Department of Mines and Resources
Surveys and Engineering Branch

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Dominion Observatory

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Report on Trip to Ishpeming, Michigan
Conference with Dr. Leonard A. Obert
October 27 - 29, 1944

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Introductory Preface:

The microseismic studies at Lake Shore Mines began in May, 1942, and a well-established routine program was under way on the west side of the mine (the west pillar), from the 3825' to the 4325'-levels, by the end of that year. On January 29, 1943, a severe burst wrecked the entire section under survey. There was good evidence (as shown in Report No. 11) that the microseismic method yielded data which predicted the burst. All the geophones having been destroyed by the burst, there was a lapse until about the middle of February, 1943, when recording began again in the west pillar region on the 3825', 3950', and 4200'-levels. A major burst on March 31 wrecked the pillar from the 3075' to the 4075'-levels. This could not have been predicted with the three geophones then in service as they were too far removed from the pressure zone. After this burst, mining in the west pillar region was discontinued for the time being and the ground became so quiet that it was decided to initiate a new program on the east side, from the 4450' to the 4825'-levels.

Preliminary studies were made and a lay-out of holes gradually developed. The new program was fully under way by the first of December, 1943. It soon became apparent that conditions here were different from those in the west pillar. Practically all the bursts occurred at or near blasting; and many, though strong enough to be heard on surface, did not leave any trace in the workings. It was concluded that a new type of burst should be included with the previous categories "crush" and "strain" bursts. These were called "slip" bursts and tentatively explained as being due to sudden slips on fault planes deep in the wall. Loose was shaken down, according to this theory, only where the fault crossed an opening or where the locus of release of strain happened to be near a free surface.

Although these bursts happen rather frequently (several times a week as evidenced by records) they are seldom severe.

Only a few are noticed on surface. To date, there has been no build-up of recorded microseismims* which could be said to predict any one of them. But, during the listening periods in the early-morning, off-shift hours, very active snapping has been heard at some of the holes. This "D-type" snapping is too distant (and hence too attenuated) to record, but it would have recorded had the geophone been nearer.

In some cases the active snapping would have predicted a burst. On two occasions since January 1, 1944, the activity was so strong that the snaps recorded. In each case, a warning was given before shift time and the Superintendent kept the men out of the threatened stope until the microseismim storm abated. In one case, this took two days. In the other, the snapping was back to its normal rate the next day. In neither case did a burst occur. But, it must be kept in mind that the method can, at present, only indicate dangerous conditions. Later, when more experience has been gained, it will probably be possible to differentiate, to some degree, between what might be called, respectively (and respectfully), "critical" and "acutely critical" conditions.

In view of the above experience two important and very pertinent questions have been asked.

(a) Are the so-called "local-type" or "pressure" snaps emitted by the rock bodies themselves because of pressure; or are they caused wholly by spalling, cracking, slipping, etc. in or on the walls?

(b) Assuming that they are due to pressure, do they develop soon enough before a burst to serve as a practically useful warning, or do they build up only at the time of the burst and continue after it is over, during the period (minutes, hours, or days as the case may be) while readjustment is being effected?

An approach to each of the above questions has been under consideration for some months. To answer question (a), it

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* The term given by Obert and his associates to the subaudible noises now being studied in mines by means of microseismic methods.

was first proposed to prepare block specimens and to submit these to increments of pressure in an hydraulic press, making microseismic records simultaneously. Unfortunately, the only press available will not maintain high pressures without running the oil pump continuously. This would preclude the use of the geophone,- the records would be too much disturbed by extraneous noise. An alternative is planned for the coming winter: to place a geophone in one of two adjacent holes drilled in a rock, filling the other with water and sealing it, some night when the temperature might be expected to reach -40° F. or less. A record will be run continuously until fracture occurs. It is believed that the increase in pressure will be so gradual that the method will throw some light on question (b) as well.

To get an answer to question (b), a high-speed chronograph has been under development in the laboratory for some months. It is now nearly ready for service. It will be used to detect time differences in the recording of so-called "simultaneous" snaps from geophones in each of two selected holes, with a view to determine the direction to the focus where the snaps are being generated. This will indicate where a new hole should be placed in order to get a geophone within recording distance of the known, active zones. It is hoped that, in this way, a geophone location can be made which will result in the prediction of some at least of the bursts occurring in the ground serviced by the present program.

An opportunity arose late in October, permitting the Lake Shore program to profit from the results of two sets of experiments designed to answer similar questions in the microseismic research being carried out by Dr. Leonard Obert and his associates of the U.S. Bureau of Mines. An invitation was received for the writer to meet Obert at Ishpeming, Mich., and to discuss these experiments, one set of which had been so lately concluded that the notes were not yet worked over into report form. The other set had been written up but the report is not to be published. The meeting was arranged. The writer arrived at Ishpeming in the early morning of Friday, October 27. Discussions and examination of data continued until Sunday morning, October 29, when Obert left by car on his previously-arranged itinerary of inspection.

All data, photographs, records, notes and manuscript reports were placed completely at the writer's disposal. A thorough study was made. Discussions cleared up obscurities and afforded an opportunity for an exchange of ideas. The following report presents the results of the conference. We are much indebted to Dr. Obert and to the U.S. Bureau of Mines for their whole-hearted cooperation in the studies being made at Lake Shore Mines.

I. Experiments Considered:

The results of two separate and distinct sets of experiments were examined.

(a) A series of microseismic records made from geophones placed in blocks of rock subjected to repeated increments of pressure in a specially-designed hydraulic press (which will hold pressures without running the oil pump), the increments being continued up to the point of failure.

(b) A program of microseismic recording designed to afford control in a pillar removal program in a mine in the United States.

The first of these sets of experiments affords a definite, affirmative answer to both questions raised in the introductory preface above; i.e. microseismims are directly due to pressure and they do occur sufficiently below bursting values to permit prediction. The second presents two experienced cases which definitely indicate that, under the conditions of the experiment, at least, the answer to the second question in the same preface is affirmative; i.e. the microseismims permit prediction.

II. Microseismic Recording from Rock Specimens under Pressure:

(1) Equipment and Program:

Rock specimens were cut by means of a diamond saw into one or the other of two shapes to be described, the approximate dimensions of which will be indicated. The top and bottom surfaces were lapped smooth and a layer of blotting paper placed between each surface and the respective contiguous plates of the press. The 120,000 lb. hydraulic testing machine used is of a special type, provided with a valve in the oil line which supplies the hydraulic ram. With this valve closed and with a block of iron under compression, high pressures can be maintained over as much as 15 min. with a loss of only about 200 lbs. With a rock specimen under compression, the pressure tends to drop somewhat with the valve closed, because of the gradual yielding of the specimen. There is a drop of about 2,000 lbs. in 15 min. at the higher pressures, under these conditions. The top plate of the machine is provided with the usual spherical compression block to compensate for slight departures from parallelism in the two contact faces of the specimens.

Most of the specimens were cut into small parallelepipeds as shown in Fig. 1. The average dimensions are about as follows: A = 4"; B = 2.5"; C = 2", H = 1".5 (see Fig. 1). One set of experiments was run with a block of approximately the same dimensions (as regards the part under compression), but of the shape shown in Fig. 2. This was done to avoid the low-pressure cracking which always occurred in the first type, i.e. upward and downward from the central hole. In Obert's opinion, there is little to choose between the two shapes. The results obtained are equally dependable and they are intercomparable. The first shape is easier to make and requires less rock, but the crystal of the geophone is more likely to be shattered in the central-hole type. In Appendix I will be found, a set of dimensions for each specimen of the central-hole type of which an account is given in this report. Specimens were obtained from 14 types of mine rocks and from 14 types of quarried granites. The specimens chosen for the microseismic tests were homogeneous and free from visible cracks and seams.

The geophones and recorders adopted were

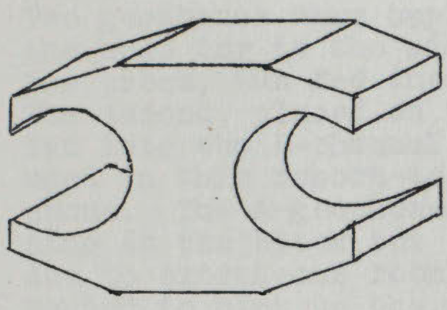

Fig. 2

Special Specimen Shape

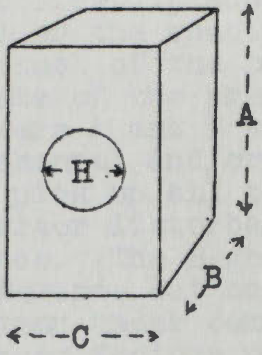

Fig. 1

Usual Specimen Shape

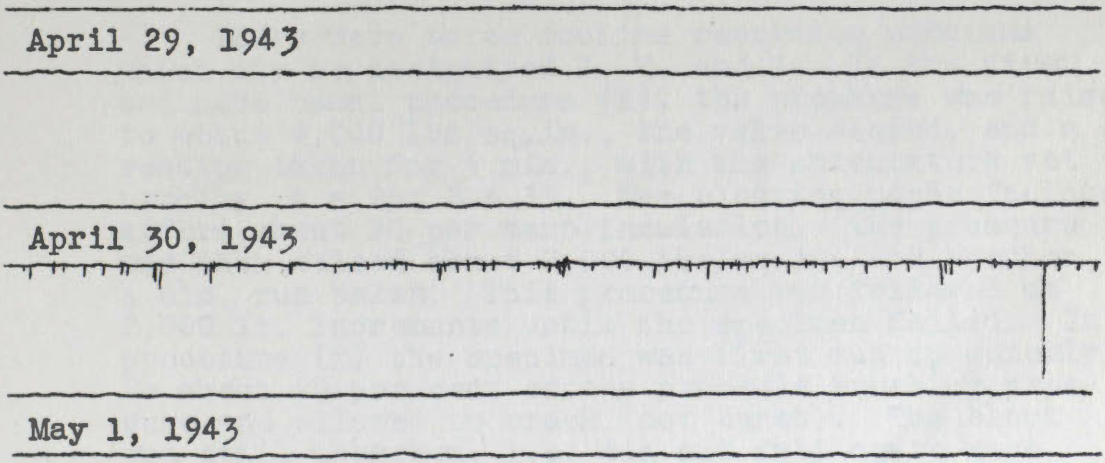

Fig. 3

Records about Six Minutes Long

Run at about 11:30 P.M. on the Dates Indicated the standard instruments as used at Lake Shore Mines. Two geophones were employed. The first, placed in the hole (or in the side channel) of the specimen in the press, was fed into the A-channel of the recorder. The second, placed on the bed-plate of the press, was fed into the B-channel. The letters A and B will be used in this report to indicate channel and/or geophone. The A-geophone tended to pick up all the snapping in the block but only the larger disturbances due to extraneous room interference. The B-geophone tended to pick up the room interference but only the larger snaps emitted by the specimen under compression. It was found that the blotting paper facings on the specimen tended to prevent the smaller noises originating in the specimen from reaching B and smaller extraneous noises from reaching A. During the course of the recording, an operator listened in on phones and kept running notes of those phenomena which could not be read from the record.

(2) Routine Procedures in Recording:

There were three routine recording programs which may be designated X, Y, and Z. In the first and more usual procedure (X), the pressure was raised to about 4,000 lbs/sq.in., the valve closed, and a reading taken for 5 min., with the attenuators set usually A = 25; B = 35. The blotting paper facings afford about 20 per cent insulation. The pressure was then raised about 2,000 lbs/sq.in. and another 5 min. run taken. This procedure was followed at 2,000 lb. increments until the specimen failed. In procedure (Y) the specimen was first run up quickly to about 90 per cent of the probable crushing pressure and allowed to crack (not burst). The block was still unbroken, i.e. did not fall apart when the pressure was removed (compare similar Ottawa experience as given in Report No. 6). It was then put through the X-routine up to complete failure. The Z-routine was designed to show microseismic behaviour under a decreasing load. The specimen was first loaded to about half its ultimate value. A record was then run for 15 min., the pressure falling slowly due to the gradual yielding of the specimen. The valve was then opened slightly and the pressure allowed to fall slowly to about 1/4 the ultimate value, recording going on while the pressure was falling, and then for 15 min. at 1/4 value. The same procedure was carried through for the ranges 3/4 - 1/4 and 9/10 - 1/4, after which the geophone was removed and the ultimate crushing value determined by slowly increasing the pressure until the specimen failed.

The rate per minute of incidence of the microseismims was determined for those which registered half scale or less at 25 Db., for those more than half scale, and for the sum, i.e. the total number, per minute. Graphs were prepared showing each of these rates vs. pressures per sq.in. Where the rate became so great (as it did for example in specimen 217.1) that the recorded snaps could not be resolved at 25 Db., the gain was cut and a rule of thumb adjustment, based on experience and experiment, was used to obtain the number which would have registered at 25 Db. Except in so far as this rule may be somewhat in error, the results of all the tests were thus plotted in such a manner that they could be intercompared.

(3) General Statement of Results:

In general, it may be said that in program X there was a crudescence of snapping when the first cracks occurred, usually 5,000-8,000 lbs/sq.in. The snapping rate then fell off as the successive pressure increments were applied in turn. Then, as the pressure approached about half the ultimate value, the snapping began again, reaching high rates some little time before the final load was attained and the specimen burst. It is to be observed that, in the few exceptional cases where there was very little snapping prior to failure, the specimen crushed quietly. In every case where the observer's notes indicate that the failure was violent, there was ample prediction snapping.

The results of routine Y were the same as those from X except that the snapping at the early cracking point was missing. It is to be noted that specimens which did not crack emitted practically the same rate and pattern of microseismims at the middle and higher pressures as did those of the same kind of rock which cracked. These specimens, taken from the press, give no visible evidence of having been subjected to pressure.

The results of the Z-routine were interesting in that the microseismims, especially the small ones, appeared as the specimen passed through a readjustment when the load was first lightened. They soon fell off to a rate, normal for the load maintained. They could be stopped instantly when the rate was high (just after the load began to lessen), if the pressure were again started up.

It is interesting, too, to note that the microseismims are generated at a faster rate at any given load level if the rate of increase in pressure is raised.

Microseismims were never generated in large numbers immediately prior to the low pressure cracking at 4,000-8,000 lbs/sq.in. (i.e. the low pressure cracks were not predicted) but there was a spate of them for a short time afterwards - a sort of sharply-initiated salvo.

In many cases, especially with those specimens which broke violently, there were a good many salvos which appeared exactly similar to those observed in Lake Shore records. In general, these were confined to the later stages of the pressure program, when the specimen was subjected to a high percentage of the ultimate crushing load.

Another point to be observed is that, although there was usually a higher rate of snapping at the beginning of each run (due to the high rate of change of pressure as the level was raised), the rate fell in a minute or less to one which was fairly uniform and sustained, and apparently normal for that pressure.

Although the average over several minutes seemed to be fairly uniform, there was a tendency in some specimens for the rate to very from moment to moment, i.e. to be sporadic runs of short duration, especially as the pressures approached the ultimate crushing value.

(4) Quotations from Obert's Statements:

The following are statements made by Dr. Obert as related to the microseismic pressure tests:

"There has always been some conjecture regarding the origin of microseismims. It is known, from observations made in many mines, that they originate in rock under pressure and that they are produced when the rock is visibly cracked or fractured. However, the number generated during the course of cracking or fracturing is far too great to be accounted for on this basis alone".

"Microseismims originate in uniform pieces of homogeneous rock without giving rise (necessarily) to any visible indications of failure".

"The microseismims as heard in the ear phones are indistinguishable in all respects except one from those heard in field operation. The one exception is that no microseismims were heard which appeared to come from a substantial distance. In field operation this characteristic can be distinguished because the microseismims coming from more distant points do not have strong, high-frequency components".

"While these experiments give considerable factual information on the origin of microseismims and on the microseismic behaviour of rocks (under pressure), the results obtained therefrom in no way alter the conclusions which had been reached heretofore. Rather they confirm what was previously supposed or based on less definite evidence".

(5) Report Planned by Obert:

The report on these experiments, in the course of preparation by Obert, will probably appear early in 1945. After a general discussion of the problem, each of about a dozen of the more typical specimens will be described in detail and a history given of its behaviour under the microseismic test. A description of each, as prepared by a Bureau petrographer, will be included. These petrographic reports were made after exhaustive studies of polished surfaces, thin sections, and fragments.

The above report, showing the results of the microseismic tests, is Part II of a four-section paper dealing with the subject of the Bureau's activities in this field. Part I will deal with the observations made by the field crew when obtaining specimens in the collaborating mines. Part III will show the application of the research program to a number of specific mining problems and Part IV will describe in detail the microseismic apparatus employed in various phases of the work.

(6) Appendixes Related to Test Experiments:

In Appendix II of this report will be found a short account of the microseismic tests made on some typical specimens. The writer examined, thoroughly and in detail, the records, photographs and observer's notes for 21 such tests. The appearance of those records, which show pre-snapping considerably in advance of failure, look exactly like the Lake Shore records preceding the big burst in the west pillar on January 29, 1943.

Appendix III gives a brief account of the studies made by the field crew of the U.S. Bureau of Mines in obtaining samples in a mine and of the tests made on this material when it is received at the laboratory.

III. Microseismic Program Controlling Pillar Removal:

As this program was carried out privately by the U.S. Bureau of Mines for one of the mines in the United States and as the report is not being published, the notes here given are not as specific as they would otherwise have been.

An excerpt has been made of some data of particular interest, as showing definitely the value of the microseismic method when applied to a specific problem in a relatively simple case. The data also very definitely prove that the microseismims do appear some hours prior to failure and so afford a method of prediction. All the evidence in this case was at the writer's disposal and he has made a careful study of all the circumstances, not only for the one specific case reported below but for the others to which reference is made.

Simply stated, the problem was to show whether or not the cap rock over a wide-spread room stope at a fairly shallow depth (less than 1000') was being weakened by the removal, one by one, of pillars of residual ore. These pillars were very large, more than 100' high in some cases and 25' or so thick. It was necessary to determine, as each was cut free from the back, whether the cap rock was weakened.

To answer this question, geophones were installed in holes drilled in such a lattice pattern about the section of roof concerned that local slabbing would record on only one geophone, but cracking in the cap rock proper would record on all geophones in the set-up. The placement of the geophones was accomplished by the usual tests to determine the conductivity of the rock with respect to elastic waves. The spacing was made so that small microseismims due to slabbing would record on the nearest geophone but would probably be attenuated so much that at others they could record only feebly or not at all. The subsequent program showed that this desirable condition was attained.

A long program of recording, extending over more than a year, showed that the normal rate of incidence for the microseismims (large and small) was very low - about 10 per hr. (<u>sic</u>)! On three occasions during the year, there were falls of rock from the back and from the top of one of the pillars in the area under operation. These ranged from about 5 tons or less in the smallest fall to over 200 tons in the largest. In every case, the preliminary snapping showed up hours before the fall and due notice was given the operators.

One of these cases is shown in Fig. 3. The top track in each of the three pairs of lines shows the record from a geophone about 250' from the imminent fall. The lower track is from a geophone less than 100' away. The successive pairs were recorded at about the same time on successive nights, i.e. about 11:30 p.m. The fall (5 tons or so) took place between midnight and 7:30 a.m. of the day immediately following the second pair of records. The microseismim count on the day prior to that shown in the first pair of records (low on both geophones) averaged about 8 per hr. The count on the nearer geophone (bottom-channel) in the second group was about 1800 per hr. an increase of over 200 per cent in less than 48 hrs.

Note that the more distant geophone failed to pick up the small microseismims generated and that the snaps ceased after the fall was over. The fact that, with the exception of the three cases of small microseismims followed by slab falls, there was no increase in the general microseismim rate after blasting or after a pillar had been cut free from the back was interpreted as indicating that the cap rock was not affected. In this way, many thousands of tons of valuable ore were recovered with a high factor of safety.

As stated at the beginning of this section, the above experience is taken as good evidence of the value of the microseismic method as applied to a relatively simple problem. It also shows that microseismims do increase in number for some time prior to failure. In applying the method in Lake Shore Mines, the principal remains unaltered, but the difficulties are greater. It is reasonable to believe that many of the difficulties can be overcome and the method be made useful in the more complicated cases which occur in deep mining.

Perhaps the lesson to be learned is that the method should be <u>developed</u> by application to more isolated definite problems, such as a stope which is known to be under pressure and likely to be dangerous. It would give a large measure of protection to the men working in that particular place. Indeed, it would seem that, in the end, the application might work out in just that way, The equipment could be made up into semi-portable units moved to sections known by the mine captains to be dangerous and run there for the local protection it will afford. When the danger passes, the set could be moved to another critical place.

Conclusions and Recommendations:

The following remarks are based on the experience gained in Lake Shore Mines, on the results of Obert's work as given in this report and on conversations with Obert regarding the problems involved.

It is established that:

(a) Microseismims are initiated in homogeneous rock under pressure even when there is no cracking or spalling - i.e. they are due to pressure.

(b) A rock may sometimes be subjected to pressures less than the bursting value without suffering any visible cracks or spalls, and yet the microseismims are generated with an activity pattern similar to that generated in another specimen of the same rock carried through the same pressure cycles. (Obert states that two specimens of the same rock, one carried through the cycles without cracking and then released and the other never submitted to pressure in the testing machine, could not be differentiated by anyone who did not know their history, unless, perhaps, he made use of physical tests: density determinations, section studies, dynamic tests, etc.)

(c) In hard, brittle rocks, which finally burst violently, there is a high microseismim count as the pressure approaches and passes about 80 per cent of the bursting value. In rocks which do not burst there is sometimes no premonitory snapping.

(d) There is a tendency for the counts to be high immediately following an increase or decrease of pressure after which the rate of snapping normal for the given rock and pressure involved.

(e) Rate of change of pressure seems to have a bearing on the incidence rate of microseismims, a higher rate at any pressure level for a given specimen resulting from a greater rate of raising the pressure to that level.

(f) The incidence of microseismims tends to become both sporadic and frequent as bursting pressure is approached. When audible snaps occur and/or when a visible crack appears, salvos are recorded which are exactly similar to those recorded so often at Lake Shore Mines.

(g) The microseismic prediction method is developed to a point where it can now be applied practically and efficiently to the relatively simple problems encountered in shallow mining. (It is so being applied by Obert now.)

(h) No other method which has so far been suggested offers anything like the promise extended by that now under study at Lake Shore Mines.

With the above facts in mind, it is recommended:

(a) That the research program now in operation on the 4575', 4700', and 4825'-levels on the east side be maintained, taking the greatest care to permit no interruption to all possible recording and listening.

(b) That the high-speed chronograph be used to determine the velocities over various paths in the above section under study and to learn the location of zones of activity (heard but not recorded) so that a new hole (or holes) may be drilled in such positions that the activity may be recorded. It will then be possible to learn to what extent there is a premonitory build-up of microseismims prior to a burst even in the "slip" type.

(c) That recording and listening on the 4450'-level be (reluctantly) abandoned and the portable set, 3 AB, used to study conditions in some limited section of ground which the Underground Superintendent and his associates consider dangerous for the time being. The geophones should be placed as close to the suspect ground as possible and a recording and listening program should be carried through regularly.

Dominion Observatory,
Ottawa, Canada,
November 2, 1944.

E. A. H.

APPENDIX I

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Details of Specimens in Microseismic Tests

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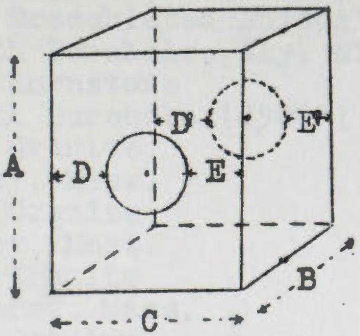
The writer examined the sets of records for each of a total of 21 specimens. Each of these specimens was the subject of a report by a petrographer and the reports were made available. For each specimen, three graphs had been prepared, showing, respectively, the number of small (half scale or less) microseismims in 3 min., the number of large ones (more than half scale) in 3 min., and the total number in 3 min. The operators notes as made while the tests were in progress were also supplied. The writer made a full set of notes on all the above, making excerpts from the petrographic reports and from the operators notes, but plotting and studying all the graphs in correlation with the actual records.

A selection of typical sets of notes are given in Appendix II. In order to segregate the general details and to give them in full for all the specimens, the table below has been prepared.

The identifying specimen numbers are those adopted by the Bureau. The dimensions, A, B, C, D, E, D', E', apply to the normal, parallelepipedal blocks with the central hole. The dimensions are identified by the diagram here given, where the number after the + sign indicates multiples of 1/32". Under the heading F is listed the type of failure using the designations: ? not recorded, C crush (quiet failure), B Burst, B very heavy burst.



The material of which each specimen was composed is taken from the petrographic report as is also the indication of the source. Where any item is doubtful, the fact is indicated by brackets around the entry.

	A	B	C	D	E	D'	E'	F
201.1 Mt. Weather Greenstone Mt. Weather, Va.	4	2	2+16	+16	+16	+16	+16	C
202.1 Sericitized Sandstone (Zenith Borehole, Ely, Minn.)	4	2	2+16	+18	+14	+16	+16	B
203.1 Andalusite Schist Miami Copper Co.	3+30	2+4	2+8	+16	+10	+8	+12	C
204.2 Greenstone (Zenith Borehole, Ely, Minn.)	4	1+28	2+12	+16	+16	+12	+10	?
205.1 Greenstone Zenith Borehole, Ely, Minn.	4	1+24	2+8	+12	+10	+12	+12	C
206.1 Epidosite Mt. Weather, Va.	3+20	2+8	2+10	+12	+12	+16	+10	B
207.1 Dolomite Breccia Mascot, Tenn.	3+24	1+31	2+16	+16	+19	+16	+16	B
208.1 Bonneterre Limestone Bonneterre, Mo.	4+4	2+18	2+28	+21	+23	+21	+19	?
209.1 Chert Breccia Tri-state District	4	2+18	2+30	+22	+22	+22	+22	?
210.2 Unmineralized Limestone Bonneterre, Mo.	4	2+18	3	+25	+25	+23	+23	?
211.1 (Amygdaloidal Basalt) Ahmeek, Mich.	5	3	3+16	+26	+22	+26	+22	B
212.1 Bonneterre Limestone Bonneterre, Mo.	2+30	2+22	2+26	+20	+22	+20	+18	?
213.1 Greenstone Zenith Borehole (1079')	4	2+14	2+20	+18	+14	+16	+18	?
214.2 Brecchiated Epidosite Zenith Borehole, Ely, Minn.	4+12	2+8	2+18	+16	+16	+14	+16	B
215.2 Hornstone Zenith Borehole (2500')	4	2+2	2+8	+12	+9	+12	+12	C
216.1 Granite Quincy, Mass.	4	2+12	2+24	+20	+20	+20	+20	B
216.7 Granite Quincy, Mass.	*							B
217.1 Granite Rockport, Mass.	4	2+8	2+16	+16	+16	+16	+16	B
217.2 Granite Rockport, Mass.	4	2+8	2+20	+18	+18	+18	+18	B

* Specimen 216.7 was the only one of those reported which was shaped as in Fig. 2

Appendix II

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Some Sample Microseismic Records

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Of the 21 record sets studied there have been selected for presentation in graph form three typical cases. The first of these (Fig. 4) is specimen 216.7, a granite from Quincy, Mass. This is the only one which was available for examination by the writer, which had been cut in the form shown in Fig. 2, with side channels for the geophone. It burst at 52,000 lbs/sq.in. There was very little microseismic activity until a pressure of 24,000 lbs/sq.in. had been applied. The pressure was thereafter increased in increments of 2,000 lbs/sq.in, up to the bursting value. Clearly, there is a good prediction from this specimen.

The next example (Fig. 5) is specimen 215.2, a hornstone from a depth of 2500' in the Zenith Borehole, Ely, Minn. This specimen crushed at 17,000 lbs./sq.in. There was no prediction. It is to be noted that this specimen suffered the low-pressure cracking at 7,000 lbs./sq.in.

In Fig. 6 is given the graph for specimen 214.2, a brecciated epidosite, also from the Zenith Borehole. (It is to be noted here that all three graphs shown are of the full microseismim count, not the larges or the smalls but both.) The arrows on several of the ordinates indicate that, for the pressures concerned, snapping was too frequent to be counted. The low-pressure cracking occurred at 8,000 lb./sq.in., after which the activity fell off to the point where the pressure was 18,000 lb/sq.in, after which the activity became continuously greater. At 36,000 lb./sq.in. it was too frequent to count. The specimen burst violently at 38,000 lb./sq.in.

The specimens which were pre-cracked (schedule Y, see p. 6 of the report) showed graphs much like that of Fig. 4. Of the specimens listed on p. 2 of Appendix I, good prediction was shown for every specimen except:

201.1	C
203.1	C
205.1	C
210.2	?
213.1	?
215.2	C

In every case, where the observer's notes definitely stated that the specimen failed by crushing, not bursting, there was no prediction. In every case where the rock was sufficiently hard and brittle to fail by bursting, there were graphs showing ample prediction.

The graphs for specimens 207.1, 208.1, 209.1, 211.1, 216.1, and 217.1 show even better prediction values than those exhibited in Figs. 4 and 6.

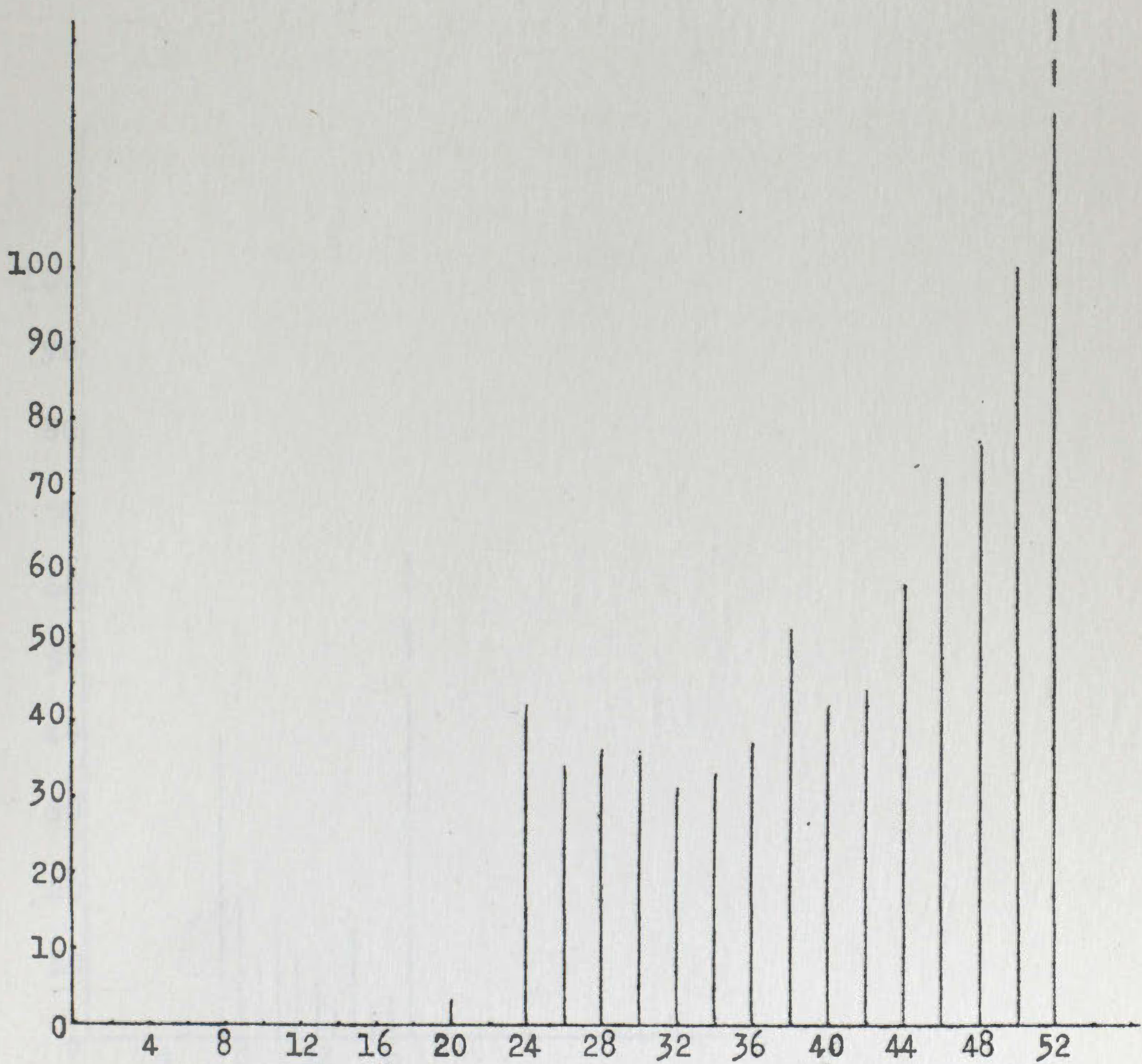
It seems evident that for hard, brittle rocks, such as those found in Lake Shore Mines, it must be concluded that:

(a) Microseismims are generated by pressure.

(b) The microseismim pattern gives ample warning of critical pressure.

Specimen 216.7

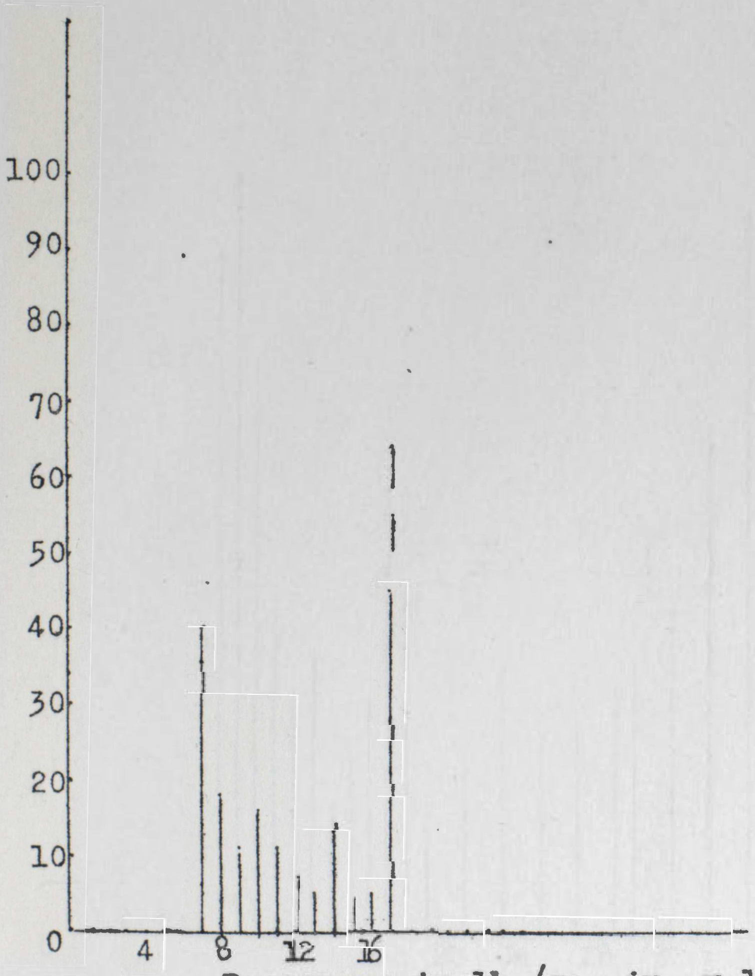
Fig. 4



Pressure in lbs/sq.in. x 10^3
Ordinates = Microseismims in 3 min.

Specimen 215.2

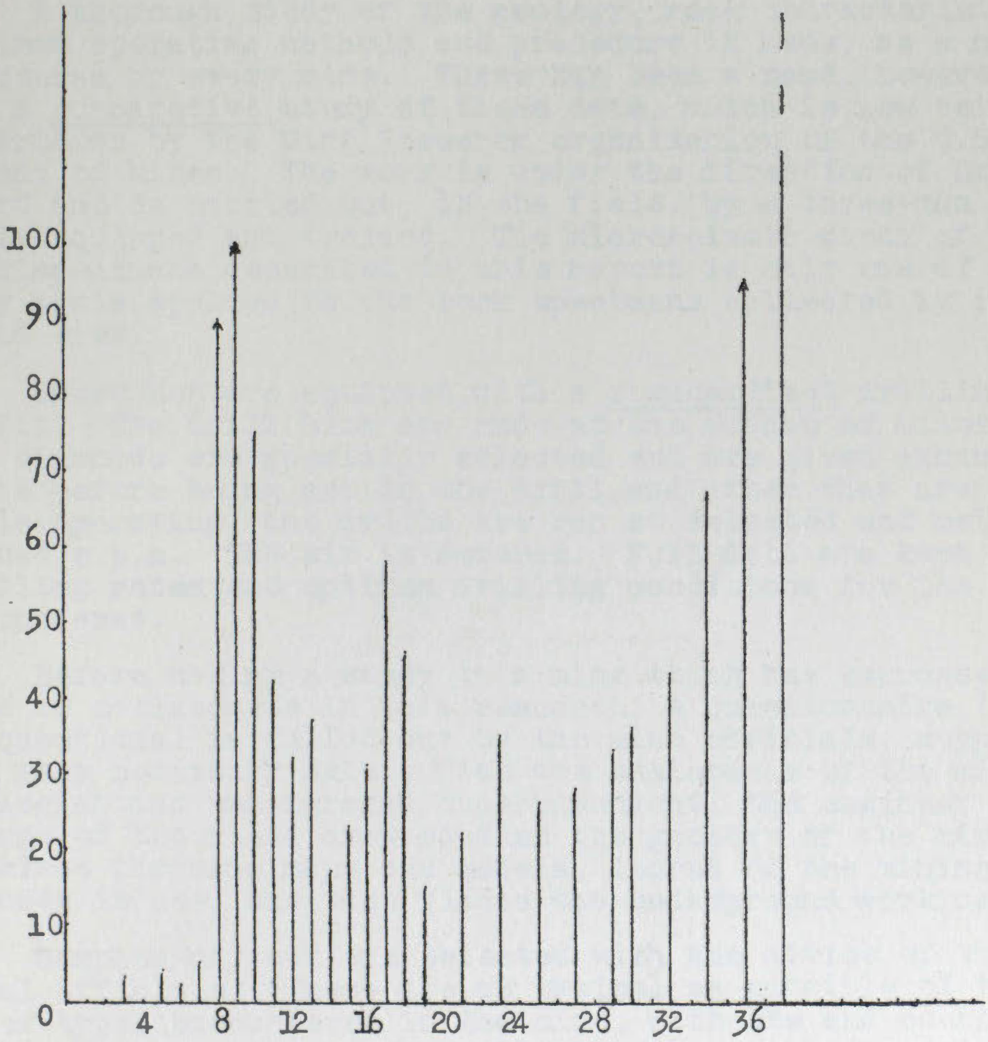
Fig. 5



Pressures in lb./sq. in. x 10^3
Ordinates = Microseismims in 3 min.

Specimen 214.2

Fig. 6



Pressures in lb./sq.in. x 10^3
Ordinates = Microseismims in 3 min.

APPENDIX III

**

Mine Research Program
U.S. Bureau of Mines

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A thorough study of the geology, rock characteristics, optimum operating methods and procedure is made, as a matter of course by every mine. There has been a need, however, for a comparative study of these data, which is now being undertaken by the Mine Research organization of the U.S. Bureau of Mines. The work is under the direction of Dr. Obert and is carried out, in the field, by a three-man crew, fully equipped and trained. The microseismic study of the rock specimens described in this report is only one of the many tests applied to the rock specimens collected by the field crew.

These men are equipped with a standardized drilling outfit. The drill bits are made at the Bureau of Mines. The diamonds are specially selected and are given exhaustive tests before being set in the drill and after they are worn. While operating, the drills are run at selected and maintained r.p.m. The air is metered. Full data are kept on drilling rates and optimum drilling conditions for the rocks encountered.

Before making a study in a mine which has expressed a wish to collaborate in this research, a questionnaire (30-40 questions) is filled out by the mine officials, supplying many necessary data. With the assistance of the mine geologist and underground superintendent, the engineer in charge of the field crew studies the geology of the mine, examines the mine maps and models, learns of the mining methods in use, and then visits the underground workings.

Samples of rock are selected with the advice of the local officials. These are as typical as possible of the chief types encountered in the mine, both ore and country rock. The crew then make drilling tests at places selected after consultation with the local men. These are run with the standardized drill and full drilling data are noted.

The relation of the direction of the hole with the dip and strike and with the rock foliation is recorded. Holes are drilled in the foot and hanging walls and in the ore body, depending on the tests desired. An endeavour is made to recover 42' of core from each hole. This supplies sufficient material for three full sets of tests. For each set, at least one piece of core, preferably two or three, must be at least six inches long, preferably eight.

The larger rock specimens and the cores are taken to the laboratory of the Bureau at College Park, Md. The following tests are there made, one set requiring at least 14' of core. The various tests are repeated under varying degrees of moisture content, from oven-dried samples to others of the same specimen soaked for two weeks. Various water softening agents and similar products are also experimented with, to determining how much moisture the rock can be made to absorb. The effect of these agents as drilling liquids is also under investigation.

I. Dynamically Measured Elastic Constants:

(a) Young's Modulus (E), - wave velocity vibration test.

(b) Modulus of Rigidity (G), - wave velocity vibration test.

(c) Poisson's Ratio (calculated).

(d) Specific Damping Capacity (Energy, in ergs, lost per cycle of vibration).

II. Measurements on Compression Machines:

(a) Compressive strength.

(b) Modulus of Rupture, - Flexure test: where the ore specimen is supported at its outer ends and broken by pressure at its centre, the modulus being a function of the length between the supports, the diameter of the core sample, and the applied pressure.

(c) Tensile Strength, - The sample is held in special clamps and pulled apart without flexure.

III. Other Tests:

(a) Density.

(b) Apparent Porosity, - difference in density when as wet as possible and as dry as possible.

(c) Sclerescope Hardness Test, - dropping diamond pointed weight and measuring the rebound.

(d) Impact Strength, - a piece of core as long as its diameter and having lapped ends is set on a solid base, has a semi-spherical anvil placed centrally on its top face and is broken by a weight, - the height of fall and the mass being noted.

(e) Dory Abrasive Hardness Test, - rock ground with dry carborundum and the amount abraded in a given time measured.

(f) Grindability Tests:

(1) Disc-mill test.

(2) Ball-mill test.

IV. Microseismic Test Routine;

Similar to the tests described in this report.

V. Petrology:

6 thin sections, - in 2 directions parallel with and across the core.

6 polished surfaces.

6 fragment studies.

Just what will emerge from so detailed a study of the large number of mines on the list is not at once apparent, even to those undertaking the work. It is felt, however, that a comparative research of this kind is needed and that no possibly-significant data should be neglected. Already, the work has resulted in some interesting and valuable deductions as to the optimum choice of drills and their operating conditions and on the best strength of powder for use under various combinations of underground conditions including depth.

Supplement
to
Report on Trip to Ishpeming, Mich.
Conference with Dr. Leonard A. Obert
October 27-29, 1944

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Ernest A. Hodgson

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The following somewhat unorganized notes were taken by the author during the period of the above conference but were regarded as too confidential, too indefinite, or too irrelevant to be included in the report. They are not distributed generally with the report, being furnished only to those officials of the Department or of Lake Shore Mines to whom they may be of some interest.

Supplement
to
Report on Trip to Ishpeming, Mich.
Conference with Dr. Leonard A. Obert
October 27 - 29, 1944

....

Ernest A. Hodgson

....

The following notes were included in those made by the writer while at Ishpeming, but were omitted from the report proper as being too confidential, too indefinite, or too irrelevant. They are given here for the information of those officials of the Department or of Lake Shore Mines who may be interested. They are not to be considered as published.

I. Microseismic Control in Pillar Removal Operations:

In addition to the excerpted notes given in the body of the report, the following are here recorded. The title of the paper reporting the work by Dr. Obert is

Memoranda Report No. 926
Microseismic Control in Pillar Removal Operations
Republic Steel Corporation, Port Henry Division
Port Henry, N.Y.

....

Leonard Obert

....

The report will not be published. The following are items of interest noted by the writer in reading the photostat copy of the typewritten report.

Magnetite iron ore. Operated intermittently for over 100 years. Witherbee-Sherman Co. produced over 30,000,000 long tons, 1870-1838. Pillar ore up to 33 per cent left in some places. Pillar ore remaining in two of the older mines, at least 8,000,000 tons in 1938. Pillars left to prevent dilution of ore, prior to magnetic separation methods,

Republic Steel took over in 1938. In period 1938-1943, the ore they recovered from pillars made up 25 per cent of the ore mined,- a total of 250,000 tons in 1942. The question arose: Had the strength of the cap rock been significantly weakened? If not, how much more pillar ore could be safely recovered?

E. E. Mailot, Mining Engineer, U.S. Bureau of Mines, and L. A. Obert examined workings November 5-6, 1942. Project started January, 1943. Terminated February, 1944.

Mining: open stope. Peculiar structure in "Clonan" workings where the folded beds completely surrounded a rock core 1500' long and 300' across, this mass being held in place by residual pillars of iron ore; bottom, top and sides, as shown in Fig. 1. Procedure: cut pillars free of roof and bench them down. Takes 3-4 months to mine per pillar per crew. Average pillar yields 20,000 to 30,000 long tons of ore in "Clonan" workings or 12,000 to 15,000 in "Old Bed".

Account given of the application of the microseismic method to a pillar in the "Clonan" workings, substantially as given in the report. Some idea as to the size of the pillars can be gained from the sketch in Fig. 2.

Records were kept of all mining operations, when rounds were fired, when pillars were cut free from roof, when roof slab falls occurred, the production from the area. In the year and a half covered by the microseismic recording 75,000 long tons of pillar ore was removed.

In addition to the period of activity April 28 - May 1, 1943, outlined in the report proper there was another July 12 - August 9, 1943. Obert's notes read in part, as follows:

On July 22, 5 days after activity started, a small fall of 3 tons occurred and, on July 29 approximately 200 tons fell from the top side of pillar No. 5.

The variation in rate was erratic. From July 12 - 20 the rate rose from 8 per hr. to over 2,000 where it remained to July 22 when the fall occurred. It dropped to 200 for July 23-24 and then went up to 2,000 on July 25-26-27. On July 28 the rate dropped to 540 but no fall preceded the decrease. On July 29 it went back to

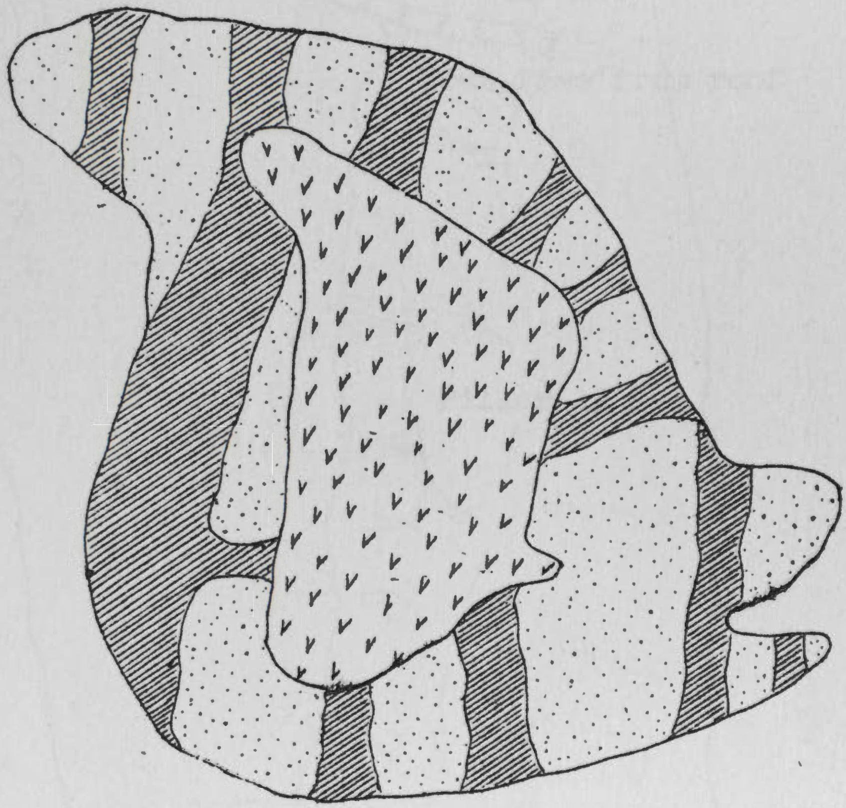

Fig. 1

Idealized Vertical Section of
Clonan Workings
(after Obert)

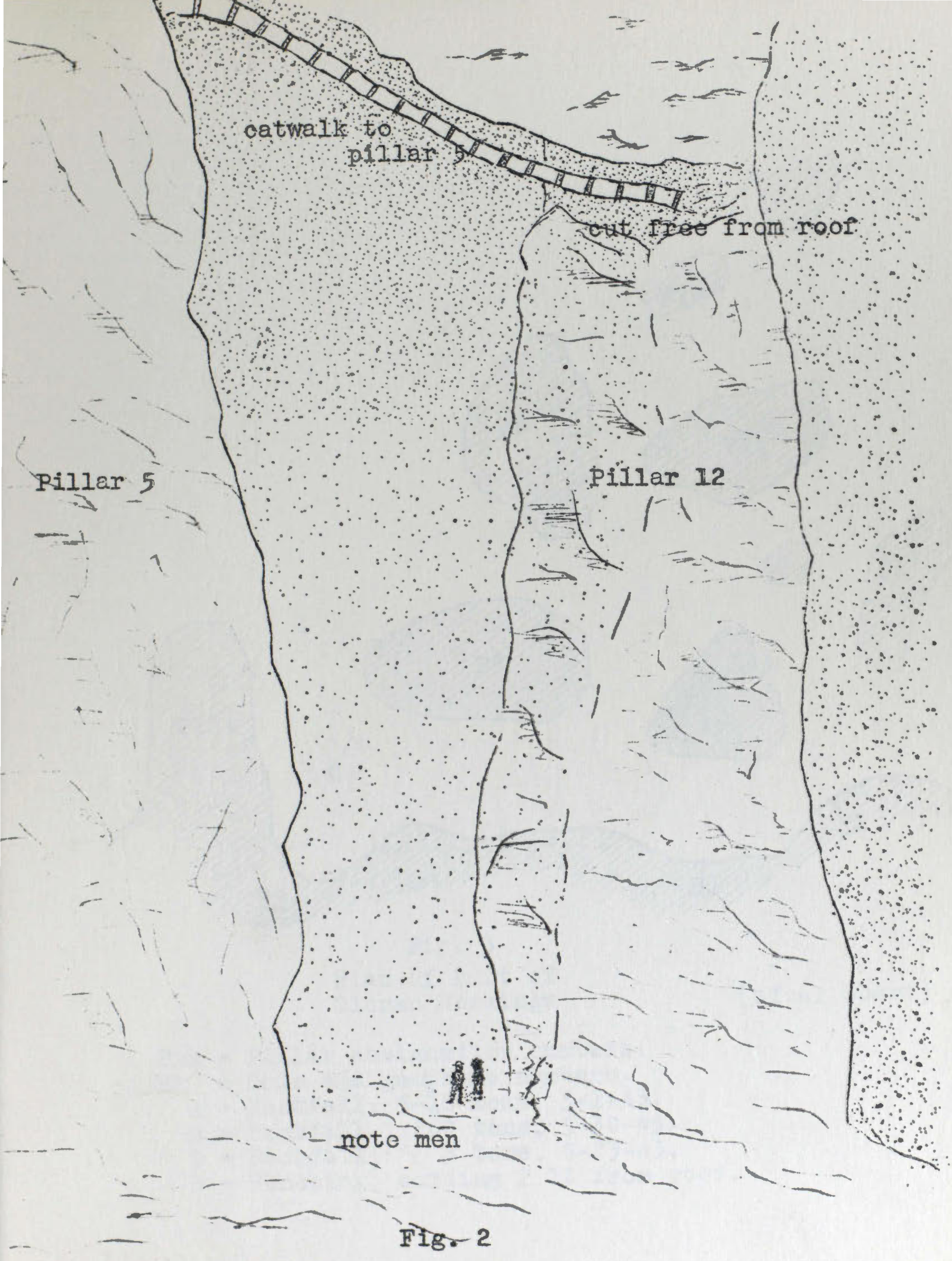

Fig. 2

Pillars in Clonan Workings
(tracing from photograph)

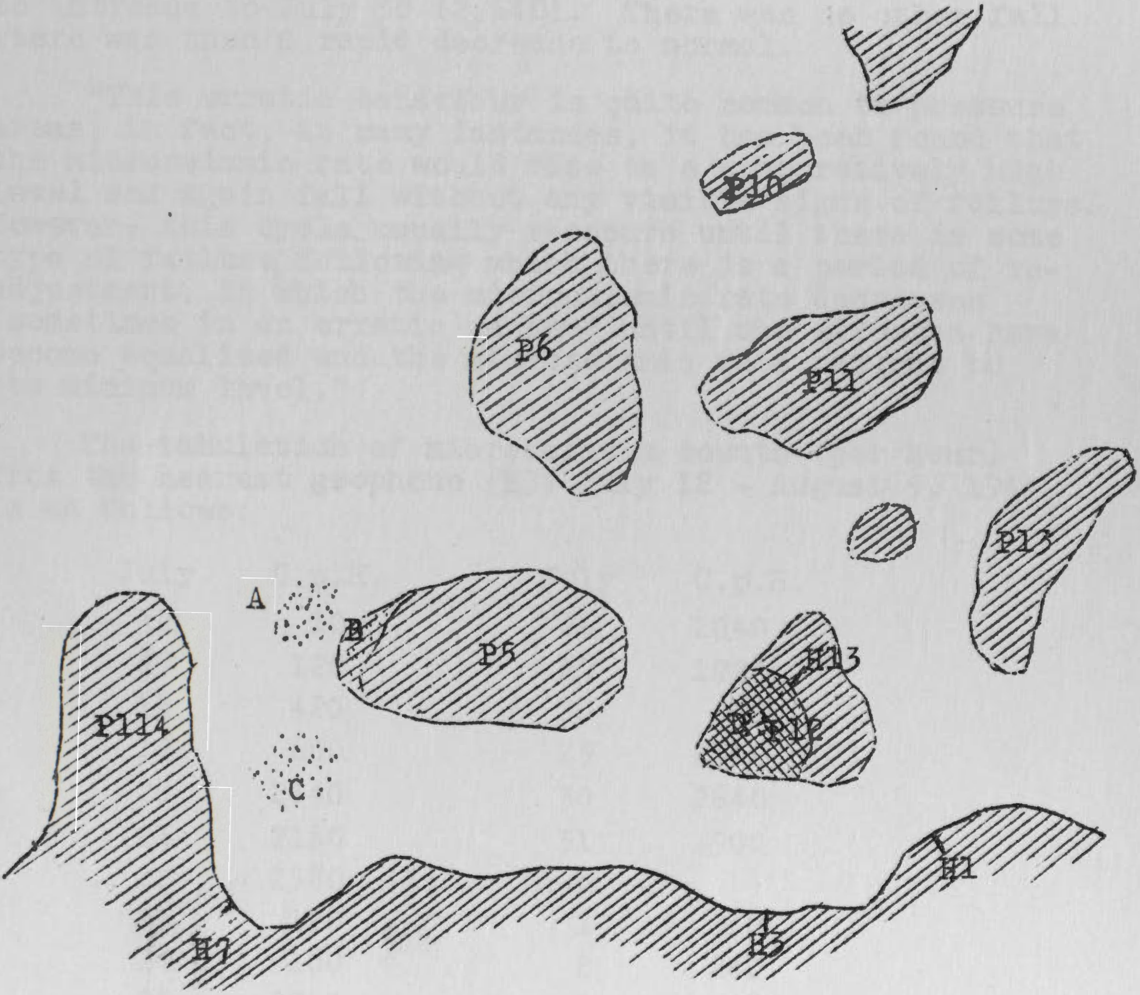

Fig. 3
Plan of Part of
Clonan Workings (after Obert)

Pxx = Pillar designation numbers.
Hx = Hole and geophone numbers.
A = Rockfall, 5-10 tons, 5-1-43.
B = Rockfall, 200 tons, 7-30-43.
C = Rockfall, 3 tons, 7-23-43.
D = Benching, cutting P 12 from roof.

2,000 after which the fall occurred. The rate continued to increase to July 30 (2,640). There was no other fall. There was then a rapid decrease to normal.

"This erratic behaviour is quite common to pressure areas, in fact, in many instances, it has been found that the microseismic rate would rise to a comparatively high level and again fall without any visible signs of failure. However, this cycle usually reoccurs until there is some type of failure; following which there is a period of readjustment, in which the microseismic rate decreases (sometimes in an erratic manner) until the stresses have become equalized and the microseismic rate returns to its minimum level."

The tabulation of microseismim counts (per hour) from the nearest geophone (H3) July 12 - August 9, 1944, is as follows:

July	C.p.H.		July	C.p.H.	
12	10		26	2040	
17	120		27	1920	
18	420		28	540	
19	600		29	2160	(2)
20	2640		30	2640	
21	2160		31	900	
22	2580	(1)	Aug.		
23	120		1	360	
24	180		2	240	
25	2760		9	38	

(1) Fall of 3 tons followed this record.

(2) Fall of 200 tons followed this record.

Except for the microseismic activity of April 28 - May 1, 1944, discussed in the report proper, and that of July 12 - August 9 outlined above, there were no changes in the extraordinarily low minimum rate, even after blasting or on cutting a pillar free from the roof. Hence the work of pillar removal was continued with considerable assurance of safety.

II. An Interval Timer being Developed at Bureau of Mines:

An interval timer is being developed at the U.S. Bureau of Mines to measure (in micro-seconds) the interval between the instant when one geophone picks up a snap and when another in a different location picks up the same snap. It is a modification of the Weisz Interval Timer reported in Electronics for April, 1944. At present, it is being perfected to handle two stations, but it is proposed to have it extended to take care of four.

These geophones will be placed at the corners of a regular tetrahedron so arranged as to enclose the suspect ground. Let us suppose the units and their holes and geophones are respectively designated A, B, C, and D and let us suppose that the snap reaches the A geophone first and then the others in alphabetic order.

The impulse reaching A starts a condenser charging through a resistance at each of the other units at a rate, fixed, uniform and intercomparable. As the impulse reaches each unit, in turn, the charging is stopped. The charge on each of the respective condensers is thus a function of the time interval concerned. The charges are read by means of a vacuum-tube voltmeter so that they are not affected by the measurement.

The procedure, then, is as follows: the set is turned on. A snap occurs. The operator reads the charges one after another by means of the common meter, the unit showing no charge having received the snap first and the others in the order of magnitude of their charges. When the charging rate and the velocity of the seismic wave are known, the meter can be calibrated and read directly as differences in distance from the source to each of the geophones.

The instrument, as now constructed, measures the intervals in micro-seconds. It is difficult to standardize and maintain. It is proposed to reduce the sensitivity to a point where the instrument will measure milli-seconds with an accuracy of one per cent. At this level, it is stable and sufficiently rugged for field service.

It takes about six seconds to make a reading, after which the instrument must be re-set. It is thus possible to determine intervals for about ten snaps per minute.

When differences in distance are known, the origin of the snap will be determined by a graphical method, the calculation of its coordinates mathematically being a time-consuming process.

III. Random Notes of Interest:

(a) Expense of the mine surveys runs to about $1,000 per mine but there are unexpected and sometimes large returns on the outlay, e.g. one case where a contract for drilling was tendered at $2.75 a foot in granular corrundum but when tests showed that it drilled easily, the corrundum grains tearing loose from their matrix, the price of $1.80 was accepted and a saving of about $100,000 resulted in the single instance.

(b) Correction to plane wave velocities to convert to spherical wave is taken as about -5 per cent in core vibration work but might amount to as much as 20 per cent in a mine study.

(c) Visited Cleveland Cliffs Iron Co., Ltd., Ishpeming. Met Mr. Charles J. Stakel, Manager, and Dr. Stanley W. Sundeen, Supt. Cliffs Shaft. They are interested in a pillar removal program. Was interested in their reinforced concrete headframes which resemble Washington monument,- except as to dimensions.

(d) Obert and his associates have been experimenting with a geophone having its crystal held at both ends in rubber cushioned clamps. This raises the resonance period from 1000 cps. to about 2500 cps. and incidentally gives a much greater freedom from crystal breakage. The gain is cut about 5 Db.

(e) The specimens of core which must have smooth ends for some of the tests are lapped until, when wet, a 1 square inch area will hold up a 4 lb. steel face plate.

(f) Damage indications in pillars: hour-glassing and pinchoidal cracking at contacts of faces with either footwall or hanging wall.

(g) Reminded of Bridgman's experiment: wrapping a rock specimen in foil, immersing it in a liquid under compression and raising it to 5,000 atmospheres. The rock did not fail. Query: was it altered?

(h) The A.S.T.M. (American Society for Testing Materials) states that lead plates as pressure distribution contacts in a testing press are not good.

Dominion Observatory,
Ottawa, Canada,
November 4, 1944.

E. A. H.

AMENDMENTS TO REPORT OF CONFERENCE
ISHPEMING - OCTOBER 27-29, 1944

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The following notes have been supplied by Dr. Obert as amending or supplementing parts of the report on the conference at Ishpeming, Mich., on October 27-29, 1944. The numbers in brackets are to be interpreted in order as follows:

(a) R or I, II, III or S (Report, Appendixes, Supplement).

(b) Page number.

(c) Paragraph number.

(d) Line number.

That is to say, for example (R-8-3-3) refers to the main body of the report, page 8, paragraph 3, line 3.

The notes carry serial numbers 1-38. If these are endorsed on the copy at the locations indicated in the brackets preceding each note, it will facilitate a reading of the important contributions given by Dr. Obert's comments.

Department of Mines and Resources,
Dominion Observatory,
December 21, 1944.

E. A. H.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

EASTERN REGION

EASTERN EXPERIMENT STATION
COLLEGE PARK, MARYLAND

November 22, 1944.

Dr. Ernest A. Hodgson,
Department of Mines and Resources,
Dominion Observatory,
Ottawa, Ontario,
Canada.

Dear Dr. Hodgson:

The three copies of your report on our recent conference were forwarded to College Park via Rolla, Missouri, and were just received. I have read the report over and have made a number of notes which are discussed on the enclosed pages. Reference to the notes is given in the margins of the report.

Considering the brief time that you have had to go over this data, I believe you did a remarkable job. I hope that the following notes clarify the report. It may be possible that I will quote from your report in my final publication to which, I presume, you will have no objection. Please give my regards to everyone at Lake Shore.

Very truly yours,

(Signed) Leonard Obert
Senior Physicist.

Enclosure.

1. (R-5-2-10) Regarding the two shapes: While both give satisfactory results, the proper interpretation must be given to Figure 1, that is, it is necessary to allow for the vertical splitting. Therefore, Figure 2 is preferred and will be used in subsequent tests.

2. (R-5-2-15) The geophone is likely to be broken in either case if the rock fails violently. We removed the geophone from the type two rock in this case only because it belonged to this class.

3. (R-5-2-19) This sentence should read: Specimens were obtained from 14 types of mine rocks and two types of quarry granites.

4. (R-6-2-4) Change 4,000 to 2,000. Equal increments of either 2,000 or 4,000 lbs. per square inch were used in these tests.

5. (R-6-2-6) The blotting paper, plus the added distance, plus the loss in the bed of the pressure accounted for a difference of as much as 20 db. which means in terms of amplitude that geophone B picked up only 1/100 part of that picked up by geophone A.

6. (R-6-2-11) Only one specimen was tested by procedure Y.

7. (R-6-2-18) The Z routine was designed to show the effect of the rate-of-change of pressure both positive and negative, that is for increasing and decreasing pressure.

8. (R-6-2-22) The pressure decrease in 15 minutes amounted to less than 5% the total pressure, except at the 9/10 total pressure.

9. (R-7-1-6) Delete "slowly".

10. (R-7-2-10) All records indicate when this correction was applied.

11. (R-7-3-3) Rather than 5,000-8,000 lbs. per square inch, use approximately 1/5 the crushing strength.

12. (R-7-3-6) In most records the microseismic rate jumped to a high level when the rock split vertically, then decreased, sometimes slowly, sometimes rapidly, as additional increments were added, going through a minimum at approximately 1/2 the crushing strength and then increasing rapidly as the point of failure was

approached,

13. (R-7-3-9 to 12) I would delete this sentence because it needs considerable expansion if it is to be included.

14. (R-8-1-2 to 6) Are you referring to the one Y-tested specimen in this statement? The last sentence in this paragraph seems unrelated, as all specimens were carried through to failure. We have taken specimens from the press after subjecting to high pressure which has produced abundant microseismims but which showed no visible indications of failure.

15. and 16. (R-8-2-4 to 8) The two tested specimens should be referred to in terms of rate-of-change of load. The general results are as follows:

   1. Specimens raised to 1/2 total pressure. Some microseismims produced at first, diminish after two or three minutes to comparatively low level.

   2. Pressure released to 1/4 total pressure microseismims produced during period pressure was decreasing, but stopped as soon as change of pressure was stopped. Very few microseismims produced at 1/4 total pressure.

   3. Pressure raised to 3/4 total pressure, same as one, except rate higher.

   4. Pressure reduced to 1/4 total pressure, same as two, except more pronounced.

   5. Pressure raised to 9/10 total pressure, same as one or three, except still more pronounced. Also sporadic burst and salvos.

17. (R-8-3-3) I am not certain as to what you mean in this statement. I believe you refer to this case; assume the pressure on a specimen to be at some given load. If the pressure is then increased to higher value, there will be a surge immediately thereafter associated with this increase. This surge will die out, but leave the rate at a higher value than in the initial state.

18. (R-8-6-5) Change a minute or less to several minutes.

19. (R-9-3-1 to 8) I believe these disconnected statements would be clarified if you would insert the following:

In a introductory remark (quote)

20. (R-9-4-1 to 3) The above mentioned experiments show that (quote).

21 and 22. (R-10-2-5 to 8) Part I discusses the <u>general microseismic methods and technique</u> and Part III discusses application of these methods to the specific mining problems.

23. (R-10-5-1) This program was not carried out privately. The report is confidential because it has not officially been released by the Director of the Bureau of Mines and by the mining company in question. It will, however, be released in Part III in a condensed form.

24. (R-13-3-12) Delete the statement, regarding physical tests, density, determinations. I am of the opinion that even these tests would not disclose any evidence of failure.

25. (R-13-4-1 to 5) This would read better as follows: In hard, brittle rocks which finally burst violently, there is a tendency toward higher microseismic rates. Microseismims usually start at about 25 to 50 % of the crushing strength and increasing rapidly in the region from 80 % of the crushing strength to the point where the specimen fails.

In no case did we test any rock, whether of the bursting or crushing type that did not show some microseismic indications prior to failure. It was more pronounced in the hard or brittle types of rocks.

26. (R-13-5-1 to 4) Should read — Snapping becomes normal.

27. (R-13-6-1) Delete "seems to have" and insert "has".

28. (R-14-1-1 to 5) Should read — The incidence of microseismims become more frequent, although in some instances sporadic as . . . .

29. (II-1-2-3) I do not agree that there was no prediction.

Although there was a surge of 7,000 lbs. per square inch associated with the vertical splitting, I am certain that if this piece has been cut like the number two specimen, there would have been microseismims prior to failure. What you mean is that there was no strong acceleration in the rate as the crushing strength was approached.

30. (II-2-1-3) Again I disagree that there was no prediction. The fact that in this small volume of rock there were even a few microseismims produced prior to failure seems to me to serve as a basis for making predictions. How this rate produced in the small volume would compare with mine rock collectively cannot be established definitely.

31. (III-1-2-2) The drill bits were not made by the Bureau of Mines, but they were made to Bureau of Mines specifications.

32. (III-1-3-2) This is a confidential questionnaire. It is not a mandatory prerequisite, but to date we have had no refusals.

33. (III-4-1-1) Delete the statement about the strength of powder as we have not made sufficient correlations to make any statement as yet.

34. (S-1-2-10) The gist of this report will be presented in Part III.

35. (S-5-3-8) There must be some misunderstanding regarding this statement because I do not know what saving was effected.

36. (S-5-4-1 to 4) Should be qualified regarding the geometry of the media or else deleted.

37. (S-5-6-5 to 6) The last sentence should read — The output is reduced from 5 to 15 decibels depending upon the frequency at which the measurement is made.

38. (S-5-7-1 to 4) The specimens of core used in the compression tests must have flat parallel ends. The specimens are cut with diamond saw and lapped flat, so that a one square inch area will pick up a 4 lb. flat (ground) plate.