillar. The conditions here are more simple in that there are fewer faults. The pillar is smaller, too, and changing more rapidly as mining advances.

Conclusion:

The five forms of investigation proposed above, carried along simultaneously, would give a comprehensive and detailed picture of the tectonic conditions in the mine. No such concerted attack on the problem of rockbursts has ever been attempted so far as the writers have been able to learn. Indeed, until quite recently, the progress in electronics art had not been sufficiently advanced to permit the attack here proposed.

As noted on page 10, only the larger items of equipment expense have been entered. If we make allowance for overhead, supplies, duty, etc. it may reasonably be set down that the program proposed would cost not less than $15,000 and not more than $25,000.

It is the opinion of the writers that this amount is both necessary and sufficient to develop instruments and technique to a point where a regular routine program could be followed. The data obtained from the start through this interim program would be of ever-increasing value. It is believed that the ultimate goal of rockburst prediction is more nearly possible than had been thought and that the proposed program is a reasonable method of procedure toward that end.

We, the undersigned, would recommend its adoption as a coordinated whole.

Kirkland Lake,
Ontario.
March 26, 1940.

....
Ernest A. Hodgson

....
Zack E. Gibbs

CLOCK CORRECTION = + 33 sec.

JAN 6 1940 JAN 7 1940

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