SEISMIC RESEARCH PROGRAM
ROCK BURST PROBLEM
LAKE SHORE MINES

Report No. 6
Experiments with Rock Specimens under Pressure
May _ June, 1941

Ernest A. Hodgson

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Acknowledgments

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The work of arranging for these experiments was done entirely by Mr. V. E. Hollinsworth of the Dominion Observatory staff, who is responsible for the original design and development of the microgauge. He collaborated throughout the entire range of the actual experiments and has assisted in the preparation of the data for this report. The painstaking and skilled work of Mr. W. Allingham, in sawing and lapping the specimen blocks, and that of Mr. Howells Frechette and his assistant, Mr. R. H. Picher, in the actual tests with the hydraulic press are acknowledged in the text of the report. The rough blocks were, with considerable difficulty, selected, drilled, and supplied through the collaboration of Mr. W. T. Robson of Lake Shore Mines.

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As intimated in Report No. 5 (p. 9), experiments were to be conducted at Ottawa to determine the behaviour of drilled specimens of Lake Shore rock under pressure. This was planned as a short study which could be carried out while waiting for the delivery of equipment ordered for the further testing of the microgauge in the mine.

It was realized, of course, that the conditions for rock in place could not be attained. At depth, rock pressure is pseudo-hydrostatic. Even when excavations have been made, only a part of the area of a pillar is exposed. In the laboratory, with the time and means available, it was possible to use only unilateral pressure. However, it was felt that the experiments should be attempted, in the hope that some leading ideas might emerge on testing, with the microgauge, the deformation of a diamond drill hole in a prepared specimen of mine rock as the pressure was gradually increased up to the bursting point.

1. <u>Preparation of Specimen Rocks</u>.

Three specimens, each with a 1,5 inch diamond drill hole, were supplied by Mr. W. T. Robson of Lake Shore Mines. These were: one of porphyry and two of syenite. They were rough blocks weighing upwards of seventy-five pounds each. The porphyry specimen showed some signs of jointing, the others seemed quite solid. The rough syenites are shown in Figs. 1 and 2. In referring to these in the text, they are designated S_1 and S_2, respectively, the porphyry being indicated by P.

Through the cooperation of Mr. F. C. C. Lynch, Chief, Bureau of Geology and Topography, each of these rough blocks was sawn into a regular form, approximating a cube five inches to the side, with the drill hole approximately in a symmetrical position in the finished specimen. Two opposing planes, parallel to the axis of the drill hole, were selected and lapped to smooth surfaces. This work was done with considerable skill and care by Mr. W. Allingham at the Victoria Museum, Ottawa.

Arrangements were made with Mr. W. B. Timm, Chief, Bureau of Mines, to have the use of their hydraulic testing press. The specimens were checked by Mr. Howells Frechette, Chief, Division of Industrial Minerals, in whose laboratory the hydraulic press is situated. One of these (S_2) was not as well surfaced as desirable. It was capped for the pressure test by Mr. R. H. Picher of the same office, who also assisted throughout the testing operations.

As prepared for the tests, the specimens were found to have the following areas on the faces to be subjected to pressure: P = 21.0 sq. in.; S_1 = 20.3 sq. in.; S_2 = 26.6 sq. in.

The drill hole effectively reduced these areas by an amount equal to its projection on the pressure plane. The areas sustaining the pressure thus become:

P = 14.2 sq. in.

S_1 = 13.8 sq. in.

S_2 = 19.1 sq. in.

2. The Hydraulic Press.

The hydraulic press is shown in Figs. 3, 4, and 5. The upper pressure plate is provided with a ball and socket joint at the base of the large adjusting screw so that slight lack of parallelism in the two faces of the block to be tested is not important. Pressure in the chamber below the bottom plate is built up by a pump operated by the motor shown at the lower left hand corner of Fig. 4. The rate at which this pressure* builds up is controlled by a screw valve which appears just below the bowl of the pipe of the operator (A) sitting beside the controls. The pressure is

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* Unless expressly referred to as "pressure per square inch" the word "pressure" in this report indicates simply the force applied.

Fig. 1
Small Syenite Block
S1

Fig. 2
Large Syenite Block
S2


KEUFFEL & ESSER CO. 1913.


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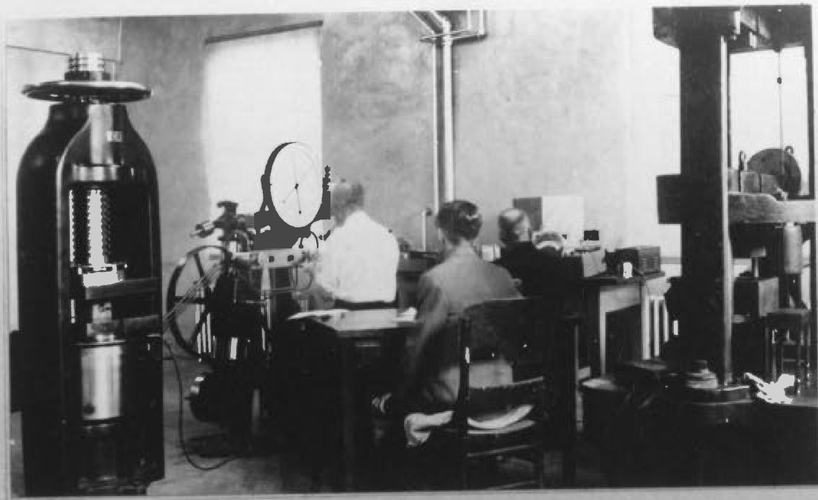
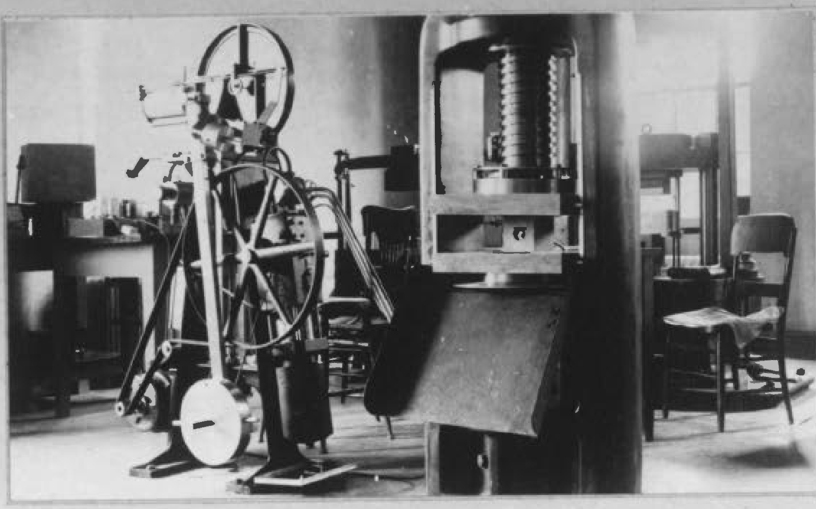
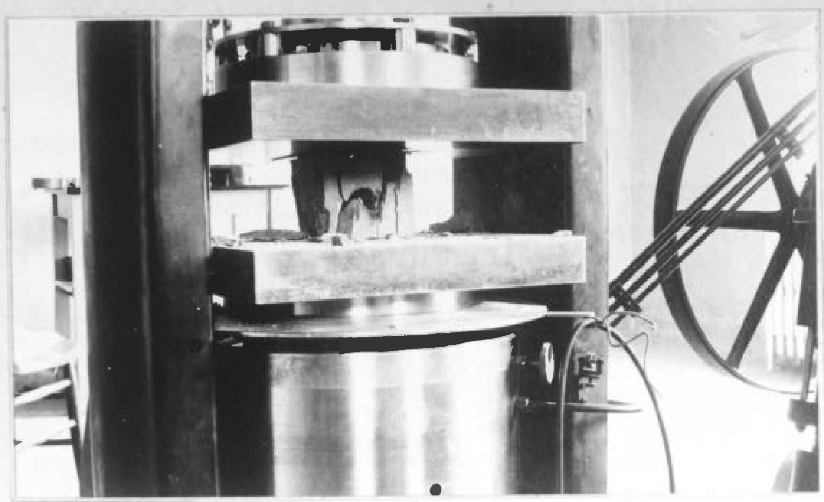
Fig. 3
Routine of Experiments
Pressure Laboratory

Fig. 4
Hydraulic Press
Rear View

Fig. 5
Small Syenite Block S1
after Crushing







balanced against a weight on a hanging lever shown in Fig. 4, which operates the dial pointer. The full capacity of the press is 600,000 lbs. For the largest specimen, therefore, it was possible to attain a maximum pressure of about 31,400 lbs/sq. in. The pressure could be applied as slowly as desired by suitable adjustment of the valve. A slight overall leakage operated to lower the pressure very slowly if the valve were completely closed. It was possible therefore to hold the pressure constant or have a slow gain or a slow loss.

3. Adjustment of Gauge and Routine of Observations.

The microgauge has been described in some detail in Report No. 5. It was inserted in the drill hole of the prepared specimen, set between the plates of the press and taking pressure. A piece of cardboard was inserted above and below the specimen, between it and the steel plates of the press. The connecting wires were run to the amplifier and milliammeter shown over the shoulder of the operator (B) farthest to the right in Fig. 3. The control equipment was set to a sensitivity such that an increase in pressure from 0 to 1,000 lbs. (in the case of the specimen to be tested) would just cause the milliammeter to traverse its full scale of 30 divisions (3 milliamperes). It is not known what this represents in contraction of the hole at the gauge. Means were lacking to measure it. From previous experiments it is known that the compression is roughly of the order of 30×10^{-6} for the full scale. It really does not make any difference what the exact value was. It was important only to keep the amplification at the same value throughout, thus giving a unit of compression of the drill hole. To assist in holding this unit constant, a Raytheon voltage control was used. The power source was the 60-cycle, 110 volt, lighting supply.

An observation consisted in clamping the gauge so that the pointer of the milliammeter was just lifting off its bottom bumper. Operator A, at the press control, then set the valve so that the pressure slowly increased and gave the press dial reading at the instant that B, watching the milliammeter, gave a signal that the pointer on that meter was just passing the zero and the thirty mark, respectively. The operator C (centre in Fig. 3) recorded the two pressure values and differenced them. This gave the increase in pressure necessary to cause a unit of compression in the drill hole, at whatever pressure level was being used.

Initially, these values were taken successively. That is, as soon as the pointer on the milliammeter reached full scale, A set the valve to hold the pressure constant while C re-jacked the gauge to make the pointer of the milliammeter rest on its lower bumper. Then the pressure was again stepped up over the range and the two values recorded as before, and so on. This proceeding was found so slow and the results were so constant that the program was changed to take unit compressions only at intervals of about 10,000 lbs.

4. Preliminary Crushing Strength Tests.

In order that the crushing strength of the rock might be known approximately, permitting removal of the gauge shortly before the specimens were likely to burst, tests were run on small cylinders, two inches in diameter and two inches long, cut with a core drill from some of the larger pieces sawn from the large syenite rock in reducing it to regular form. These test cylinders, three in all, were carefully capped by Mr. Picher and then crushed in the press. The data yielding the pressure per square inch at which the samples broke were as follows:

Sample No.	Breaking Strength (lbs.)	Diameter in.	Area sq. in.	lbs/sq. in. Pressure
1	115,000	1.97	3.04	37,800
2	118,000	1.97	3.04	38,800
3	98,000	1.97	3.04	32,200
				Mean 36,266

5. Behaviour of Specimens under Pressure.

The behaviour of all these specimens (P, S_1 and S_2) under pressure was substantially the same. Up to about 250,000 lbs. (depending of course upon the specimen concerned) the difference in pressure for a unit of compression (described in section 3) was, within the errors of observation, apparently constant. That is to say, the diameter of the drill hole, perpendicular to the plates of the press, shortened linearly as the pressure increased.

Then, sometimes accompanied by a warning "crack!" and sometimes not, the pump control being left unchanged in setting, the pressure dial would show a falling off in pressure and at the same time the milliammeter pointer moved rapidly in a positive direction. That is to say, the specimen was yielding, compressing the hole and reducing the pressure between the plates of the press in spite of the steady slow pumping in of oil.

The observations here are, perforce, only qualitative. The amount by which the block as a whole yielded and the amount by which the diameter of the hole was reduced could not be measured. Indeed, at the first sign of such a reversal, the gauge was unclamped as quickly as possible. In no case was the gauge injured by this yielding, initially sudden followed by a gradually attenuating diminution.

After the press dial again began to move positively, with the controls as they were, the gauge was reclamped and a unit compression reading taken. The initial one of these was sometimes as low as 400 lbs. but the second and successive readings, as the pressure was gradually raised some thousands of pounds, were of normal value, showing the rock to be, apparently, as strong as before.

At a higher value another sudden yield occurred and the experiences of the two paragraphs next above were repeated. In some cases as many as four yield points were passed before the pressure was so near the probable bursting value, as indicated by the test experiments described in section 4, that the gauge had to be removed from the hole. It is to be noted that throughout all the regular compression including the yield points, the hole was never compressed so much that the available adjustment on the jacking device of the gauge would not permit its ready removal. This available range of the jacking device is about .02 in. The total yield of the hole is thus of the order of .01 in. This is of no particular importance except for the indication that the design of the clamping device is satisfactory for conditions likely to occur in practice at the mine. Before using the gauge at the mine it will be calibrated at the Lake Shore laboratory.

The diagram of Fig. 12 indicates the course of the experiments as described above in this section. The position of the yield points, the loss in pressure at each, and the final, bursting pressure are taken from the experience with the specimen S_1. The slope of the compression is the

Fig. 6

Small Syenite Block S1

after Crushing

(Photograph by Courtesy
Mr. Howells Frechette)

average for the observations made over the so-called unit compressions (see section 3). The amounts and the rates by which the compression increased during the yield period is not known,- hence the dotted lines in these sections of the graph.

The loss of pressure just before the bursting point was much more pronounced with S_1 than with either of the other two specimens. The control valve was left at the position it had been set for this section of the curve and the gauge had been removed from the specimen. The energy of the burst was very much the greatest with S_1. The appearance of the specimen S_1 after bursting is shown in Figs. 5 and 6.

6. Character of the Specimens after Yielding.

After the porphyry specimen, P, had been subjected to pressures up to 130,000 lbs., it suddenly yielded but did not burst. It was removed from the press and taken to the Observatory to be examined and photographed. It is shown in Fig. 11. The jointing due to pressure is quite marked and a spalled line along the inside of the hole is clearly shown. The block seemed quite strong, however, and evidently was; for, on being returned to the press, it showed about the same resistance to compression up to 257,000 lbs. when it again yielded. It recovered its normal strength with increasing pressure and finally burst at 294,000 lbs.

The porphyry specimen was not as strong as the syenites but this was due, in part at least, to the fact that it was visibly jointed. One of these joints opened as a slab was cut from the rough block. The split slab is shown in Fig. 10.

The large syenite specimen, S_2, was capped and the plates of the press were oiled to reduce lateral friction. The other specimens were left dry. In every case, a piece of cardboard was used above and below the block to isolate it from the press. Prior to 510,000 lbs. pressure, the specimen had yielded only once. It snapped at 505,000 lbs., and the pointer on the press dial fell to 462,000 lbs. before the specimen again resumed its normal resistance to compression. At 510,000 lbs. it snapped again. It was removed and taken to the Observatory. Fig. 7 shows S2 before being subjected to pressure. Figs. 8 and 9 show it after it had been subjected to pressures up to 510,000 lbs.

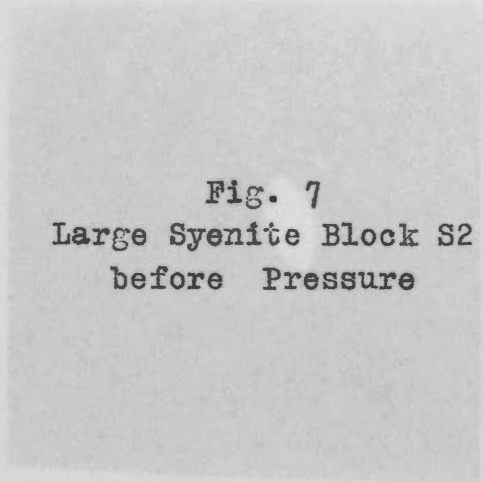


Fig. 7
Large Syenite Block S2
before Pressure

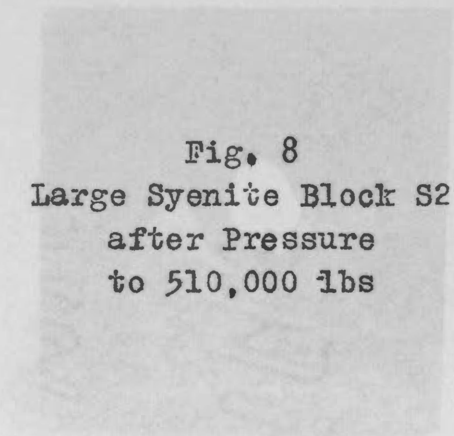


Fig. 8
Large Syenite Block S2
after Pressure
to 510,000 lbs

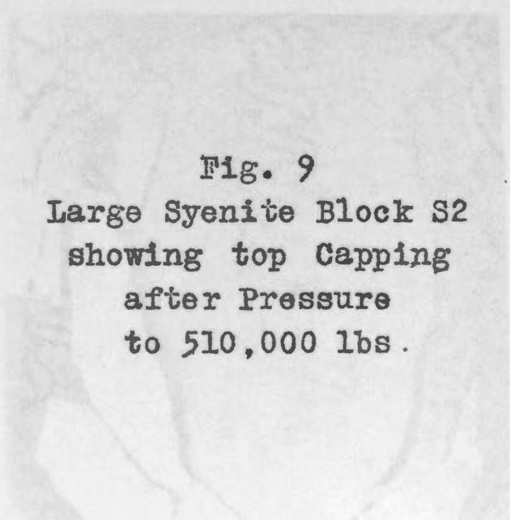
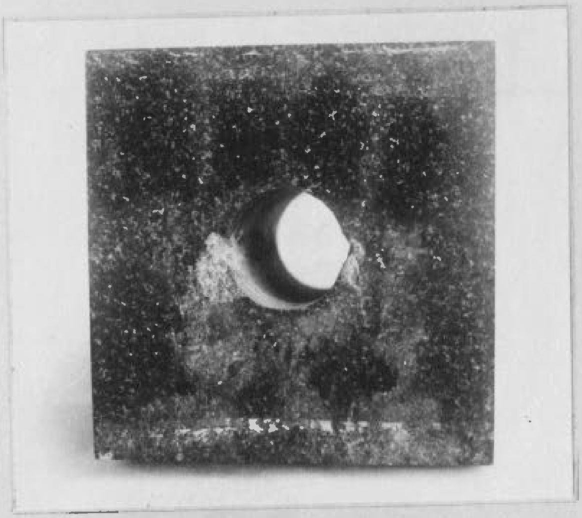
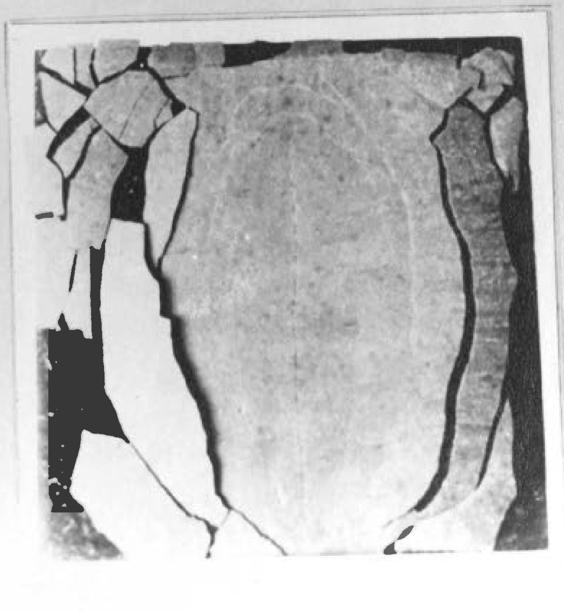


Fig. 9
Large Syenite Block S2
showing top Capping
after Pressure
to 510,000 lbs.





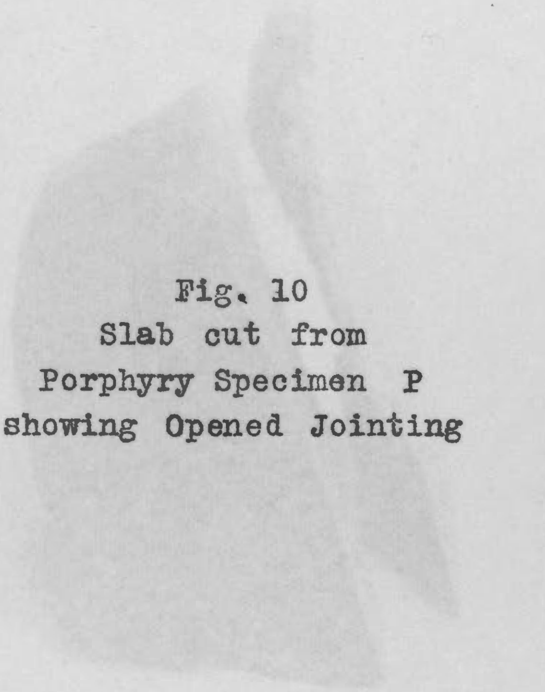


Fig. 10
Slab cut from
Porphyry Specimen P
showing Opened Jointing

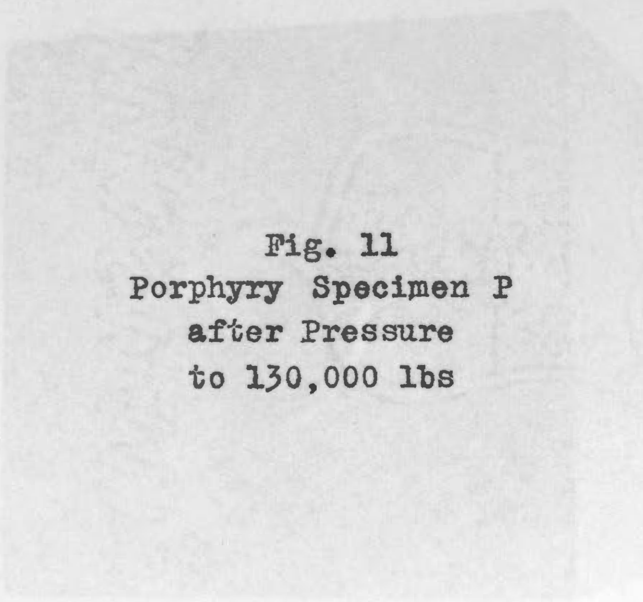


Fig. 11
Porphyry Specimen P
after Pressure
to 130,000 lbs

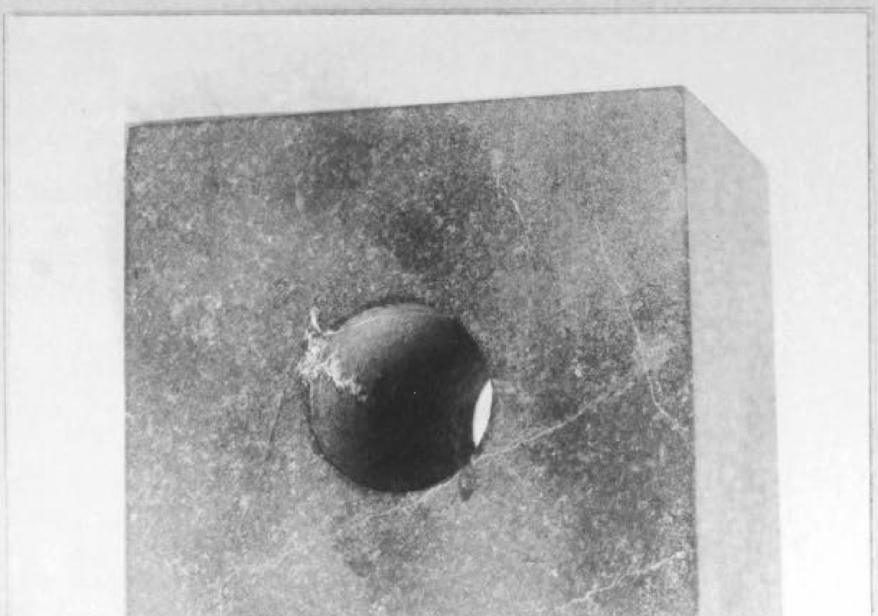


Fig. 12

This graph indicates, qualitatively rather than quantitatively, the behaviour of the small syenite specimen, S_1. The series of determinations of the difference in pressure for a unit of compression (defined in section 3) indicated that the variation was linear. The slope selected for the unbroken lines of up-trend is quite arbitrary. It was approximately uniform, however, throughout the experiment.

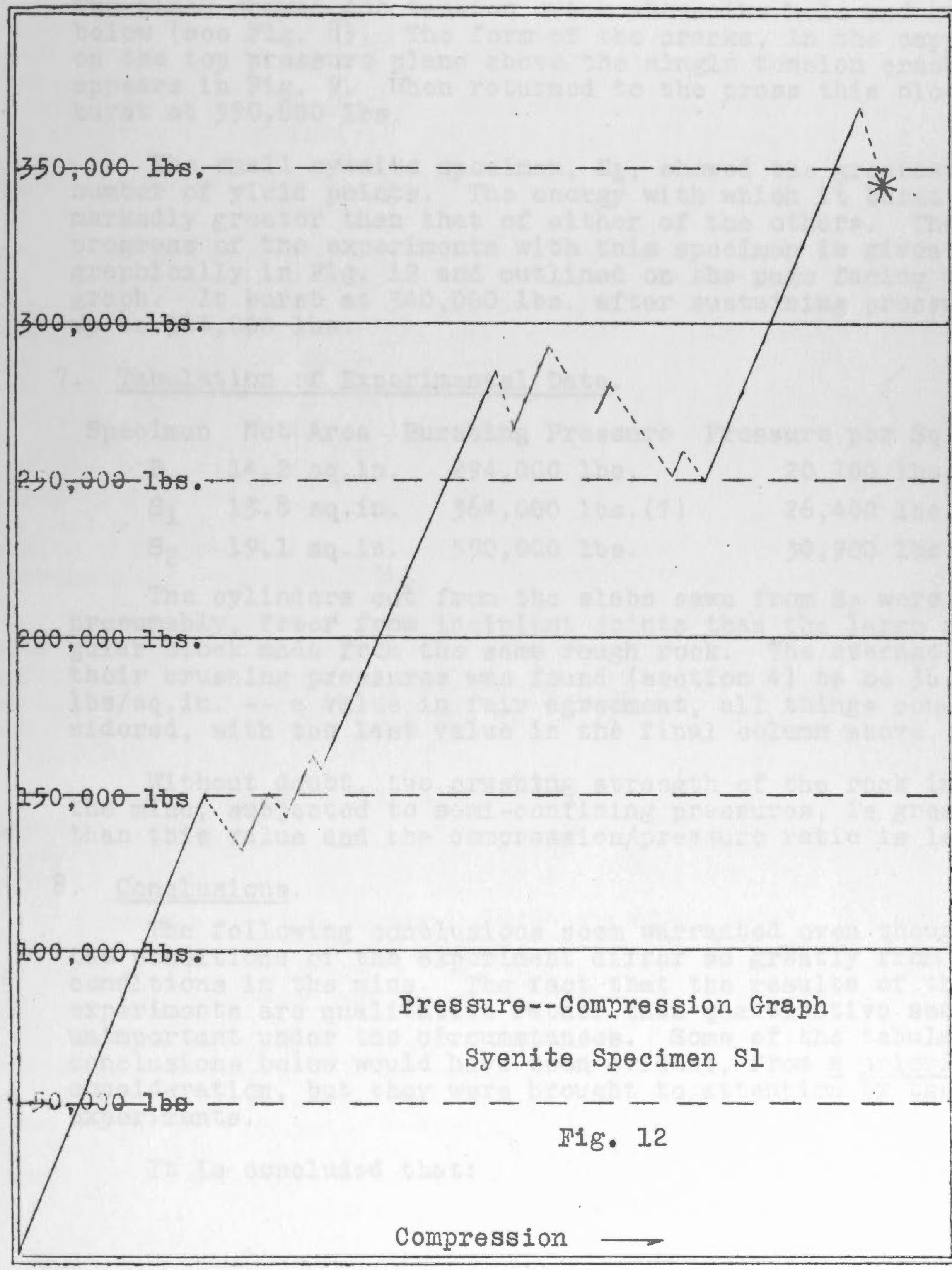
At 150,000 lbs., a tension crack opened above the centre of the hole (see evidence of this crack as a fine dark line on Fig. 8). In spite of a continued, slow input of oil to the press, the pressure fell, indicating that the block, and also the hole, was yielding. The amount of pressure-fall and that of compression not being known, the slope of the broken, down-trending lines was not determined. This slope was arbitrarily chosen. It may not have been uniform for any one instance and may have differed for different parts of the graph. The specimen yielded several times in this region (150,000 lbs.) but terminal pressure values were not defined,- hence the indefinite (faint) terminations made in drawing the otherwise solid lines.

The block yielded several times in about the same pressure region and, each time, resumed its former strength. This strength was then maintained from a little over 160,000 lbs. to about 270,000 lbs. At this point several cracks opened, with temporary resumption of strength in the intervals.

The experiment was discontinued at noon, the pressure being left on at 272,000 lbs. What change occurred in compression was not known; but, on resuming the experiment, the press dial read 266,000 lbs.

A series of yield points followed, after which the rock again became, apparently, as strong as before. At 350,000 lbs., the gauge was removed from the hole and the control valve set to slowly build up pressure.

At 364,000 lbs, the pointer on the press dial wavered, stopped, and then began to move in reverse quite rapidly. As it reached 340,000 lbs., the specimen burst with great violence. It then appeared as in Figs. 5 and 6. Note the multiple fine lines of shear in otherwise solid wedges, as shown in Fig. 6.



Pressure--Compression Graph

Syenite Specimen S1

Fig. 12

The block showed one tension crack above the hole and two below (see Fig. 8). The form of the cracks, in the capping on the top pressure plane above the single tension crack, appears in Fig. 9. When returned to the press this block burst at 590,000 lbs.

The small syenite specimen, S_1, showed the greatest number of yield points. The energy with which it burst was markedly greater than that of either of the others. The progress of the experiments with this specimen is given graphically in Fig. 12 and outlined on the page facing that graph. It burst at 340,000 lbs. after sustaining pressure up to 364,000 lbs.

7. Tabulation of Experimental Data.

Specimen	Net Area	Bursting Pressure	Pressure per Sq. In.
P	14.2 sq.in.	294,000 lbs.	20,700 lbs.
S_1	13.8 sq.in.	364,000 lbs.(?)	26,400 lbs.
S_2	19.1 sq.in.	590,000 lbs.	30,900 lbs.

The cylinders cut from the slabs sawn from S_2 were, presumably, freer from incipient joints than the large regular block made from the same rough rock. The average of their crushing pressures was found (section 4) to be 36,266 lbs/sq.in. -- a value in fair agreement, all things considered, with the last value in the final column above.

Without doubt, the crushing strength of the rock in the mine, subjected to semi-confining pressures, is greater than this value and the compression/pressure ratio is less.

8. Conclusions.

The following conclusions seem warranted even though the conditions of the experiment differ so greatly from conditions in the mine. The fact that the results of these experiments are qualitative rather than quantitative seems unimportant under the circumstances. Some of the tabulated conclusions below would have been evident, from a priori consideration, but they were brought to attention by the experiments.

It is concluded that:

(a) The gauge as at present designed is more sensitive than required. A reduction in sensitivity would result in a marked gain in stability.

(b) The range of the clamping device seems to be sufficient.

(c) It does not appear likely that the gauge will be damaged by any strain short of actual crushing.

(d) The graph of Fig. 12, showing the typical behaviour of a prepared block under unilateral pressure, cannot be considered any indication of what will be the behaviour of rock in place under confining pressure.

(e) The fact that blocks under unilateral pressure did behave essentially the same lends strength to the conviction that the law of consistent behaviour may be determined for rocks under pressure at the mine.

(f) The lines of spalling in a drill hole are 90° from the axis of compressive stress.

(g) Tension cracks in a drill hole indicate the axis of compressive stress.

(h) It is not likely that a pillar will crush under pressure before ample warnings have been given by sudden yieldings in its component blocks. Some of these take place long before crushing conditions are reached.

(i) The syenite specimen was found to have a specific gravity of 2.81. Presumably, in the mine, the average value would be 3. Thus, on an isolated pillar under homogeneous rock, the pressure would be 1300 lbs/sq.in. for each 1000 ft. in depth. The small test cylindrical specimens (see page 4) were crushed at from 32,000 to 39,000 lbs/sq.in., corresponding, roughly, to depths of 25,000 to 30,000 ft. Confining pressures would probably enable rock to be stable at even greater depths. Faulting and other departures from uniform conditions, so prevalent in the mine, explain failures at lesser depths. These considerations supplement previous conclusions from seismic recording of bursts that pressure of overburden alone is sufficient to account for these failures.

(j) Since rock under unilateral pressure becomes as strong as before after yield, it is even more likely to be the case for rocks under mine conditions.

(k) It must be remembered that a pillar bursts because of partial relief of confining pressure. That is to say, it bursts from a combination of confining pressure and resultant unilateral pressure. The former tends to increase the strength of the rock prior to bursting, but contributes to the force of the burst when it occurs. Because of the resultant directional pressure, the drill hole in the mine will go out of round under conditions tending to favour bursting.

(l) To detect the conditions developing at a given point in the mine two gauges, measuring compression in two directions at right angles, should be used; and, preferably, at least two such pairs at different depths in the same hole. Similar quadruple set-ups should be employed near the middle of the arch of a dome and also near the abutment on the smaller pillar end. The gauges in the centre of the dome should be set in at considerable depths - well within the suspected zone of compression. Those near the pillar should be just well within the zone of spalling. Eight gauges, as suggested above, could be arranged to record through a single amplifier, etc.; and, possibly, on a single recording meter.

Dominion Observatory,
Ottawa, Canada,
July 1, 1941.

Ernest A. Hodgson.