A STUDY OF THE RUPTURE OF ROCKS UNDER STRESS WITH SPECIAL REFERENCE TO MINE EXCAVATIONS

by

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Frontispiece

A specimen of 2½ inch diameter fine grained sandstone ruptured in compression. The main fragments are glued together.

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Abstract.

A Study of the Rupture of Rocks Under Stress With Special Reference to Mine Excavations.

Specimens of Lake Shore Tuff and Porphyry, Nundydroog Amphibolite, Kerr Addison Green Carbonate Breccia, and McIntyre Carbonated Lava have been ruptured under compression, tension, torsion and direct shear. The results were graphically plotted according to Mohr's strength theory, and the constructed angles of failure compared with the experimental measured angles. According to Mohr, the strength of the rock is a function of sliding friction, but the graphical and experimental results indicate rather that sliding friction and interlocking govern rock failure. Assuming this to be correct, and that Mohr's failure envelope continues as a straight line under confinement, it can be said that the rock with the higher angle of internal friction will store more energy, and will have a greater bursting potential while under the same degree of confinement, than rocks of lower angles of total internal friction.

INTRODUCTION.

With the world's increasing demand for metals, man is forced to go deep into the earth for their recovery. Deep mining sets many difficulties in the way of the engineer. One of the major of these difficulties is in overcoming the great pressures which are set up around mine openings. These pressures will, if sufficiently concentrated, cause the sudden rupture of the enclosed rocks. This phenomenon has been called a "rockburst". Morrison (4) has defined the term as follows:

"A rockburst may be defined as that phenomenon which occurs when a volume of rock is strained beyond the elastic limit and the accompanying failure is of such a nature that accumulated energy is released instantaneously." The definition thus covers all forms of sudden rock failure from the spitting of a quartz face to a major collapse of a stoping area.

Rockbursts are not a new phenomenon, but have been recorded in Europe and India since the latter part of the nineteenth century. In 1908 considerable focus was brought on the subject in South Africa where a drive was in progress to make work conditions safer in the mines. Since that date considerable work has been carried out all over the world.

By definition the cause of a rockburst is the concentration of pressure on a mass of rock causing it to fail suddenly. When this concentration does occur, a rockburst is not the only alternative as the mass may crumble slowly without any bursting effect and the same ultimate distribution of stress be accomplished.

The object of this paper is, "To study the rupture of rocks under stress with special reference to mine excavations." To achieve this the approach is twofold. (1) To ascertain by experiment the applicability of Mohr's strength theory to rocks. (2) To apply the physical aspects revealed to the practical operation.

Under (1) above, a series of different experiments have been performed upon suites of similar rocks. Five principal rock types have been tested in compression, tension, torsion and direct shear. In each experiment the ultimate breaking stress is recorded. These ultimate stresses have been plotted according to Mohr's theory, and the resulting failure envelopes have been drawn. As a further aspect, the type of break has been recorded and the angles produced compared with the theoretical angles predicted by the theory.

Under (2) above, part of the paper is of a much more general nature. It is attempted to coordinate the phenomena produced by experiment and acquired from literature with the practical field.

PREVIOUS WORK.

Previous work connected with this paper falls into three groups.

(1) Mohr's Strength Theory and its application.

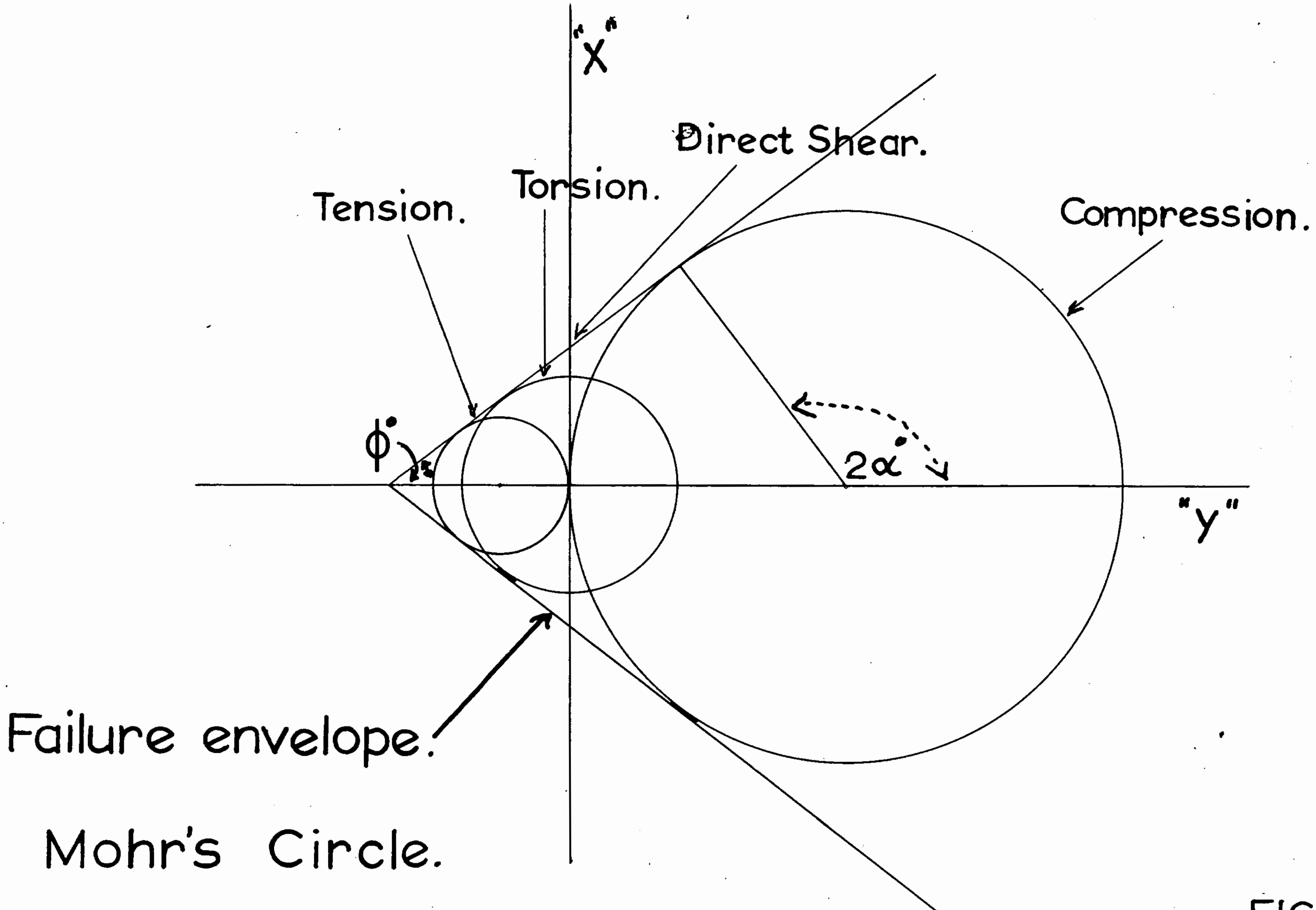
(2) Investigations into the physical properties of mine rocks.

(3) Study into rock fractures in underground workings.

(1) Mohr's Strength Theory and its Applications.

Mohr's Strength Theory is a generalization upon Coulomb's theory of internal friction. Coulomb's theory was based on the conception of failure as a sliding along planes inclined to the direction of principal stress. Mohr's strength theory postulates that failure of a material depends only on the relative value of the two extreme principal stresses, the normal stress(σ) and the shearing stress(τ). As the limiting values of the normal and shearing stresses are interdependent, the limiting value of one, above which failure will occur, is a function of the simultaneous value of the other. In fig.(1), the Y axis in cartesian coordinates represents normal stresses(σ) while the X axis represents shear stresses (τ). The mutual tangent to any failure stress circle will make an angle ϕ to the normal stress, this angle being the angle of sliding friction. The point contact between the stress circle and the tangent are the stress conditions at failure. The equation of the mutual tangent or envelope is:

$$\tau = \sigma \tan \phi$$



Mohr's Circle.

FIG 2

The angle between the maximum principal plane and the plane of failure is α where

$$\alpha = 45 + \frac{\phi}{2} \quad \text{..............(2)}$$

<u>(2) Investigations Into the Physical Properties of Mine Rocks.</u>

Considerable work has been done in the past to determine the physical properties of rocks in general. Geophysicists have obtained information on the physical properties to gain the elastic constants - Young's modulus, modulus of rigidity, and Poisson's ratio - as these qualities determine the propagation characteristics of seismic waves. Architects have studied the structural properties of building stone and road metal. Considerable work has been performed on mine rocks in connection with primary and secondary crushing, diamond and pneumatic rock drilling, explosive breaking and fragmentation of rock, rate of mining and other allied problems. Too little work has been done in connection with the behaviour of rock under the pressures accumulated in mining. A few papers have been written attempting to connect the elastic constants for rocks with rockburst potentials in the field.

<u>(3) Study into Rock Pressures in Underground Workings.</u>

The cause of rockbursts has been and is still strongly disputed. In the world today there are two main theories:-

(a) The Doming Theory as presented by R. G. K. Morrison (4 & 5).

(b) The Elastic Hysteresis Theory by Dr. O. Weiss (7).

Both theories throw a lot of light upon the problem, Professor Morrison's views on doming are evolved from the practical field. They take into account the signs and effects of rockbursts underground. Dr. Weiss is, on the other hand, a geophysicist, who has attacked the theoretical problem from a mathematical standpoint. It is the writer's opinion that Dr. Weiss' theory does not take into account much that has been observed and recorded underground in connection with bursts; also it does not seem possible to get the large stress fluctuations required by his theory in practice. However, a resumé of both theories is in order.

(1) Doming Theory.

Professor Morrison's theory can be explained best in his own words:

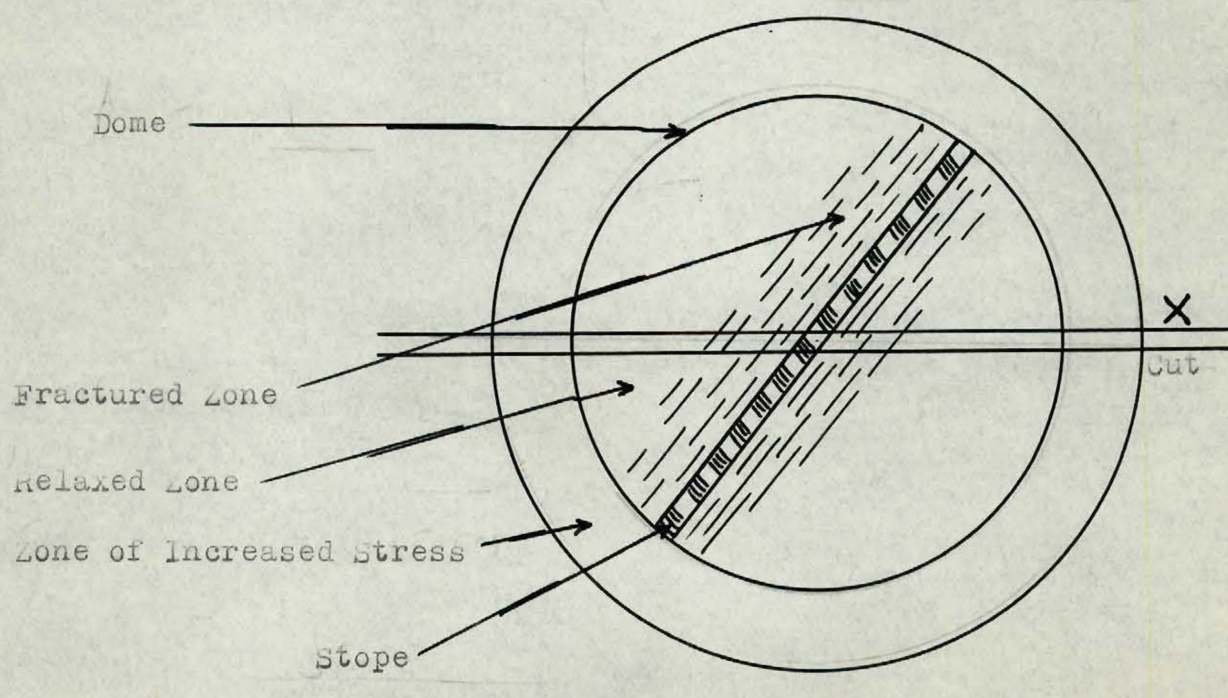
" At shallow depths hangingwall failure is usually related to local gravitational effects inducing tension in the wall. The excavating of a deep opening upsets a more sensitive condition of equilibrium which must be re-established if the excavation is to remain open. In the process there is an elastic expansion of rock towards the free faces of the excavation. With the resulting wedging effect compression develops a stress ring around the excavation which resists further expansion, and thus establishes equilibrium in the outer rock mass. Inside this stress ring some rupturing will have taken place due to shear and tensile stresses, and weaknesses in the rocks. However, fractured or otherwise, the rock inside the stress ring, due to the free faces of the excavation, is no longer subjected to complete confinement. It is thus in a comparatively relaxed condition as compared with the major compressive stress outside.

The sketch Fig. 2 permits reference to a dome as the indeterminate surface or zone separating the fractured and relaxed zone from the zone of increased stress surrounding the excavation. The dome is thus a simple term to describe an otherwise complex and in practice a rather indefinite condition. If this conception can be regarded as the Doming Theory the writer finds it hard to refute on either practical or theoretical grounds."

Fig. 2

The Apparent Fractured and Relaxed Zones

Dome and Stress Zone



Generalizing on this, Morrison states, " A rockburst is a possibility whenever the variables associated with the growth of a dome, change to a degree where stability demands the reshaping of a single dome or the merging of two or more domes."

(2) Elastic Hysteresis Theory.

Dr. Weiss divides rockbursts into two main types - strain bursts and crush bursts. The strain bursts only affect the immediate walls, when splinters of rock fly from the face and slabs suddenly flake off. They seem greatest where the rock is silicified or flinty in character, giving conchoidal fractures and no perceptible movement of the hanging or the foot wall. The crush bursts are due to substantial forces accumulated in the solid rock due to elastic hysteresis. These bursts originate in the solid rock and affect both the immediate and solid rock remote from excavations.

Weiss states in regard to the nature of major crush bursts that,

" The source of energy is in the solid rock, the action is instantaneous, the energy is very considerable, the movement being in solid rock, must be very small. All that we know about seismology suggests that it is only the elastic hysteresis of rocks that could produce the slowly accumulating stresses, which in rocks like the quartzites of the Rand could produce very high values."

Weiss compares the release of elastic hysteresis stresses as being similar to the action of tectonic earthquakes. Just as buildings are affected by earthquakes, mine workings, where the elasticity of the rock is low and where equilibrium is not firmly established, will be destroyed.

In the case of minor bursts, Weiss states that in individual pillars, the stresses are accumulated inside the pillar by elastic hysteresis, which is influenced by local variations in the distribution of loads.

TESTING PROCEDURE.

Introduction.

Four different tests were performed on each rock type. All specimens within a group were selected as being as near uniform in character as possible and free of all visible planes of weakness. In the tension and compression tests ten or more samples were taken in each suite, while in the torsion and direct shear tests, three or more were taken. To overcome the variables of Temperature and Solution, all the specimens were kept together under the same condition of temperature and humidity.

COMPRESSIVE STRENGTH

General.

The test procedure employed in determining the compressive strength was adapted from the procedure recommended by the U. S. Bureau of Mines.(8). The specimen size available was the EX core, 7/8 " diameter. Tests carried out on different sizes of specimens by the U. S. Bureau of Mines show that the core size does not alter excessively the compressive strength; therefore in this work no compensating factor has been brought in. The U. S. Bureau of Mines did find that the length of the specimen considerably varied the compressive strength. Tests showed that a specimen h 2" = D 2" x gave results equal to tests on a cubic specimen 2" x 2" x 2", but reduction in the compressive strength was found as $h > D$.

Adjustments had to be made by the formula.

$$C_c = \frac{C_p}{0.778 - 0.222D/h} \quad ....(3)$$

where C_c = Compressive strength of an equivalent cubical specimen

C_p = Compressive strength of the specimen having a height greater than the diameter or lateral dimension

D = Diameter or lateral diameter in inches.

h = height in inches.

For the sake of uniformity of tests and in consideration of the above all specimens were made to where h = 2D.

Apparatus.

The Compression machine used was a Baldwin, Tate, Emery Testing Machine, hydraulic type, having three load ranges - namely, 20,000 pounds, 100,000 pounds, and 440,000 pounds. The accuracy within ranges was good to one percent of load. A six inch spherically seated compression block was used on the table of the press and a rigid compression block on the head. Two accurately surface - finished blocks whose faces are parallel are placed top and bottom of the test specimen. The press is equipped with a Tate - Emery Maintainer having a range of 1,000 to 500,000 pounds per minute.

Preparation of Test Specimens.

Specimens, after being cut, were ground flat on a lath, then the ends were polished on a glass plate using aluminum

600 grinding powder. This polishing was carried on until the specimen would lift the plate by suction. The polished ends were then coated with a thin coat of Aquadag and a sheet of .005 " lead foil was placed over the ends before testing. The advantages of the Aquadag coating and lead foil were not proved but it was considered that the two would reduce horizontal friction stresses being set up at the ends.

Test Procedure.

Care was exercised in centering the specimens in the testing machine and the initial load was applied at a low rate to permit adjustment of the spherical compression block so that when the load was applied to the specimen the surface of the plate paralleled the end of the specimen. The loading after the initial low start was kept constant at 4,000 pounds per minute per square inch.

TENSILE STRENGTH.

General.

The American Society for Testing Materials (8) has no prescribed procedure for testing the tensile strength of rocks. The lack of such procedure is probably due to the experimental difficulties encountered in preparing suitable test specimens, in mounting the specimens in tension grips without damaging the surface of the specimen, and in applying the load parallel to the axis of the specimen. It should be pointed out that if the load is not applied axially to the specimen, bending will occur which, in turn, will produce abnormal stress concentrations.

The U. S. Bureau of Mines did perform some tensile tests by setting shoulder grips on specimens with leadite, but this would allow stresses only up to 1200 pounds to be applied.

In endeavoring to find some means of testing rocks in tension, various ideas were tried. Eventually it was found that, by adaptation, a Fairbanks concrete testing machine could be used.

The Tensile Strength of the rock was then found by the formula.

$$C_t = \frac{W \times 100}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

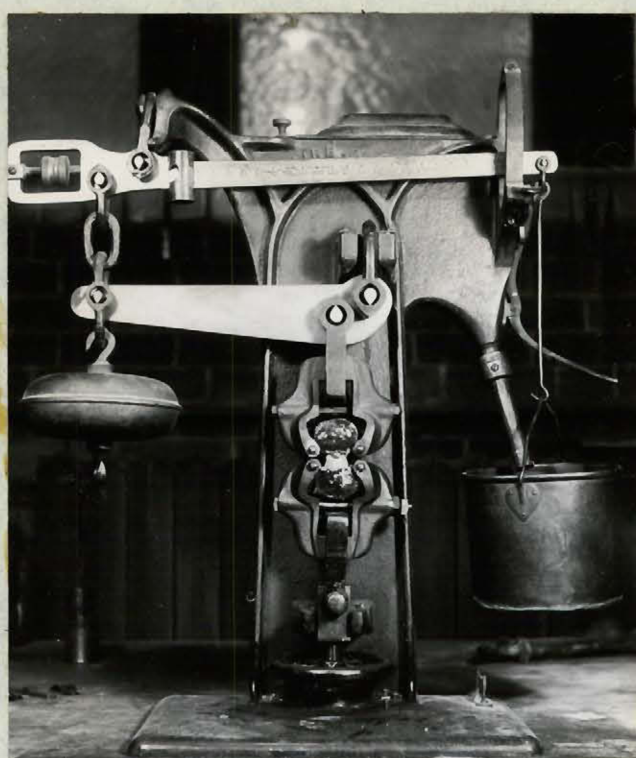
where C_t = tensile strength of the rock tested.

W = weight of lead pellets weighed on lever arm in ounces.

A = cross sectional area of specimen tested.

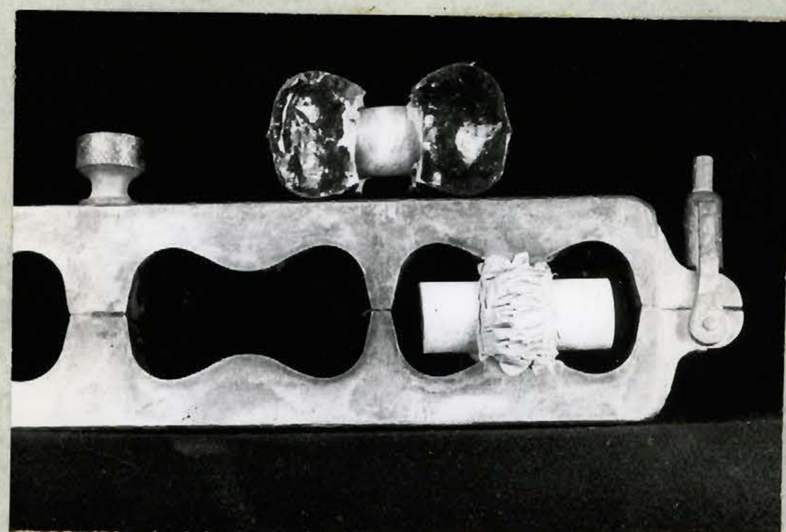
Apparatus.

The tensile machine was a Fairbanks concrete testing machine. Tensile strength was exerted on the spedimens by means of lead shot collecting in a bucket which was connected to the specimen by means of a lever arm.(Photograph 2). The shot was then weighed by means of the same lever arm in ounces, one ounce being equal to 100 pounds tensile stress on the specimen.(Photograph 3). Loading was kept at as near a constant rate as possible.



Photograph No. 2 - Specimen set, stress being applied by lead pellets in bucket acting by levers to givestress to the specimen.

Photograph No. 3 - Specimen broken, lead shot being weighed to determine rupture stress value.



Photograph No. 4

Mold for setting specimens in bakelite cement, specimen inset ready for pouring and resultant setting.

Preparation of Test Specimens.

Specimens were of EX core, 7/8" diameter, and approximately $2\frac{3}{4}$ " long. The center portion, one diameter in length, was covered with plasticine and placed in the mold. (Photograph 4). In the mold the specimen was adjusted to make sure that it lay true to the main axis and in the center of the mold. The mold was then filled with the cementing material. The cementing material was a polyester resin set by Lupersol D. D. M. Catalyst (10), the liquid was thickened by short asbestos fibres. The whole set hard in four hours. This cement has been found to be of sufficient strength to hold all rocks tested, (maximum tested 2,370 pounds / sq. in.)

TORSIONAL STRENGTH.

General.

The test procedure employed in determining the torsional shear strength was adapted from the procedure recommended by Baldwin of the Canadian Ingersoll Rand Company and used by Cameron (10). The specimen size available was EX, $\frac{7}{8}$ " diameter, core. By this method the samples were cemented into machined blocks which fit into the jaw of the torsion machine. The torsional shear strength was determined by the formula.

$$Cg = \frac{W \times 174.65}{A} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

where Cg = the torsional shear strength of the rock in psi.

W = the applied load at point of failure in pounds.

A = the cross sectional area in square inches.

Apparatus.

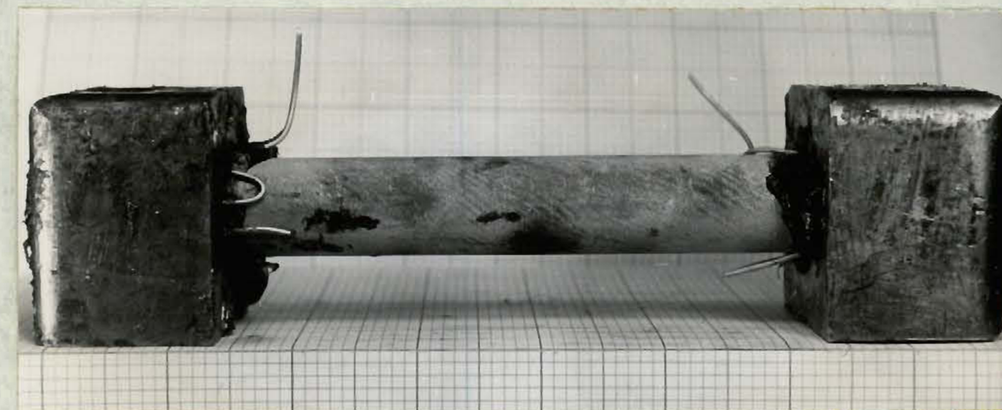
The torsion machine used was a manually operated machine made at McGill University, the load being applied by means of a lever arm arrangement attached to a weighing pan counteracting twist imposed by a manually operated worm gear.

Preparation of Test Sample.

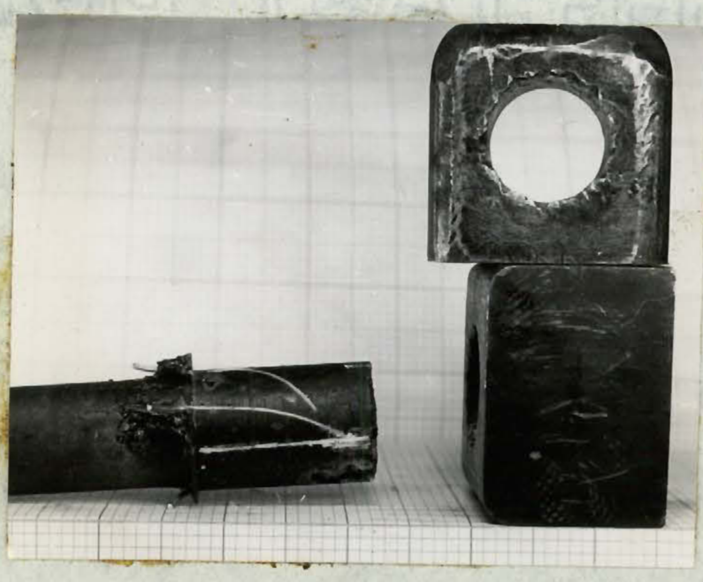
The samples, seven inches long, were thoroughly cleaned with acetone and centrally wedged with wire into the one inch hole in the blocks. The cementing material, a polyester resin set by two percent Lupersol D. D. M. Catalyst (10), and thickened prior to setting to a " would not run " consistency by short asbestos fibre, was then forced between the specimen and the block. The specimen would set hard in four hours. (Photographs 5 & 6).

Test Procedure.

Considerable care was required in setting the blocked specimen in the machine. While the blocks were being inserted the lever arm was left free to swing. Once set and tightened up, the lever arm was brought central by means of the manual torsion wheel. Load was then added in half pound increments to the pan, the lever being brought horizontal after each load increase.



Photograph No. 5 - Specimen set up and ready for insertion into testing machine.



Photograph No. 6 - Specimen extracted from holding blocks after testing.

DIRECT SHEAR

General.

The test procedure employed in determining the direct shear strength was adapted from blueprints sent out by the Ontario Hydro Company. A simplified apparatus was made up in the university workshop which proved to be very satisfactory for the required testing. No record was found for tests of this nature being carried out on mine rocks before.

The tests were carried out in double shear and divided by two to get the direct shear strength.

From the experimental data the single shear strength was calculated from the following formulae:

$$Css = \frac{1}{2} (R / D) \quad \ldots\ldots\ldots\ldots\ldots (6).$$

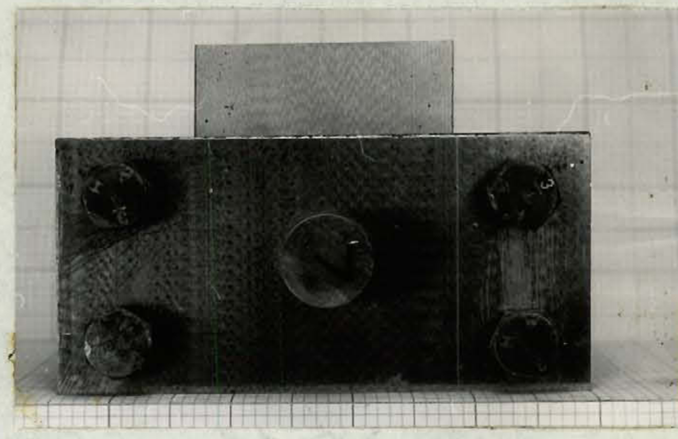
where Css = direct single shear strength

R = load at rupture in pounds.

D = diameter of specimen in inches.

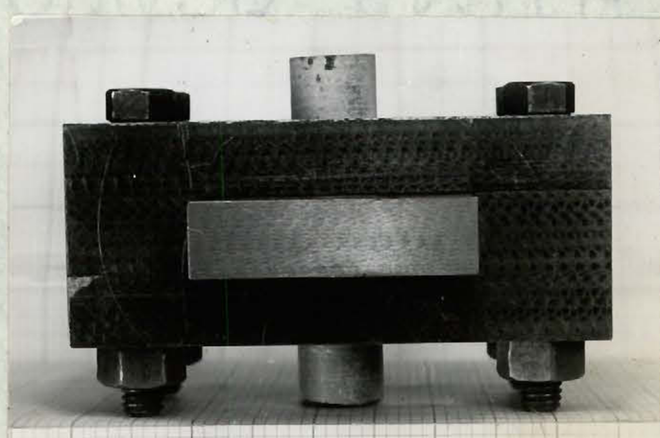
Apparatus.

The apparatus used was made up in the university shops on the specifications of the writer. It consisted of two plates ½ " thick, set apart by blocks, the inside faces being polished. A third plate with polished faces on either side passed between. A hole 0.758 " diameter was drilled through the plates at the middle of the outside pair and in the lower half of the inside plate. (Photographs 7 & 8).



Photograph No. 7

Side View



Photograph No. 8

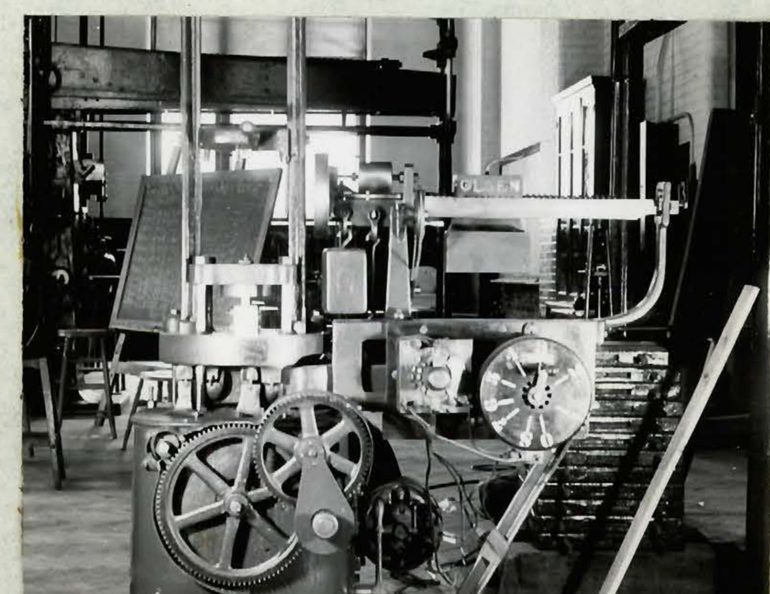
Top View

Preparation of Test Specimens.

Specimens were ground down until they formed a tight fit through the testing block - slackness would have caused bending stresses to be set up and the experiment to be useless.

Test Procedure.

With the specimen fitting tightly in the block, the block is placed in the jaws of a compression machine. Load is applied at a constant rate of 4,000 pounds per minute. (Photograph 9).



Photograph No. 9

Block in place in compression machine

CLASSIFICATION OF FRACTURE TYPES

Not all the specimens of any one rock type failed in the same pattern. For this reason the type of failure was classified into three classes.

Group R. These are specimens which show angles of break consistent with Mohr's theory.

Group S. These are specimens which have failed in vertical fractures under compression or perpendicular to the major principal plane in tension. Two theories are presented to account for this vertical fracturing; some specimens show a great inclination for one, some for the other. Griggs (15) suggests that the splitting effect of a wedge would cause tensional failure along the vertical fracture. This is supported by several specimens which show a wedging effect, and considerable grinding on the wedge faces. Brandtzaeg (14) suggests from experimental work by Karman and Boker (15) that splitting failure occurs where tensile stress has been produced above a limiting value by irregular plastic deformation in a heterogeneous material. These stresses causing cracks running parallel to the direction of the principal compressive stress. Several specimens tested have failed wholly by vertical fractures throughout; one specimen, no. 18, broke explosively into fourteen pieces, each showing vertical splitting with no wedging effect.

Group T. These are specimens where a weakness has influenced the break or angle of break.

LAKE SHORE TUFF

COMPRESSION

Ex. No.	Sample No.	D in.	A sq. in.	Failure lbs	Cp psi.	Cc psi.	Rock Type	Fracture Type
17	12	.905	.645	20,000	31,000	34,600	B_1	S
18	12	.905	.645	27,000	42,200	47,200	B_1	S
38	2	.905	.645	25,000	39,000	43,800	B_1	S
39	2	.905	.645	27,200	42,500	47,000	C_1	S
40	14	.910	.65	20,700	33,400	37,000	B_1	S
61	38	.910	.65	26,800	41,800	47,000	B_1	S
62	33	.910	.65	26,500	41,300	46,300	B_1	S
124	34	.895	.632	14,500	23,000	26,000	A_1	S
125	34	.895	.632	14,100	22,400	25,100	A_1	S
126	34	.895	.632	16,500	26,200	29,300	A_1	S
127	34	.895	.632	16,700	26,500	29,700	A_1	S

Average Value Type A_1 27,500

Average Value Type B_1 43,750

Average Value Type A_1, B_1 & C_1 38,300

Table 1

LAKE SHORE TUFF

TENSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Ct psi.	Rock Type	Fracture Type	Angle degree
36	2	.902	.640	972	1,520	C,	S	
37	14	.902	.640	1,050	1,640	B,	S	
45	33	.910	.650	1,075	1,700	B,	S	
46	33	.910	.650	1,375	2,100	B,	R	10
47	38	.910	.650	1,350	2,070	B,	S	
48	41	.910	.650	815	1,260	A,	R	15
83	42	.900	.638	790	1,240	A,	R	22
91	37	.900	.638	720	1,125	B,	R	18
92	37	.900	.638	695	1,090	B,	R	25
100	43	.908	.646	990	1,530	B,	R	18

Average of Group Test A, 1,250

Average of Group Test B, 1,600

Average of Group Test A, B, & C, 1,325

Table 2

LAKE SHORE TUFF

TORSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cg psi.	Rock Type	Fracture Type	Angle degree
128	38	.904	.638	cement bonding failed first				
148	35	.904	.638	8	2,200	x	T	
167	19	.902	.640	12½	3,450	A_1	R	31-60
165	44	.902	.640	12	3,300	B_1	R	39-45

Average of Group Type A_1 3,450 psi.

Average of Group Type B_1 3,300 psi.

Average of Group Type A_1, B_1 & C_1 3,370 psi.

x Break followed a short plane of weakness in the rock.

Table 3

LAKE SHORE TUFF

DIRECT SHEAR

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cds psi.	Css psi.	Rock Type
149	45	.757	.450	3,970	8,850	4,425	A_1
150	45	.755	.450	3,095	6,800	3,400	A_1
156	43	.743	.436	1,967	4,500	2,250	x
176	13	.750	.440	3,087	7,000	3,500	B_1
172	40	.750	.440	3,660	8,350	4,175	A_1

Average of Group Type A_1 4,000 psi.

Average of Group Type B_1 3,500 psi.

Average of Group Type A_1,B_1 & C_1 3,875 psi.

x The size of the specimen was such that bending stresses were set up prior to direct stresses. The specimen was therefore eliminated from calculation.

Table 4

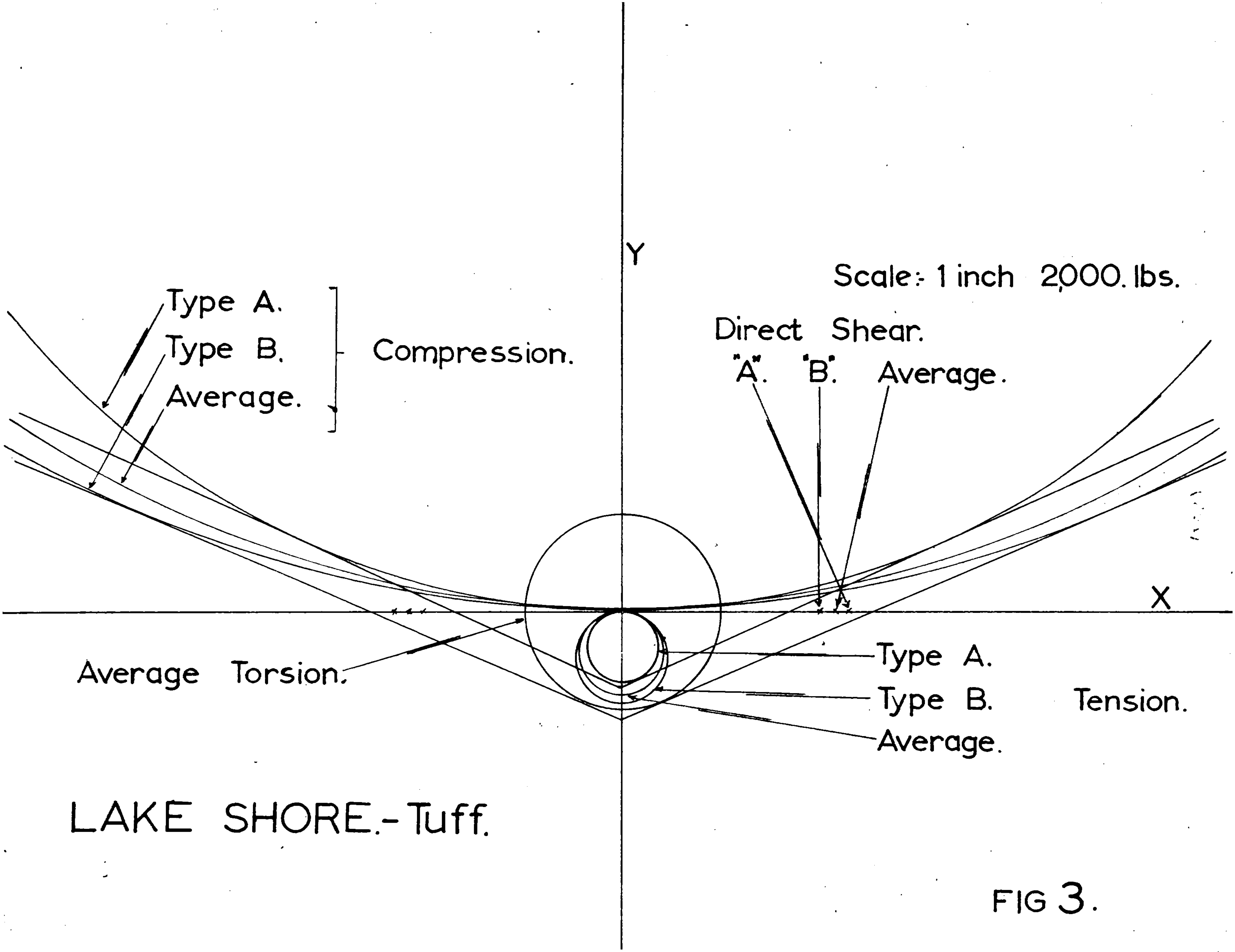

Y
X
Scale:- 1 inch 2,000. lbs.
Type A.
Type B.
Average.
Compression.
Direct Shear.
"A". "B". Average.
Average Torsion.
Type A.
Type B.
Average.
Tension.
LAKE SHORE.-Tuff.

FIG 3.

LAKE SHORE TUFF - Discussion of Results

The Lake Shore Tuff petrographically falls into two groups. The A_1 type, less altered and fine grained, is distinctly weaker than the B_1 type, which is more altered and coarser grained; intermediate types grade from one to the other, but have not been tested. Graphically, the main envelope for each type has been drawn. The angles of the two envelopes are very close. In compression, the rupture planes were all vertical,(Group S). A fuller geological description of the rock can be found in Appendix A.

LAKE SHORE SYENITE PORPHYRY

COMPRESSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure No. lbs.	Cp psi.	Cc psi.	Rock Type	Fracture Type	Angle degree
1	25	.894	.630	19,600	31,000	34,800	B_2	S	
2	25	.894	.630	20,000	31,800	35,700	B_2	S	
57	59	.910	.650	27,400	42,000	47,100	C_2	S	
58	59	.910	.650	28,700	44,200	49,500	A_2	R	70 & 30
59	59	.910	.650	27,300	42,000	47,100	A_2	R	25 & 55
60	51	.910	.650	26,500	40,800	45,800	A_2	S	
63	53	.900	.638	28,000	44,000	49,400	A_2	S	
64	53	.900	.638	26,500	43,000	48,200	B_2	S	
119	52	.894	.630	26,000	41,200	46,200	A_2	S	
120	52	.894	.630	24,500	38,400	43,100	A_2	S	
121	52	.894	.630	26,500	42,000	47,000	A_2	S	
122	52	.894	.630	20,500	32,500	36,500	A_2	S	
123	52	.894	.630	8,000	12,700	14,200	x	T	

Average of Group Type A_2 45,600

Average of Group Type B_2 39,600

Average of Group Type A_2 B_2 & C_2 44,200

x Specimen failed along smooth surfaced plane at 25 degrees to plane of major stress.

Table 5

LAKE SHORE PORPHYRY

TENSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Ct psi.	Rock Type	Fracture Type	Angle degree
31	29	.902	.640	1,340	1,340	B_2	R	10
32	29	.902	.640	1,065	1,670	B_2	R	15
50	60	.910	.650	1,050	1,620	B_2	R	12
51	54	.910	.650	1,340	2,050	A_2	R	15
78	53	.900	.638	1,550	2,450	A_2	S	
88	57	.900	.638	1,362	2,130	A_2	S	
89	57	.900	.638	1,310	2,050	B_2	R	10
90	57	.900	.638	1,120	1,770	A_2	R	15
98	53	.908	.646	1,490	2,300	A_2	S	
99	53	.908	.646	1,670	1,670	A_2	R	15

Average of Group Type A_2 2,055 psi.

Average of Group Type B_2 1,670 psi.

Average of Group Type A_2, B_2 & C_2 1,900 psi.

TABLE 6

LAKE SHORE PORPHYRY

TORSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cg psi.	Rock Type	Fracture Type	Angle degree
87	54	.900	.638	20	5,200	B_2	R	15-35
154	47	.902	.640	17	Cement bonding failed first			
166	28	.902	.640	17½	4,780	B_2	R	28-65
181	20	.900	.640	17	4,670	A_2	R	30-45

Average of Group Type A_2 4,670

Average of Group Type B_2 4,990

Average of Group Type A_2 B_2 & C_2 4,880

Table 7

LAKE SHORE PORPHYRY

DIRECT SHEAR

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cds psi.	Css psi.	Rock Type
139	58	.747	.435	2,762	6,350	3,175	B_2
140	58	.749	.434	1,547	3,400	1,700	x
141	58	.750	.440	3,120	7,100	3,550	A_2
157	51	.753	.445	3,760	8,500	4,250	A_2
162	48	.750	.442	3,337	7,525	3,760	A_2
173	27	.750	.440	3,660	8,300	4,150	B_2

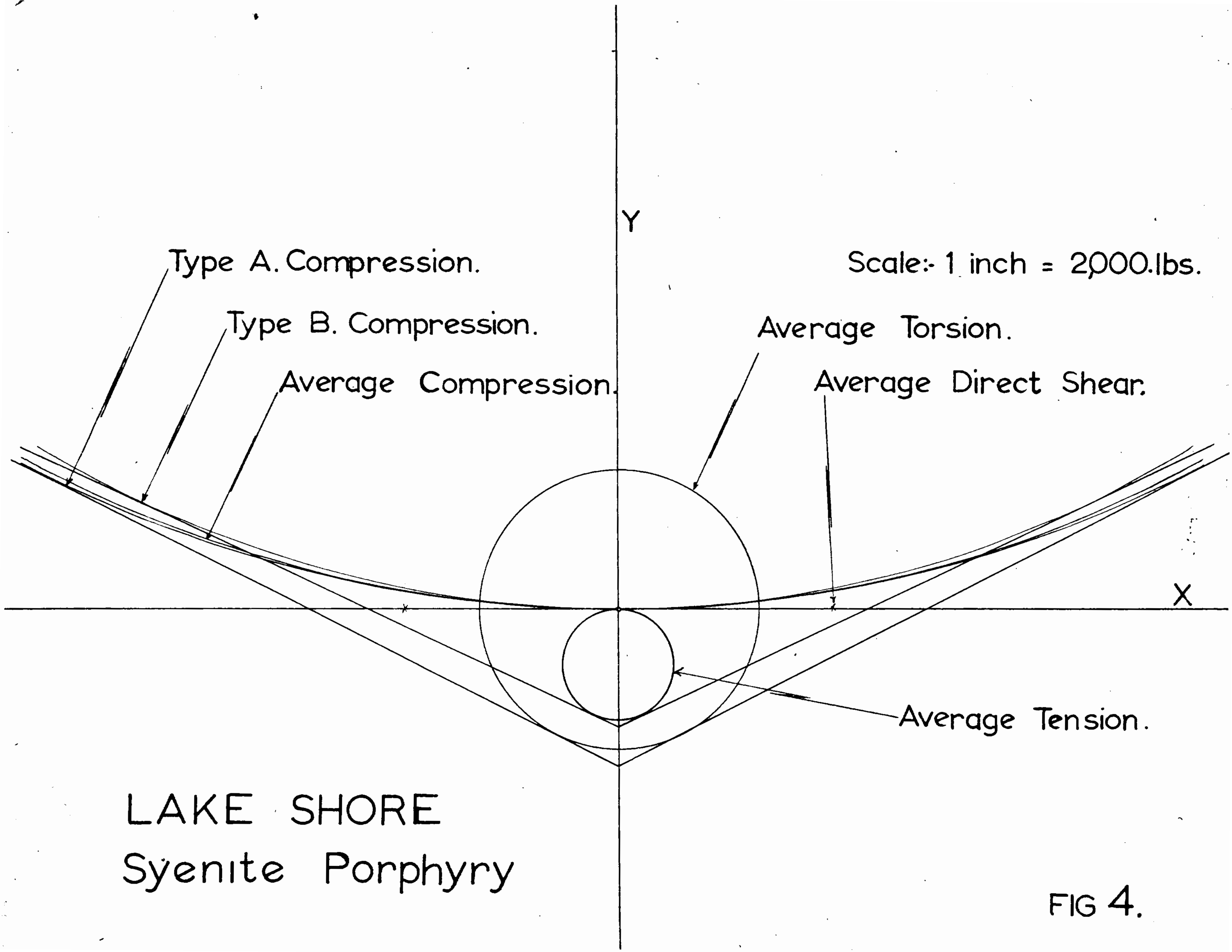
Average of Group Type A_2 3,850 psi.

Average of Group Type B_2 3,662 psi.

Average of Group Type A_2, B_2 & C_2 3,777 psi.

x specimen broke prematurely due to bending stresses as specimen was too loose in hole.

Table 8


Y
X
Type A. Compression.
Type B. Compression.
Average Compression.
Scale:- 1 inch = 2,000.lbs.
Average Torsion.
Average Direct Shear.
Average Tension.
LAKE SHORE
Syenite Porphyry
FIG 4.

LAKE SHORE PORPHYRY - Discussion of Results.

The porphyry, like the tuff, shows a tendency towards vertical fracture in compression. Only two compression specimens show angles of break consistent with Mohr's theory,(Group R). In compression, these specimens with phenocrysts, type B_2, have a slightly lower value than the more equigranular specimens, type A_2. In tension, type B_2 values are slightly higher. In torsion and direct shear, the phenocrysts appear to have little effect on the rupture value. Graphically, the tension circle falls within the torsion circle. A minimum envelope is drawn from the tension circle to the minimum compression circle, and from the torsion circle to the maximum compression circle. The values for direct shear seem low in either case. The Lake Shore Porphyry is described fully in Appendix A.

NUNDYDROOG - AMPHIBOLITE

COMPRESSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cp psi.	Cc psi.	Rock Type	Fracture Type	Angle degrees
143	98	.880	.610	13,500	22,200	24,700	B_3	R	21
4	98	.880	.610	26,500	43,500	49,000	B_3	S	
5	98	.880	.610	22,900	37,500	42,000	B_3	S	
6	98	.880	.610	7,500	12,400	14,000	x	T	
7	98	.880	.610	26,600	44,000	49,300	B_3	S	
8	98	.880	.610	17,800	29,200	32,700	B_3	S	
73	95	.925	.675	28,200	41,500	46,500	x	T	
74	95	.925	.675	23,800	35,500	40,000	x	T	
75	102	.880	.612	15,900	23,500	26,400	B_3	R	35
114	43	.900	.635	14,600	22,700	25,400	A_3	R	32
115	43	.900	.635	27,000	42,000	47,000	A_3	S	
116	43	.900	.635	28,500	44,300	49,600	A_3	S	
117	43	.900	.635	39,400	61,000	68,300	A_3	S	
118	43	.900	.635	30,200	47,000	52,800	A_3	R	34

Average of Group Type A_3 50,500

Average of Group Type B_3 37,300

Average of Group Type A_3 & B_3 43,400

x Weakness planes cutting smoothly through the centre of specimens at 0 and 20 degrees.

Table 9

NUNDYDROOG - AMPHIBOLITE

TENSION

Ex. No.	Sample No.	D in.	A sq. in.	Failure lbs.	Ct psi.	Rock Type	Fracture Type	Angle degree
23	97	.920	.670	1,382	2,050	B_3	S	
24	95	.920	.670	1,142	1,720	A_3	R	15
25	95	.920	.670	873	1,300	x	T	
26	95	.920	.670	1,114	1,660	A_3	S	
49	87	.885	.610	440	780	B_3	S	
101	95	.900	.635	825	1,300	A_3	R	18
102	95	.900	.635	780	1,200	A_3	R	xx
93	95	.918	.660	1,570	2,370	A_3	R	60
94	95	.918	.660	880	1,360	A_3	S	

Average of Test Group A_3 1,600

Average of Test Group B_3 1,400

Average of Test Group A_3 & B_3 1,550

x fine calcite veins across the break

xx angle too irregular to measure

Table 10

NUNDYDROOG - AMPHIBOLITE

TORSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cg psi.	Rock Type	Fracture Type	Angle degree
86	87	.925	.675	9	2,340	A_3	R	40-62
95	100	.925	.675	9	2,340	B_3	T	
177	46	.917	.675	9½	2,480	A_3	R	25-55

Average of Group Type A_3 2,410

Average of Group Type B_3 2,340

Average of Group Type A_3 & B_3 2,390

Table 11

NUNDYDROOG - AMPHIBOLITE

DIRECT SHEAR

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cds psi.	Css psi.	Rock Type
145	44	.750	.442	2,595	5,850	2,925	x
146	44	.753	.445	3,735	8,375	4,187	B_3
158	73	.750	.442	2,395	5,425	2,710	B_3
159	73	.751	.443	3,585	8,100	4,050	B_3
160	73	.750	.442	2,790	6,300	3,150	B_3
168	40	.750	.442	4,110	9,300	4,650	A_3
169	40	.750	.442	2,870	6,500	3,250	A_3

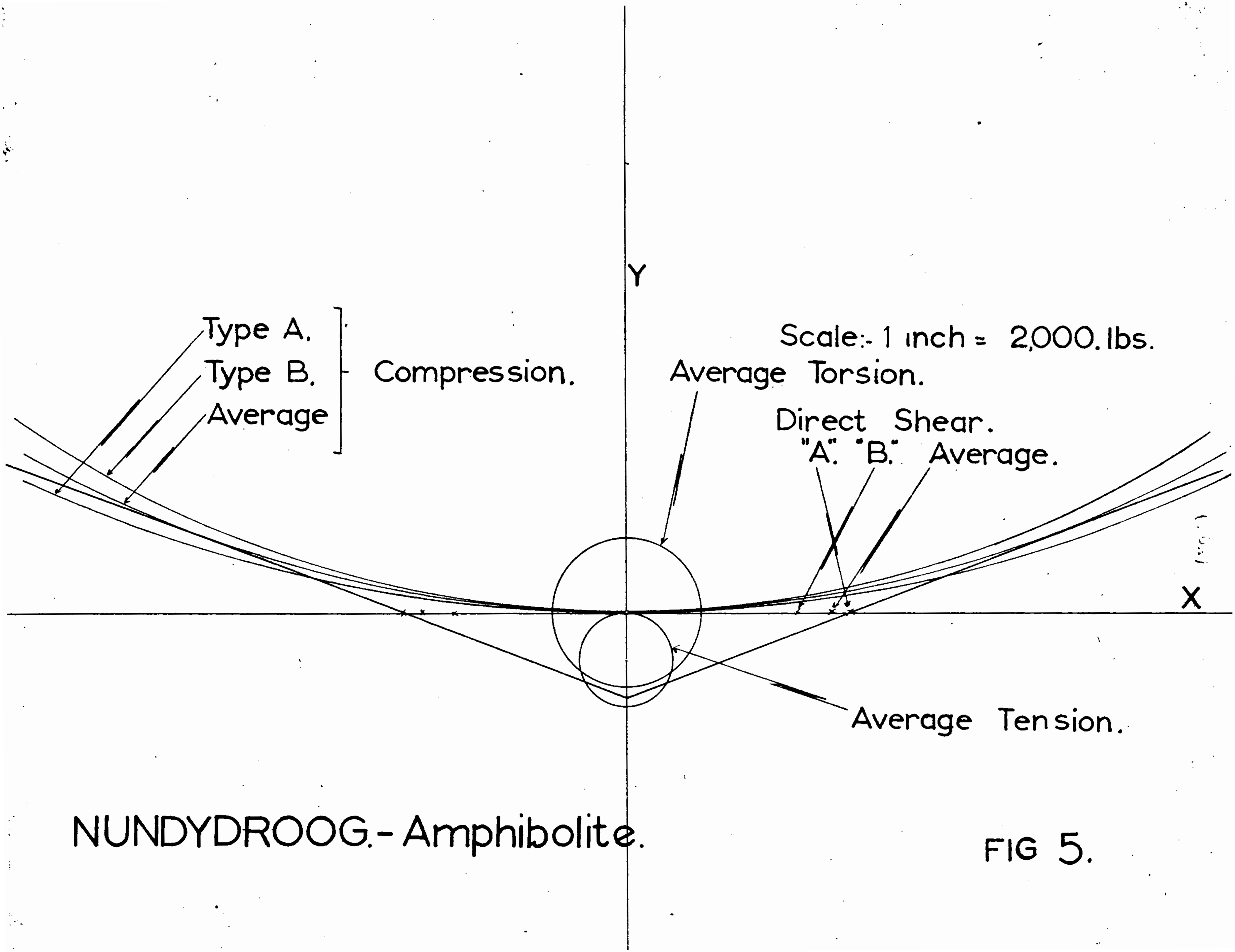
Average of Group Type A_3 3,950 psi.

Average of Group Type B_3 3,525 psi.

Average of Group Type A_3 & B_3 3,665 psi.

x specimen broke due to bending stresses as specimen was too close in block.

Table 12



Y
X
Type A.
Type B.
Average
Compression.
Scale:- 1 inch = 2,000. lbs.
Average Torsion.
Direct Shear.
"A". "B". Average.
Average Tension.
NUNDYDROOG.- Amphibolite.

FIG 5.

NUNDYDROOG AMPHIBOLITE - Discussion of Results.

The Amphibolites were divided by texture, type A3 being coarser than type B3. The fine grained and more compact rock produced so wide a range of values in compression that their average has little meaning. For this reason, only one envelope has been drawn on the graph, which is the most probable one for the results. A geological description of the Nundydroog Amphibolite is given in Appendix A.

KERR ADDISON GREEN CARBONATE

COMPRESSION

Ex. No.	Sample No.	D in.	A sq.in	Failure lbs.	Cp psi.	Cc psi.	Rock Type	Fracture Type	Angle degree
15	18	.900	.640	7,000	11,000	12,400	B_4	R	11&20
16	16	.900	.640	4,760	7,300	8,200	x	T	-
56	20	.910	.650	9,200	14,200	16,000	B_4	R	19&29
55	20	.910	.650	7,200	11,000	12,400	B_4	R	30
53	17	.910	.650	13,960	20,000	22,500	A_4	R	21&45
54	17	.910	.650	5,000	7,700	8,650	x	T	
70	57	.850	.612	10,600	17,300	19,400	B_4	R	15&25
71	57	.880	.612	13,800	22,500	25,300	B_4	S	
72	57	.880	.612	12,800	21,000	25,500	B_4	R	18&25
76	55	.880	.612	11,400	18,600	20,800	B_4	R	25
77	55	.880	.612	12,700	20,800	23,400	B_4	R	33

Average of Group Type A_4 22,500

Average of Group Type B_4 15,800

x compression fracturing followed along bedding structure of quartz stringers

Table 13

KERR ADDISON GREEN CARBONATE

TENSION

Ex. NO.	Sample No.	D in.	A sq.in	Failure lbs.	C_t psi.	Rock Type	Fracture Type	Angle degree
27	28	.902	.640	168	263	B_4	R	15
28	28	.915	.660	226	354	B_4	R	30
29	28	.915	.650	182	285	B_4	S	
43	56	.910	.650	205	315	B_4	R	35
44	20	.910	.650	248	380	B_4	R	45
131	27	.904	.644	360	560	A_4	R	30
132	27	.904	.644	810	1,260	A_4	R	47
133	36	.904	.644	360	560	A_4	S	
134	36	.904	.644	180	270	x	T	
135	69	.885	.615	305	500	A_4	R	30

Average Value of Group Test A_4 950

Average Value of Group Test B_4 359

x fractured along border weakness of quartz and green carbonate for 2/3 of specimen.

Table 14

KERR ADDISON GREEN CARBONATE

TORSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cg psi.	Rock Type	Fracture Type	Angle degree
129	70	.885	.613	8.5	2,420	A_4	R	40-58
130	64	.885	.613	8.0	2,280	A_4	R	35-55
164	67	.883	.612	8.0	2,280	A_4	R	36-54

Average of Group Type A_4 2,330 psi.

Table 15

KERR ADDISON GREEN CARBONATE

DIRECT SHEAR

Ex, No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cds psi.	Css psi.	Rock Type
136	39	.745	.433	1,481	3,425	1,712	A_4
137	39	.745	.433	2,230	5,150	2,575	x
138	71	.752	.444	1,435	3,250	1,625	A_4
161	36	.750	.442	2,740	6,200	3,100	A_4

Average of Group Test A_4 2,150

x Intermittent failure building up inside ; again specimen was crushed, not sheared.

Table 16

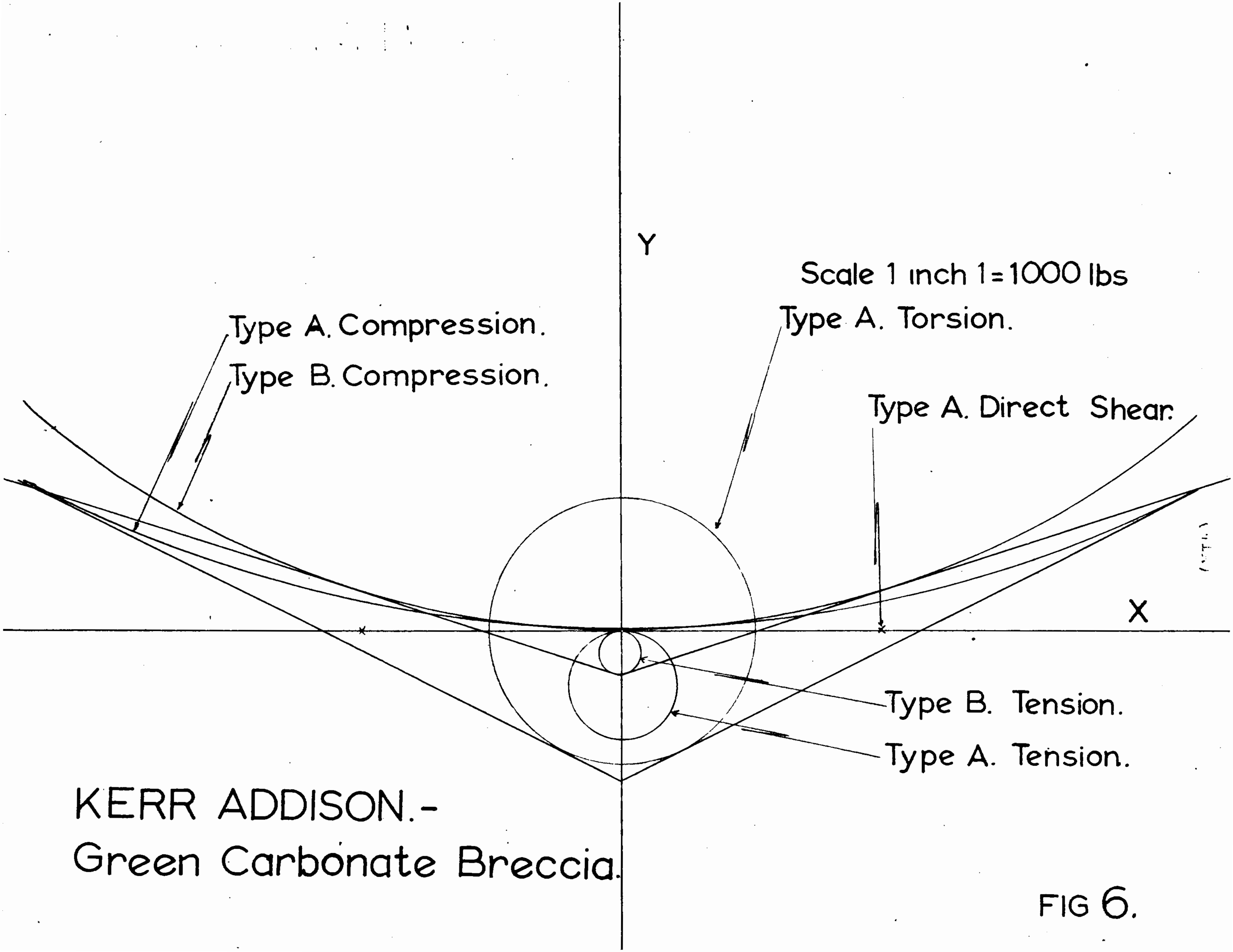

Y
Scale 1 inch 1=1000 lbs
Type A. Compression.
Type B. Compression.
Type A. Torsion.
Type A. Direct Shear.
X
Type B. Tension.
Type A. Tension.
KERR ADDISON.-
Green Carbonate Breccia.

FIG 6.

KERR ADDISON GREEN CARBONATE - Discussion of Results.

Classification within the green carbonate was by the intensity of green of carbonate minerals. Type A_4 was olive green in colour and the rock was well bonded; type B_4 was deeper green and the bonding was weaker. Values occur over a wide range, and little reliance can thus be placed upon individual or average results. Graphically, the tension circles fall well within the torsion circle. The envelope from the torsion circle to the maximum compression circle gives an angle ϕ of 62.5, similar to that for the McIntyre Carbonated Lavas. A mean envelope angle ϕ of 67.5 is similar to that of the Lake Shore Porphyry. Most of the specimens failed at an angle which could be in agreement with Mohr's theory. A full description of the Kerr Addison Green Carbonate is to be found in Appendix A.

COMPRESSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Cp psi.	Cc psi.	Rock Type	Fracture Type	Angle degree
9	12	.835	.550	11,100	20,000	22,400	As	R	53
10	12	.835	.550	12,500	22,400	25,200	As	R	54
20	17	.835	.550	3,900	7,000	7,900	x	T	
21	17	.835	.550	7,160	12,800	14,400	Bs	R	20
22	4	.835	.550	6,220	11,200	12,600	As	S	
65	23	.835	.550	7,700	13,200	14,800	Cs	R	25
66	23	.835	.650	7,700	13,200	14,800	As	S	
67	23	.835	.550	6,200	11,300	12,700	Bs	S	
68	23	.835	.650	8,900	16,200	18,400	As	R	25
69	23	.835	.550	5,800	10,600	11,900	Cs	S	
103	16	.835	.550	12,700	22,800	25,700	As	R	35 & 50
104	16	.835	.550	9,500	17,100	19,200	As	R	23 & 28
105	16	.835	.650	4,900	8,800	9,850	x	T	

Average of Group Test As 18,300

Average of Group Test Bs 13,550

Average of Group Test Cs 13,350

Average of Group Test As, Bs & Cs 16,550

x Incorrect placimg in machine caused concentration at top right and bottom left of specimen and failure of these parts.

Table 17

McINTYRE CARBONATED LAVA

TENSION

Ex. No.	Sample No.	D in.	A sq.in	Failure lbs.	Ct psi.	Rock Type	Fracture Type	Angle degree
33	4	.835	.550	1,030	1,870	B_{ς}	R	xx
79	22	.835	.550	580	1,050	A_{ς}	R	xx
80	22	.835	.550	590	1,050	C_{ς}	R	30
81	22	.835	.550	700	1,260	A_{ς}	R	30
82	23	.835	.550	685	1,240	A_{ς}	S	
96	22	.835	.550	620	1,140	B_{ς}	R	xx
97	23	.835	.550	630	1,150	A_{ς}	R	xx
34	4	.835	.550	180	417	x	T	
35	4	.835	.550	165	300	x	T	

Average of Test Group A_{ς} 1,175 psi.

Average of Test Group B_{ς} 1,500 psi.

Average of Test Group C_{ς} 1,050 psi.

Average of Test Group A_{ς}, B_{ς} & C_{ς} 1,240 psi.

x rupture following bedding planes

xx rough fracture angle measurement irregular

Table 18

McINTYRE CARBONATED LAVA

TORSION

Ex. No.	Sample No.	D in.	A sq.in.	Failure lbs.	Og psi.	Rock Type	Fracture Type	Angle degree
147	12	.840	.700	7	1,225	x	T	
153	12	.840	.700	14	2,450	C_s	R	32-50

Average of Group Type C_s 2,450

x Specimen broke along weakness plane at 30 degrees.

Table 19

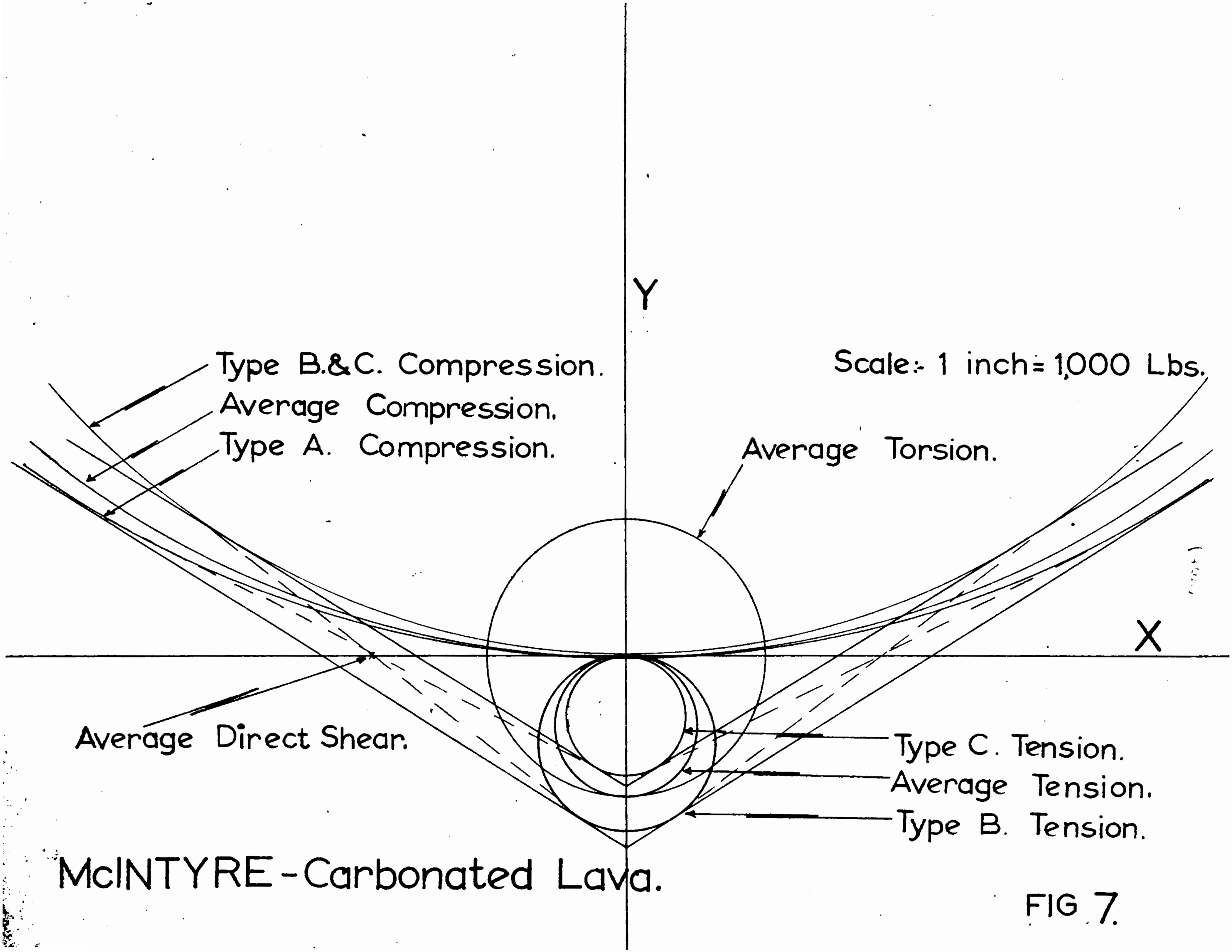
McINTYRE CARBONATED LAVA

DIRECT SHEAR

Ex. No.	Sample No.	D in.	A sq.in	Failure lbs.	Cds psi.	Css psi.	Rock Type
151	7	.757	.450	1,475	3,275	1,637	C_5
152	7	.757	.450	2,332	5,100	2,550	C_5
144	11	.750	.442	2,405	5,475	2,737	C_5
163	12	.753	.445	2,132	4,800	2,400	C_5

Average of Group Type C_5 2,330 psi.

Table 20



McINTYRE - Carbonated Lava.

FIG 7.

MCINTYRE CARBONATED LAVA - Discussion of Results.

In no case were the differences in the rock types very marked petrographically. Some specimens showed a little pyrite mineralization,(type A5), some a few residual quartz nodules,(type B5), and some neither, (type C5). In compression, type A5 showed a greater strength than the others. This increase in strength may be due to further hardening when the mineralizing solutions were injected into the rock. Insufficient rock samples were available to perform as many torsion tests as would have been desirable. In the graphical interpretation, envelopes were drawn from maximum to maximum, and minimum to minimum instead of rock type to rock type, the difference in rock types being neglected. Extreme envelopes were drawn in dotted lines. Geological description of the McIntyre Carbonated Lava are found in Appendix A.

SUMMARY OF RESULTS

ROCK TYPE	CLASS	COMPRESSION	TENSION	TORSION	DIRECT SHEAR
Lake Shore Tuff	A	27,500	12,500	3,450	4,000
	B	43,750	1,600	3,300	3,500
	Ave.	38,300	1,900	4,880	3,875
Lake Shore Porphyry	A	45,600	2,055	4,670	3,950
	B	39,600	1,670	4,990	3,525
	Ave.	44,200	1,900	4,880	3,665
Nundydroog Amphibolite	A	50,500	1,600	2,410	3,950
	B	37,300	1,400	2,340	3,525
	Ave.	43,400	1,550	2,390	3,665
Kerr Addison Green	A	22,500	950	2,330	2,150
Carbonate Breccia	B	15,800	359		
McIntyre Carbonated	A	18,300	1,175		
Lava	B	13,550	1,500		
	C	13,350	1,050	2,450	2,330
	Ave.	16,550	1,240	2,450	2,330

Table 21

SUMMARY OF ANGLE AVERAGES

ROCK TYPE	MOHR'S GRAPHICAL ANGLES		EXPERIMENTAL ANGLES					
			Compression	Tension		Torsion		Average
	ϕ	α	α	Meas.	α	Meas.	α	α
Lake Shore Tuff	67.5	79	66	33	57	(37)-56	79	67
Lake Shore Porphyry	65.5	78	-	18	72	(35)-53	82	78
Nundydroog Amphibolite	70	80	60	31	59	(32)-59	76	65
Kerr Addison Green Carbonated Breccia	67.5	79	59	30	60	(32)-50	85	68
McIntyre Carbonated Lava	62. 5	77	42	13	77	(24)-48	87	62

Table 22

CONCLUSIONS.

Mohr's Theory, from a graphical interpretation of the stresses causing failure, will produce an angle ϕ which is the angle of sliding friction. According to experiments by Tschebottarioff (13), the highest angle attained for sliding friction of any material was 42.5 degrees for quartz on quartz wet, while dry the angle was reduced to 11 degrees.

According to Mohr's concept of failure, the resistance to failure on any plane is the result of cohesion and sliding friction. From Tschebottarioff's experiments the angle of maximum sliding friction was found to be 42.5 for wet quartz. The maximum α for sliding friction would be 66 degrees. Because the angles of α produced in this investigation were usually substantially higher, the concept of sliding friction alone is not adequate. The effect of interlocking friction has to be brought into the picture. Extension of the theory towards the failure envelope to cover the combined angle of sliding and interlocking friction is supported by this investigation.

In the experimental work performed, the angle measured is a combination of the effects of the sliding friction and the interlocking friction. The angle α, the angle at which a mass should fail, is a function of ϕ. The angle α produced graphically and experimentally, is therefore related to the ϕ of the total internal friction. The graphical angles for α have a maximum deviation of 6%, while those found experimentally deviate a little more. The averages of each show that the experimental angles α are approximately 10% lower when compared to the graphical angles. (Table 22).

Assuming this to be so, the possible effect of confinement upon the compressive strength of the rocks is shown in Fig.(8). The envelopes of the graphical angles ϕ are drawn, and compression circles for 5,000, 10,000, and 20,000 pounds confinement are then drawn to touch the envelopes. A small increase in the angle of the envelope causes a large increase in the possible compressive strength of the rock under confinement. In this connection, it will be noticed that Kerr Addison has a higher angle, and thus a possible higher compressive strength under confinement than the Lake Shore Porphyry. It is understood that in the laboratory the effect of a plane of weakness upon a test specimen will differ under the different tests applied, and that a plane of weakness in a compression test is liable to be closed, and its effect minimized, while the same plane of weakness, in tension be opened, and its effect exaggerated. In the case of the Kerr Addison rocks, considerable rupture occurred around the boundaries of mineral masses. It is therefore suggested that the tension and torsion results for the Kerr Addison Green Carbonates, are lower than their true figure, causing a higher relative angle of envelope.

CONFINEMENT CIRCLES

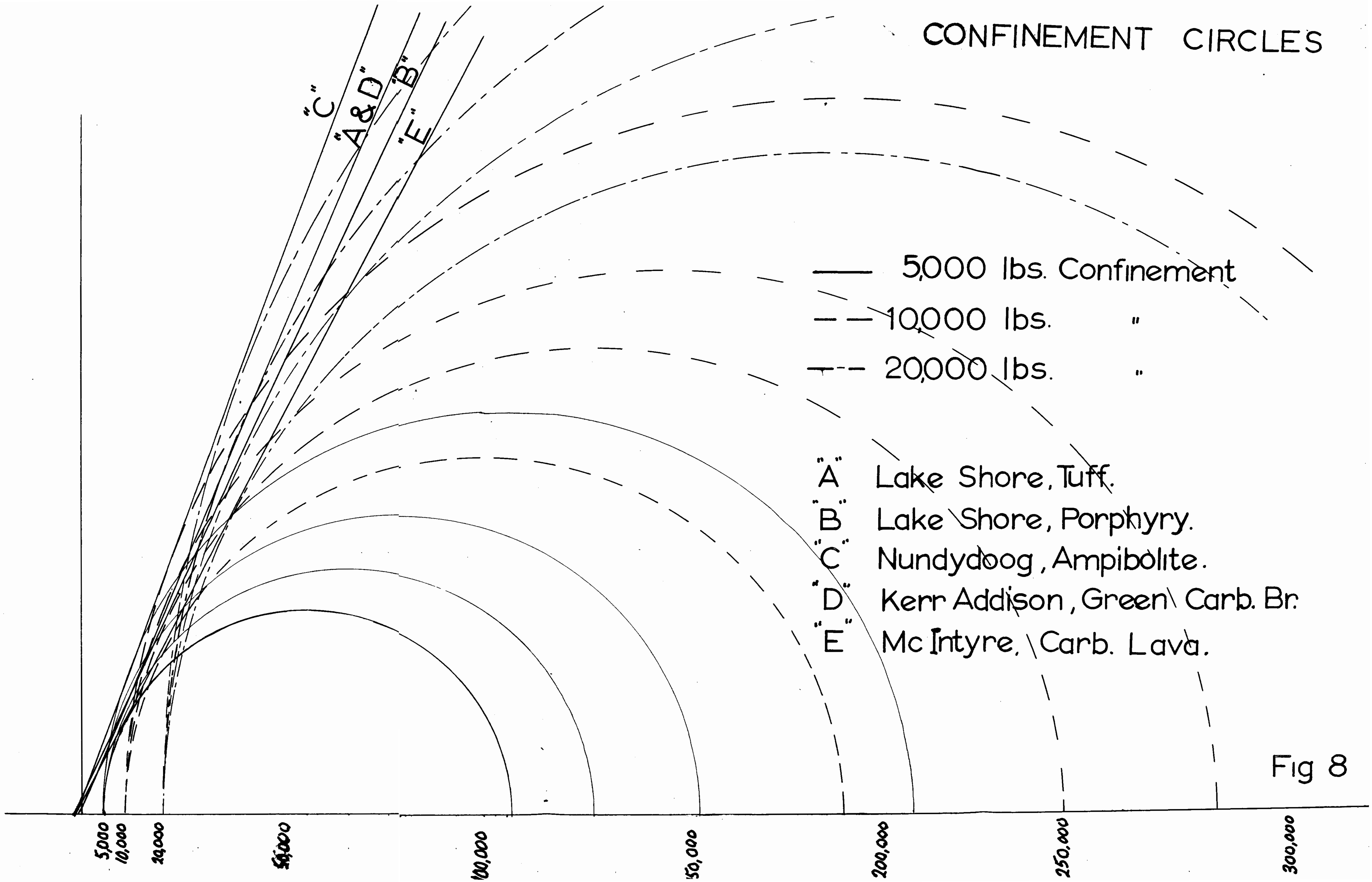


Fig 8

As there are no means available to measure the actual confinement upon a test specimen, it cannot be accurately determined whether the envelope continues as a straight line, or whether it curves downward to allow rupture under confinement to occur at a lower value than is demonstrated in Fig. 8. It would also be noticed that the higher the envelope angle, the less confinement is required to bring the rock into a state of fluid flow under which no opening is possible. It has been shown that the experimental angles are lower than the graphical angles, but it still can be seen that a hard, brittle and strong rock like the Lake Shore Porphyry will have a considerably higher angle than the McIntyre Carbonated Lava. It is suggested that it would therefore have a far higher rockburst potential than the lower angled rock under the same confining conditions.

Even though, in compression, a rock type may fail in different fractional patterns, the resultant rupture stress does not vary. It is indicated that the hard brittle rocks show a greater tendency towards vertical fracturing, while the softer, more plastic rocks tend towards an angular failure comparable to Mohr's theory. It is concluded that the resistance to deformation is responsible for the type of failure encountered.

ACKNOWLEDGEMENTS

The laboratory investigations as reported herein were conducted at McGill University and the writer desires to express his appreciation for the assistance and cooperation received, particularly from the Departments of Civil Engineering and Geological Sciences.

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Special mention should be made of the assistance received from Dr. Gill of the Geological Department, and Professor V. W. G. Wilson of the Civil Engineering Department.

It is also desired to thank Mr. J. Baker, Chief Geologist of Kerr Addison Gold Mines, for his advice and encouragement.

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APPENDIX A

GEOLOGICAL DESCRIPTION OF ROCK TYPES

GEOLOGICAL DESCRIPTIONS.

Introduction.

Mine rocks are usually highly altered, generally by hydrothermal solutions. The five rock types chosen for this paper are no exception - if anything they may be criticized for being excessively altered.

Each rock type was studied separately from a petrological standpoint and each specimen after testing was re-examined to fit it into smaller groups within each rock type.

Thin sections were made of each rock type. These were compared and discussed with geologists on the mines concerned where possible.

Lake Shore Tuff.

The first suite of specimens taken in this investigation are samples of altered tuff composed principally of water-lain volcanic ash, interbedded between lava flows. The specimens were taken from Lake Shore Mines at Kirkland Lake, Ontario. Todd (2) placed the formation as one of the oldest members of the Timiskamian series.

The rock is highly altered and none of the original minerals are identifiable, although in some sections certain fragments show vague outlines, resembling crystals of ferromagnesian minerals. The present rock varies from a fine grained, chloritic material, dark grey in colour, to a coarser grained, more altered material, reddish in colour. Microscopic examination of the rock shows the main difference to be in the grain size and in the degree of alteration. Carbonates and chlorates are predominant throughout the rock. Alteration is not surprising when it is considered that the tuffs are underlain by intrusive rocks. The tuff, owing to its original porous nature, would be particularly susceptible to the action of gases and solutions rising from the igneous masses which happen to be mostly of the basic syenite type.

The specimens tested seem to fall mainly into one or other of the extreme classes.

Group Type A₁. Dark grey in colour, fine-grained and chloritic. This is the least altered variety.

Group Type B₁. Reddish in colour, coarse grained - (grains up to one tenth inch in length). The reddish colour is due to hematite. These are representative of the more altered variety.

Group Type C₁. Very fine grained, and of a more mud brown colour with up to 10% biotite crystals.

<u>Lake Shore Porphyry.</u>

The second suite of specimens taken in this investigation are samples of syenite porphyry. The specimens were taken from Lake Shore Mines at Kirkland Lake, Ontario. Todd (2) places the formation as one of the earliest of the syenite porphyry bodies intruded in the Algoman period after the Timiskamian sediments.

The rock varies from grey to red in colour depending on the extent of alteration. During alteration the rock becomes lighter as the ferro-magnesian minerals are altered to carbonates and sericite. Phenocrysts of plagioclase and orthoclase constitute 25% to 50% of the rock and are usually less that one tenth of an inch in length. Occasionally they reach three eighths of an inch in length. Biotite in the less altered rock occupies about 20% of the rock, changing with alteration to light green chlorite, then being bleached out to sericite. Apatite, magnetite and ilmenite are accessory minerals, being commonly localized in the bleached remnants of biotite crystals.

The specimens tested are mainly all of the intermediate stage. They are altered to a considerable degree though a considerable quantity of biotite remains unaltered in them. Phenocrysts are predominant up to one tenth inch long, though in a few specimens larger ones have been found.

Group Type A_2. Reddish in colour, chloritic, holocrystaline up to one tenth inch in length.

Group Type B_2. As type A_2 but having a few isolated phenocrysts up to four tenths inch in length. (Photograph 10).

Group Type C_2. Specimens are of unusually fine grain size and darker than usual.

Nundydroog Amphibolite.

The third suite of specimens taken in this investigation are samples of Amphibolite, a metamorphic actinolite rock. The specimens were taken from the Nundydroog Gold Mine, Mysore State in India. The rocks in the area are considered to be Precambrian.

The rock consists of a fine grained matrix of actinolite and quartz grains in which have developed numerous larger crystals and grains which may be nearly equant and as much as 1 or 1.5 mm. in diameter. The ground mass actinolite is usually prismatic in habit.

The specimens tested fall into two main classes:-

Group Type A3. Fine grained matrix with a few scattered larger crystals and irregular grains. (Photograph 11).

Group Type B3. Coarse crystals and irregular grains (1 - 1.5 mm. in diameter) , with less matrix. Many of them have only a small amount of ground mass.

Kerr Addison Green Carbonate Breccia.

The fourth suite of specimens tested in this investigation are samples of brecciated and highly carbonated volcanic rocks from Kerr Addison Gold Mines Ltd., Virginiatown, Ontario.

The green carbonate rock gets its name from its vivid green colour caused by iron-bearing silicates, including fuchsite. According to Baker (3) the exact nature of the original rock is in some doubt but for the most part the rocks are considered to have been originally volcanic lavas and tuffs. The carbonate rock has been formed from the original rocks by intense stresses and hydrothermal action. The rocks used are all from the carbonate ore zone and considerable care has been taken to exclude specimens high in chlorite. The rock used is high in quartz with epidote and calcite as the main accessories. The rock is coarse and brecciated.

The specimens tested seem to fall mainly into two groups though one group could be called a weakness group.

Group Type A4. Specimens are granular in fracture. Fractures break through green mineral matrix and quartz stringers alike. Quartz is very fine grained and occupies about 35% of the rock; it is of a grey colour.

Group Type B4. Specimens are of a weaker nature. Fractures often follow around the sides of quartz stringers. The green is more vivid. The quartz is again fine grained but generally white occupying about 40% - 45% of the rock.

McIntyre - Carbonated Lava.

The fifth suite of specimens taken for this investigation are samples of carbonated lava from McIntyre Mines, Timmins, Ontario.

The carbonated lavas are in close proximity to the ore zone. They belong to the Tisdale lava series of the Keewatin period of the Precambrian. These lavas were altered by hydrothermal action at high pressure to carbonated rock.

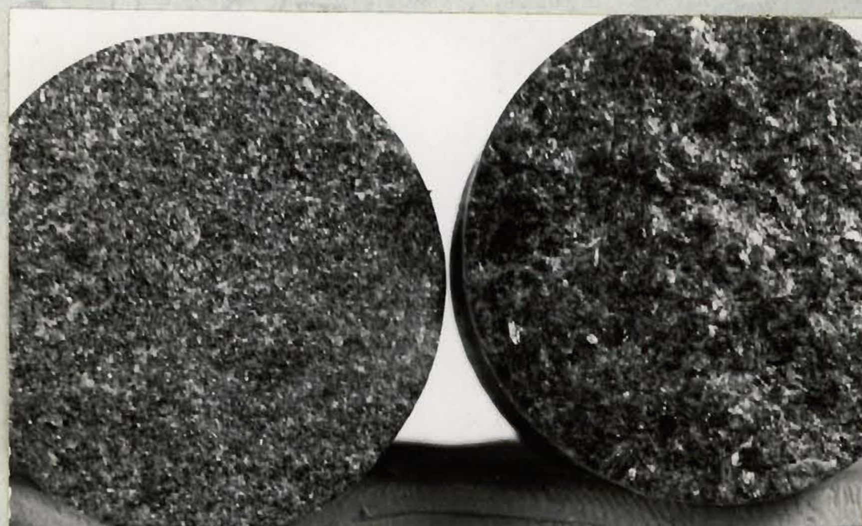
The test specimens fall into three classes, though all three are very similar.

Test Group A5. Specimens including traces of mineralization.

Test Group B5. Specimens including small spheroids of residual silica.

Test Group C6. Specimens of pure carbonated rock without mineralization or residual spheroids of silica.

Lake Shore Porphyry - Group Type B_2 showing phenocrysts



Nundydroog Amphibolite-Group Type A_3

on left - fine grained. Group Type B_3

on right - coarse grained.

APPENDIX B

PHOTOGRAPHS OF ROCK FAILURES

Photograph No. 12

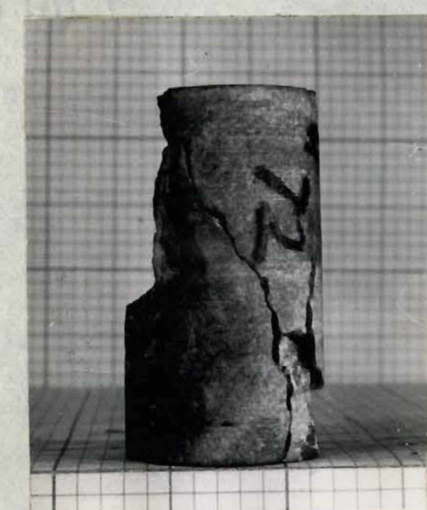
Experiment No. 59, Lake Shore Porphyry indicating a break comparable to the theoretical angle according to Mohr.

Photograph No. 13

Experiment No. 127, Lake Shore Tuff- indicating vertical fracturing with slight wedging effect.

Photograph No. 14

Experiment No. 76, Kerr Addison Green Carbonate - indicating a break comparable to the theoretical angle according to Mohr



Photograph No. 15

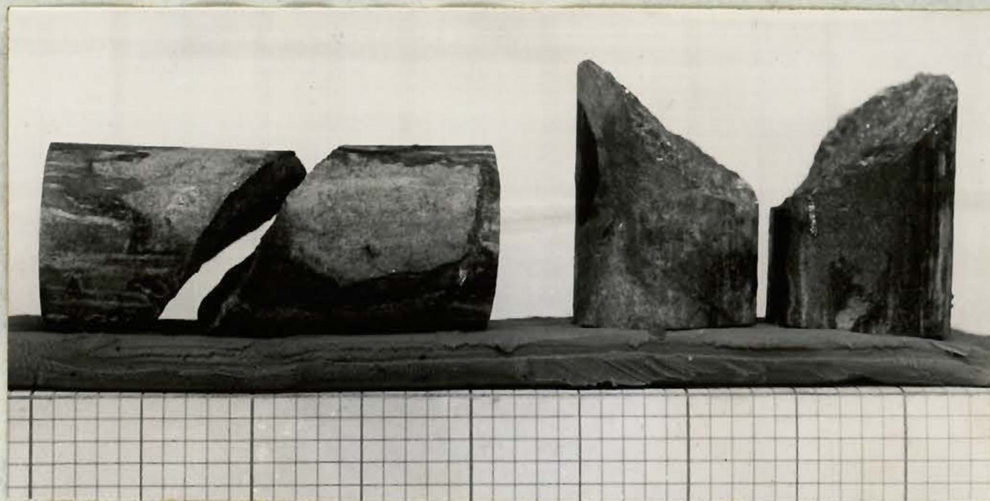
Experiment No. 72, Kerr Addison Green Carbonate - failure comparable to Mohr's theory, yet possibly affected by wedging.

Photograph No. 16

Experiment No. 54 - Kerr Addison Green Carbonate - failure along the boundaries of quartz masses.

Photograph No. 17

Experiment No. 75 - Nundydroog Amphibolite failure along planes of weakness.

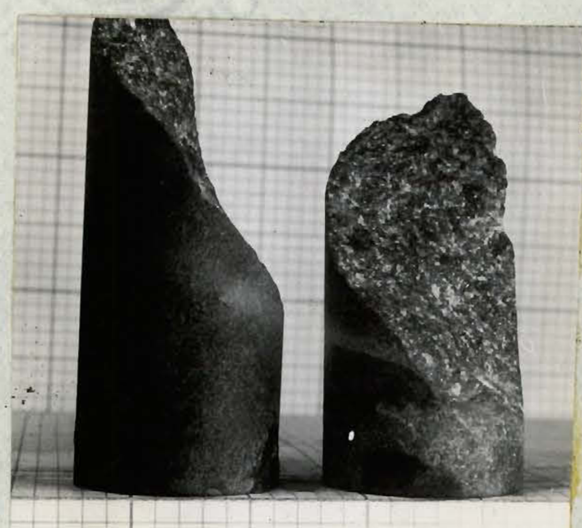


Photograph No. 18

Tension breaks on Kerr Addison

specimens No. 129 & No. 130

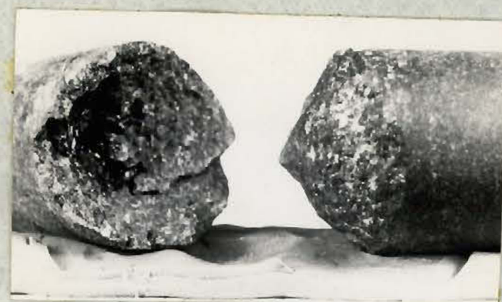
showing helicular break.



Photograph No. 19

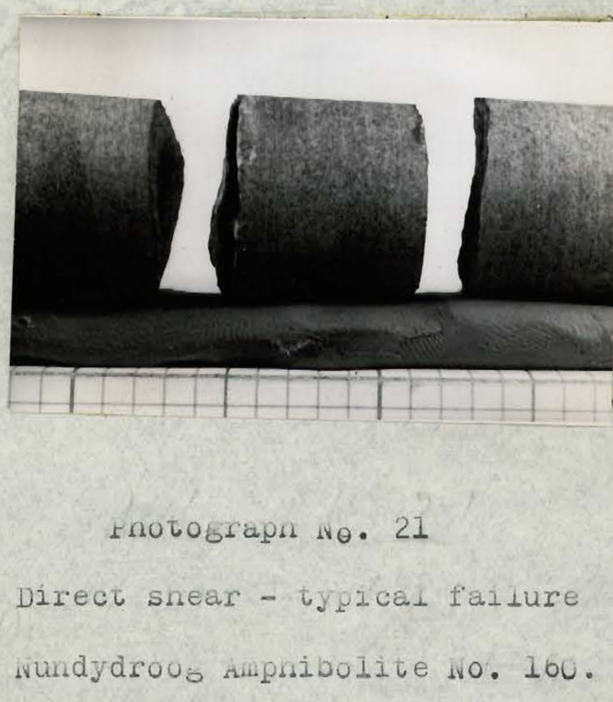
Torsion break of Lake Shore Porphyry No. 87

showing extended helicular break.



Photograph No. 20

Torsion break, Lake Shore Porphyry No. 181 - showing an unusual pointed break.



Photograph No. 21

Direct shear - typical failure Nundydroog Amphibolite No. 160.