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Reconnaissance Geotechnical Study of the Lucerne Granite, Maine

By Sharon F. Diehl and Fitzhugh T. Lee, 1931-

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Contents

Pa

Illustrations

Tables

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the Lucerne Granite, Maine

By

Sharon F. Diehl and Fitzhugh T. Lee

Abstract

Physical properties, including density and strength, of the Lucerne Granite (Wing, 1958) vary because of inhomogeneities caused by fracturing and differences in texture. Two granitic facies were found: a coarse-grained variety in the southern part of the body and near the edges of the pluton and a medium-grained porphyritic variety in the central and northern sections. Point-load strength tests indicate that the medium-grained porphyritic granite is stronger than the coarse-grained porphyritic or non-porphyritic granite. Results of bulk and grain density tests suggest that rock strength in the weaker granite samples is controlled by microfractures.

In the pluton, joint trends changed from a scattered pattern in the north to a preferred orientation in the south. Because it has a simple joint pattern and is homogeneous in texture, the southern part of the Lucerne Granite is a more suitable area for excavation and fluid storage than the northern section.

Introduction

The U.S. Geological Survey, with the cooperation of the Maine Geological Survey, is studying the effects of rock properties on the construction of energy facilities, such as underground "rock caverns" in which to store oil, and surface excavations for nuclear reactor foundations. Some of the sites under consideration by State and Federal agencies are located in granitic plutons of the Bays-of-Maine igneous and metamorphic complex, which lies along the northeasternmost section of the Maine coast. The study reported here is limited to the Lucerne pluton, a large granite body of Devonian age that intrudes a layered Silurian-Ordovician metasedimentary sequence northeast of Penobscot Bay (fig. 1).

Our objective was a reconnaissance evaluation of those properties of the granite that are important in planning excavations in the rock. We used simple field measurements to obtain estimates of the gross variations of certain physical properties and fracture patterns. Samples were collected for strength and density tests, and the attitude and spacing of joints were recorded to determine dominant trend variations in fracturing in the pluton. Some samples were tested in the laboratory for comparison with the field test results.

An additional aim was to establish reliable, uniform testing procedures for this and subsequent investigations.

Acknowledgments

The uniaxial compressive strength tests were conducted by D. R. Miller of the U.S. Geological Survey. The linear regression model used in the report was suggested by G. E. Brethauer who also aided in the analysis. We also wish to thank the Department of Geological Sciences of the University of Maine at Orono for laboratory space and the Maine Geological Survey for their cooperation.

Description of the Lucerne Granite

The Lucerne Granite of Wing (1958) is the largest of several granitic plutons that have intruded a zone, some 50 km wide, of fault-bounded blocks of diverse lithologies including banded gneisses, marine metasedimentary rocks, and volcanic rocks of late Precambrian to Devonian age (Wones, 1976). The age of the Lucerne Granite, based on Rb-Sr and K-Ar methods, is 375±25 m.y. (Brookins and others, 1973) or Devonian, as are most of the plutonic rocks in the Penobscot Bay area.

The Lucerne Granite is a medium- to coarse-grained, white-weathering biotite granite characterized by 1- to 4-cm tabular euhedral pink to gray alkali feldspar crystals. Two facies exist in the granite: a porphyritic granite in the northern part of the pluton and an equigranular "normal" granite to the south. The south contact of the porphyritic rock is a fault

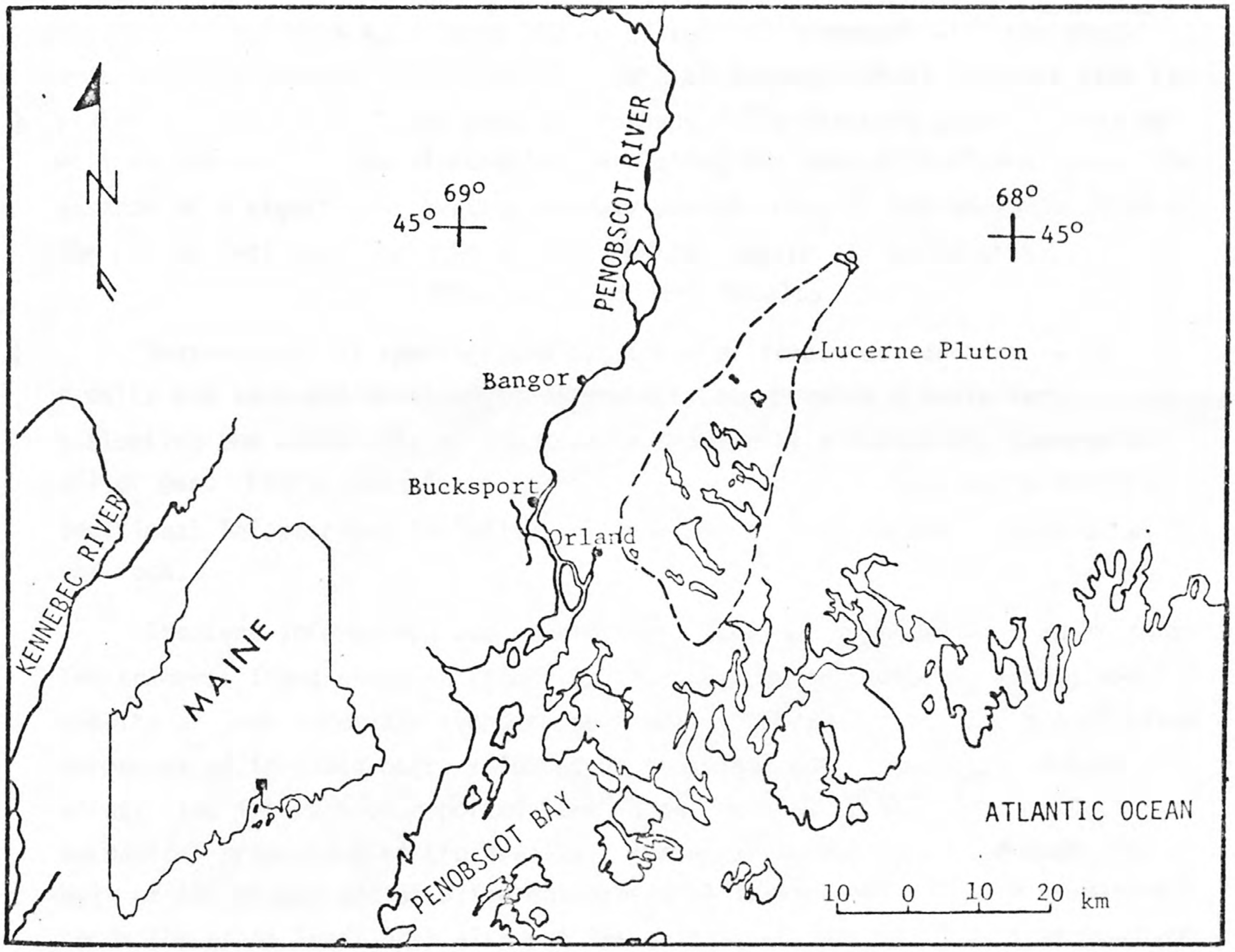


Figure 1.--Location of the Lucerne pluton northeast of Penobscot Bay, Maine.

(fig. 2), which is manifested by a mylonite zone, has 300 m of right-lateral offset, and may have as much as 1000 m of vertical movement with the south side moved up (Wones, 1976). Gravity data of Sweeney (1976) indicate that the pluton is 7-10 km thick and tabular in shape. The thickest zones (>7 km) as well as the main volume of material, are along the east side of the body. The absence of a significant gravity anomaly associated with the northern 10 km of the pluton indicates that the granite here is apparently quite thin.

Procedures and Test Results

Measurements of spacings and attitudes of fractures, combined with density and compressive-strength determinations, provide a basis for evaluating the uniformity of the Lucerne Granite as a medium for storage of oil or gas. Evaluation of the granite for storage of nuclear waste requires additional information, including a knowledge of time-dependent behavior of the rock.

Fracture information and samples were obtained from outcrops on or near the traverse lines shown in figure 2. Although we attempted to sample the granite at 1-km intervals along these lines, difficult access and insufficient exposures of in-place bedrock forced us to change some preselected sample sites. The information reported here is an overview of the gross variation of mechanical properties of the granite. These variations, observed over the bulk of the pluton and at different erosional levels, are inferred to extend to depths of at least 50 m although the spacing of near-vertical fractures may increase with depth.

Rock conditions at specific underground excavation sites, particularly the determination of in situ stresses, should be more closely defined by drilling and specialized testing.

Joint spacing and attitude

Joints in the Lucerne Granite are of two main types: subhorizontal sheeting joints and vertical or near-vertical systematic joints. The sheeting joints generally conform to the surface topography and the sheets become thicker with depth. Observed thicknesses range from 0.1 to 5.0 m and average 0.8 m. The spacing of vertical and near-vertical joints range from less than 0.1 to over 4.5 m and average 1.1 m.

The strike-frequency diagrams in figure 3 show that north-south and east-west striking systematic joints are abundant in the southern part of the

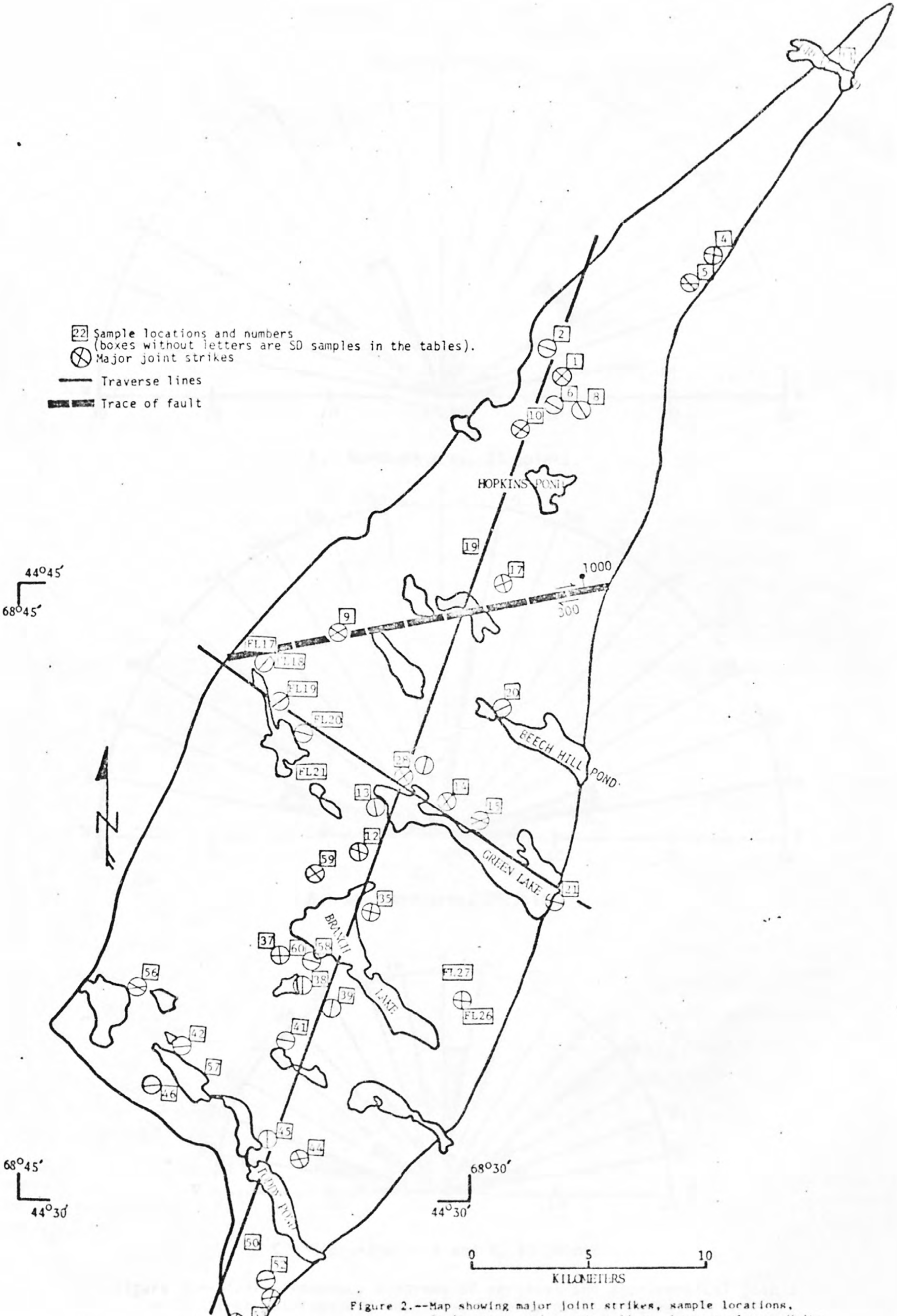
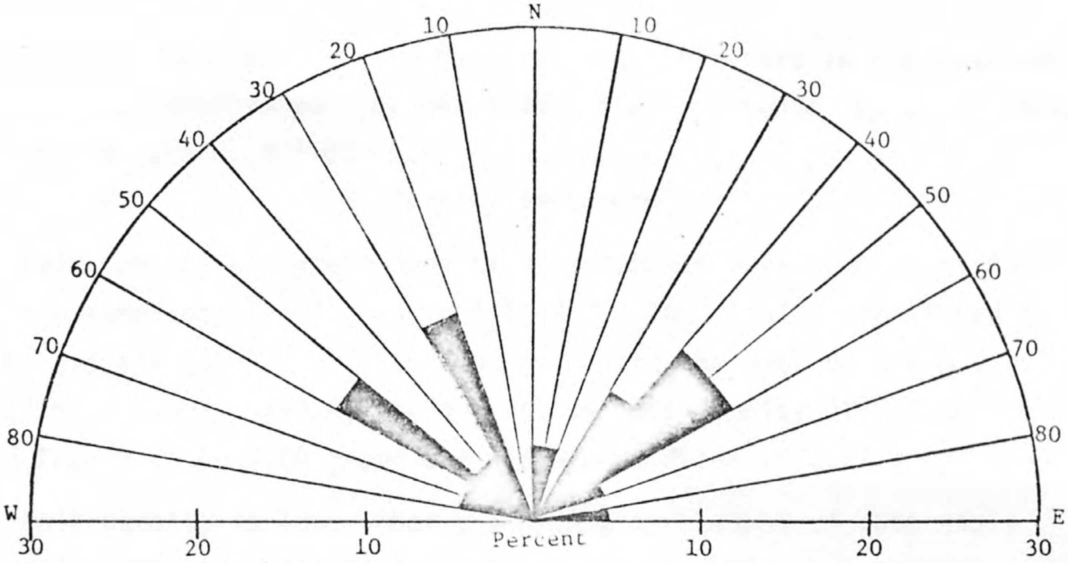
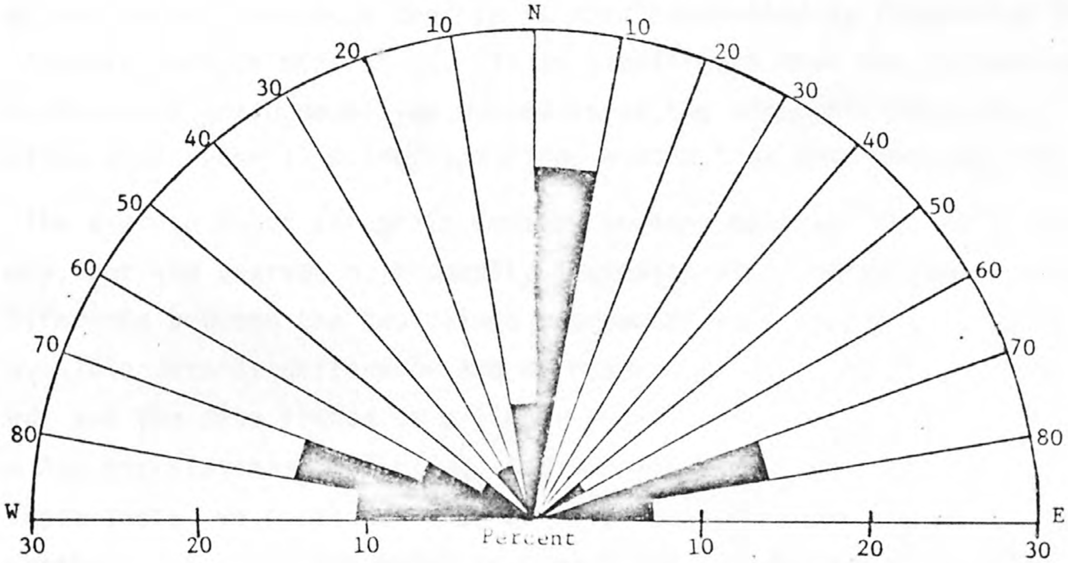


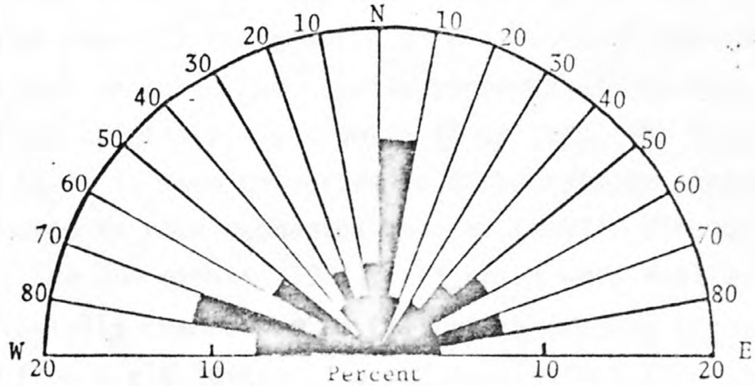
Figure 2.--Map showing major joint strikes, sample locations, fault trace, and traverse lines, Lucerne pluton, Maine.



A. Northern area, 25 joints.



B. Southern area, 28 joints.



C. Composite of A and B, 53 joints.

Figure 3.--Strike-frequency diagrams of vertical and near-vertical joints from outcrops and roadcuts, Lucerne pluton, Maine.

pluton, below the E-W traverse, but are relatively rare in the northern part. Joints in the northern part of the pluton are represented by a set striking N. 50°-60° W. and N. 40°-60° E.

Density measurements

Bulk density and grain density measurements were made on 67 samples taken from the locations shown in figure 2. The results are listed in table 1. The average bulk density is 2.60 g/cm^3 and the average grain density is 2.65 g/cm^3. Sweeney (1976) found that the bulk density of 20 Lucerne samples ranged from 2.61 to 2.69 g/cm^3 and had a mean value of 2.64 g/cm^3.

Bulk density is lower than grain density because of observable intragrain and intergrain microfractures in the whole-rock samples. Further, the range of grain density values was much smaller than that of bulk density values, indicating that bulk density is more controlled by fracturing than by other factors such as mineralogy. It is significant that the difference between bulk and grain densities decreases as the strength increases, suggesting a decrease in microfracturing, a condition that weakens the rock.

The average value for grain density remains constant for each strength category, but the average bulk density increases with increasing strength. The difference between the two values represents void spaces between the grains. This density difference and corresponding compressive strength were graphed, and the data fitted to a linear regression model (fig. 4). Because of the low correlation coefficient, additional statistical tests were run. From these tests, we concluded that we have no statistical reason to reject the hypothesis that (1) the model is linear and (2) the slope is real.

Point-load and uniaxial test results

A portable point-load testing device was used to test samples in the field in order to classify the granite on the basis of compressive strength. The point-load test measures the tensile strength of the rock by compressing a sample between two pointed platens until it splits. The figure obtained, the strength index (I_s), is then converted to a compressive strength value, which is more widely used in rock mechanics than is tensile strength (Broch and Franklin, 1972; Lee and others, 1977). NX cores were drilled out of some samples and uniaxially compressed to failure to compare strength values with those obtained from field tests. The values obtained from the cores were

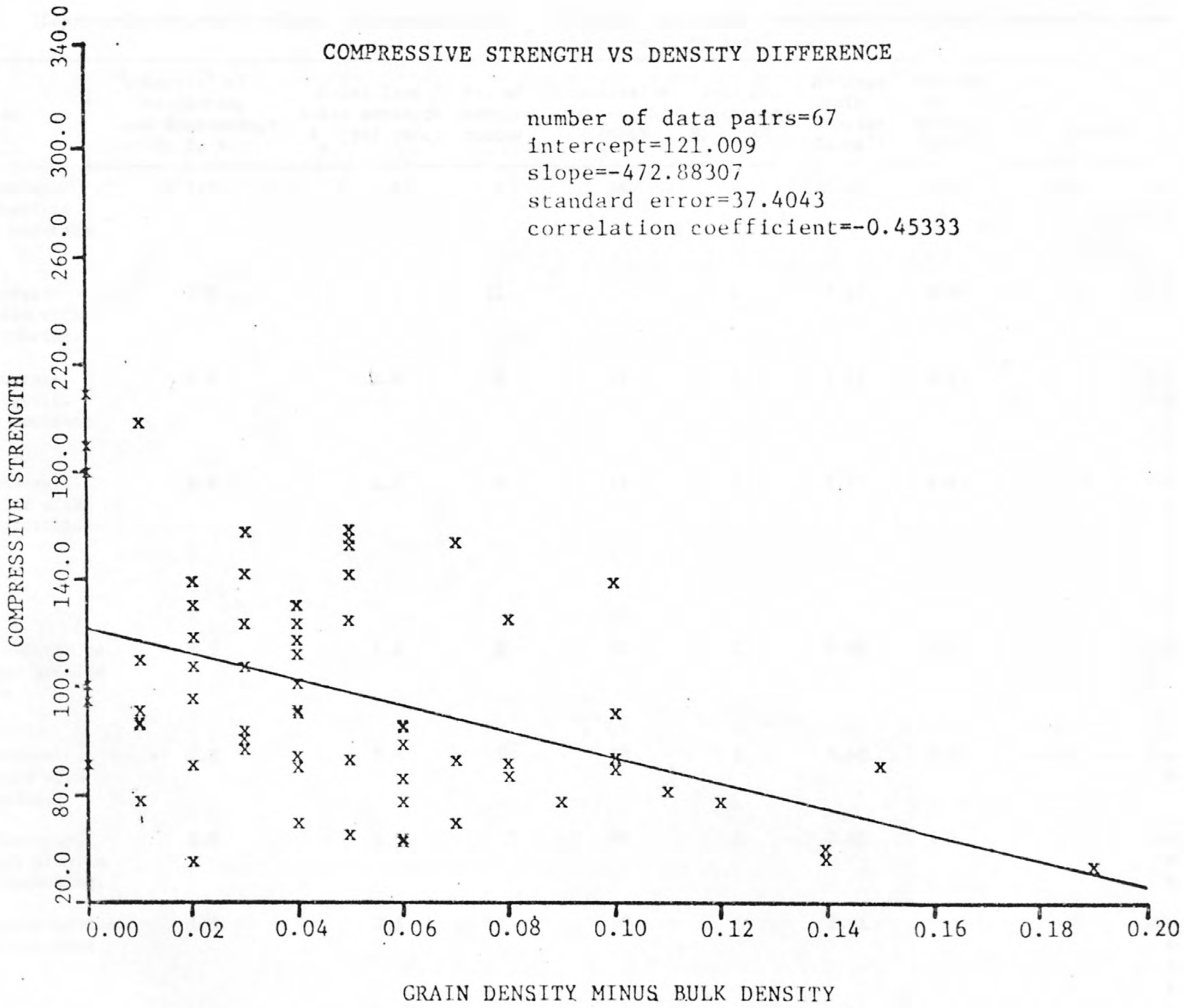


Figure 4.--Linear regression plot of compressive strength versus density difference.

Table 1.--*Results of density and point-load tests, Lucerne pluton, Maine*

[Compressive strength values are computed from I_s. Samples are ranked from lowest to highest compressive strength; ------------, no data]

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point load index strength I_s (50) (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm^3)	Average grain density (g/cm^3)	Average vertical joint spacing (m)	Remarks
SD 45	Medium-gray, coarse-grained porphyritic granite with moderate fracturing.	3.0	1.4	9	34	L	2.48	2.67	0.5	Fractures along cleavage planes of the feldspar; iron oxide staining.
SD 42	Light-gray, coarse-grained granite with moderate fracturing.	2.0	1.5	11	36	L	2.62	2.64	.5	Do.
FL 27A	Medium-gray, coarse-grained porphyritic granite with moderate fracturing.	2.0	1.6	8	38	L	2.51	2.65	3.0	Fractures healed; iron oxide staining.
SD 13	Medium-gray, coarse-grained granite with abundant fracturing.	2.0	1.7	9	41	L	2.49	2.63	.35	Two fracture directions which are perpendicular to each other; one set, parallel to the cleavage of the feldspars, filled in with quartz or tourmaline.
SD 41B	Pinkish-gray, medium- to coarse-grained granite with moderate fracturing.	2.5	1.8	6	43	L	2.58	2.64	.7	Fractures healed.
SD 57	Light-gray, coarse-grained granite with minor fracturing.	2.0	1.8	6	43	L	2.60	2.66	------------	Fractures filled or healed.
SD 46	Light- to medium-gray, coarse-grained granite with minor fracturing.	2.0	1.9	13	46	L	2.61	2.66	.5	Rock breaks easily along the cleavage planes of the feldspar.
SD 56B	Light-gray, coarse-grained granite with abundant fracturing.	1.5	2.1	7	50	L	2.61	2.65	.2	Some fractures filled by serpentine; rock breaks along cleavage planes of the feldspar.
SD 20	Medium-gray, coarse-grained granite with abundant fracturing.	2.0	2.1	9	50	L	2.57	2.64	------------	Fractures parallel to cleavage of the feldspar filled or healed.

Table 1.--*Results of density and point-load tests, Lucerne pluton, Maine--Continued*

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point load index strength I_s (50) (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm^3)	Average grain density (g/cm^3)	Average vertical joint spacing (m)	Remarks
SD 9	Medium-gray, coarse-grained granite with abundant fracturing.	2.0	2.4	6	58	L	2.57	2.63	0.6	Numerous healed fractures.
SD 39A	Medium-gray, medium- to coarse-grained granite with moderate fracturing.	2.0	2.4	6	58	L	2.52	2.64	------------	Some healed fractures.
SD 39B	----do-------------------	3.0	2.4	6	58	L	2.57	2.66	------------	Some healed fractures; iron oxide staining.
SD 1D	Light-gray, coarse-grained granite wtih moderate fracturing.	1.5	2.4	4	58	L	2.62	2.63	------------	Breaks along cleavage planes of the feldspar.
SD 2	Medium-gray, coarse-grained granite with abundant fracturing.	2.5	2.6	8	62	L	2.52	2.63	------------	Some healed fractures.
SD 38	Medium-gray, medium- to coarse-grained granite with minor fracturing.	1.5	2.8	12	67	L	2.63	2.69	.2	Mostly medium grained.
SD 37	Medium-gray, medium- to coarse-grained porphyritic granite.	1.5	2.8	14	67	L	2.59	2.67	.8	Very minor fracturing.
SD 59	Medium- to dark-gray, coarse-grained porphyritic sheared granite.	3.0	2.9	7	70	L	2.59	2.69	.5	Some quartz-filled fractures; iron oxide staining.
FL 27B	Medium-gray, coarse-grained porphyritic granite with moderate fracturing.	2.5	3.0	3	72	M	2.62	2.66	3.0	Iron oxide staining.
[5]SD 52C	Grayish-white, coarse-grained granite with moderate fracturing.	2.5	3.0	3	72	M	2.54	2.62	.3	Do.

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point-load index strength I_s (50) (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm³)	Average grain density (g/cm³)	Average vertical joint spacing (m)	Remarks
SD 14	Medium- to dark-gray, coarse-grained granite with moderate fracturing.	3.0	3.0	9	72	M	2.46	2.61	1.3	Iron oxide staining.
SD 56C	Leucocratic, medium-grained dike material.	2.0	3.0	3	72	M	2.57	2.57	.2	----------------------
SD 21B	Medium-gray, medium-grained granite with minor fracturing.	2.0	3.0	5	72	M	2.59	2.61	-----------	----------------------
SD 50	Grayish-white, coarse-grained granite with moderate fracturing.	2.0	3.1	6	74	M	2.62	2.66	-----------	Breaks easily along the cleavage planes of the feldspar.
SD 21A	Medium-gray, coarse-grained granite with minor fracturing.	2.0	3.1	4	74	M	2.56	2.63	.8	Iron oxide staining.
SD 52A	Medium- to dark-gray, medium- to coarse-grained granite with moderate fracturing.	3.0	3.1	7	74	M	2.58	2.68	.3	Heavy iron oxide staining.
SD 52B	----do----------------	3.0	3.1	3	74	M	2.62	2.67	.3	Heavy iron oxide staining; some healed fractures.
FL 19C	Medium-gray, coarse-grained granite with abundant fractures.	2.0	3.3	10	79	M	2.60	2.66	4.5	Numerous healed fractures.
SD 56A	Pinkish-gray, coarse-grained granite with moderate fracturing.	2.0	3.3	8	79	M	2.60	2.63	.2	Some healed fractures; chlorite present.
SD 10A	Light-gray, coarse-grained granite with abundant fracturing.	2.0	3.4	3	82	M	2.56	2.59	.9	Fractures are healed or filled; some iron oxide staining.
[5]SD 60A	Medium-gray, coarse-grained granite with moderate fracturing.	1.5	3.5	6	84	M	2.64	2.62	-----------	Healed fractures mainly parallel to feldspar cleavage.

Table 1.--*Results of density and point-load tests, Lucerne Pluton, Maine--Continued*

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point load index strength $I_s(50)$ (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm^3)	Average grain density (g/cm^3)	Average vertical joint spacing (m)	Remarks
SD 28	Dark-gray, medium- to coarse-grained granite with moderate fracturing.	2.5	3.5	5	84	M	2.56	2.59	1.6	Fractures are healed or filled with tourmaline.
SD 53	Medium-gray, coarse-grained granite with moderate fracturing.	2.0	3.5	9	84	M	2.62	2.68	------------	------------------------
SD 12	Medium-gray, coarse-grained porphyritic granite with abundant fracturing.	2.0	3.6	8	86	M	2.63	2.64	------------	Fractures are mainly parallel to cleavage planes of the feldspar; some are filled with quartz.
FL 18B	Medium- to dark-gray, coarse-grained granite with moderate fracturing.	2.0	3.6	8	86	M	2.66	2.72	.3	Contains a fine-grained xenolith; some filled fractures.
[5]FL 26A	Light-gray, coarse-grained granite with abundant fracturing.	2.5	3.6	9	86	M	2.61	2.62	.8	Many fractures filled or healed; iron oxide staining.
SD 60B	Medium-gray, coarse-grained granite with moderate fracturing.	1.5	3.8	7	91	M	2.64	2.68	------------	Many fractures filled with tourmaline.
SD 1A	Medium-gray, coarse-grained granite with minor fracturing.	2.0	3.8	3	91	M	2.64	2.65	------------	------------------------
SD 1B	----do------------------	2.0	3.8	6	91	M	2.57	2.67	------------	Contains a fine-grained xenolith.
SD 15	Medium-gray, fine- to medium-grained porphyritic granite with moderate fracturing.	3.0	3.8	8	91	M	2.59	2.63	.6	Iron oxide staining.
SD 10B	Pinkish-gray, coarse-grained granite with moderate fracturing.	2.0	4.0	7	96	M	2.60	2.60	.9	------------------------
SD 11A	Some pink, medium-gray, coarse-grained granite with minor fracturing.	2.0	4.0	8	96	M	2.64	2.66	------------	----------------------

Table 1.--*Results of density and point-load tests, Lucerne pluton, Maine*--*Continued*

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point load index strength I_s (50) (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm^3)	Average grain density (g/cm^3)	Average vertical joint spacing (m)	Remarks
SD 19B	Dark-gray, coarse-grained, sheared cataclastic granite.	1.5	4.2	8	101	M	2.63	2.63	------------	Sheared, mylonitic; fractures healed.
FL 20B	Medium-gray, coarse-grained granite with minor fracturing.	2.5	4.2	10	101	M	2.62	2.66	0.75	Some iron oxide staining.
[5]SD 41C	Pink-gray, coarse- to medium-grained porphyritic granite with moderate fracturing.	1.0 (1.5?)	4.3	5	103	M	2.50	2.70	.7	Fractures healed; some chlorite.
SD 17	Medium-gray, medium-grained porphyritic granite with minor fracturing.	2.0	4.5	10	108	M	2.58	2.61	1.4	Minor fracturing, healed; some iron oxide staining.
[5]SD 58	Light- to medium-gray, medium-grained porphyritic granite.	1.5	4.5	10	108	M	2.65	2.67	.5	No fracturing observed.
FL 21A	Light-gray, medium-grained porphyritic granite with minor fracturing.	2.0	4.6	9	110	M	2.62	2.63	------------	Healed or filled fractures.
FL 19B	Medium-gray, coarse-grained granite with minor fracturing.	1.5	4.7	4	113	M	2.61	2.65	4.5	Minor fracturing.
[5]FL 26B	Medium-gray, coarse-grained granite.	2.0	4.9	4	118	M	2.60	2.62	.8	Some iron oxide staining.
FL 26C	----do-------------------	2.0	4.9	4	118	M	2.62	2.66	.8	No iron oxide staining.
FL 21B	Medium-gray, medium- to coarse-grained granite with moderate fracturing.	2.0	5.1	9	122	M	2.63	2.49	------------	Fractures healed.
FL 17A	Medium-gray, coarse-grained granite.	1.5	5.0	14	124	M	2.58	2.61	.3	---------------------
FL 19A	Medium- to dark-gray, coarse-grained granite.	1.0	5.0	6	124	M	2.70	2.74	4.5	Contains fine-grained xenoliths.

Table 1.--*Results of density and point-load tests, Lucerne pluton, Maine--Continued*

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point load index strength I_s (50) (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm^3)	Average grain density (g/cm^3)	Average vertical joint spacing (m)	Remarks
SD 19A	Dark-gray, coarse-grained granite with abundant fracturing.	2.0	5.2	11	125	M	2.62	2.67	------------	Fractures healed; not as sheared as SD 19B.
SD 5	Medium-gray, coarse-grained granite with moderate fracturing.	2.0	5.2	9	125	M	2.60	2.68	0.2	Fractures parallel to feldspar cleavage, filled with tourmaline
FL 18A	Medium-gray, coarse-grained granite with minor fracturing.	2.0	5.4	4	130	M	2.64	2.66	.3	Do.
FL 18C	Medium-gray, coarse-grained granite with moderate fracturing.	2.0	5.4	4	130	M	2.62	2.66	.3	Fractures healed; some filled with tourmaline
FL 20A	Medium-gray, coarse-grained granite with minor fracturing.	1.0	5.6	8	134	M	2.65	2.63	.75	-----------------------
SD 35B	Medium-gray, medium-grained porphyritic granite with minor fracturing.	2.0	5.8	6	139	M	2.61	2.63	1.4	-----------------------
SD 35C	Medium-gray, medium- to coarse-grained granite with minor fracturing.	2.0	5.8	6	139	M	2.59	2.69	1.4	Some iron oxide staining
FL 20C	Medium-gray, coarse-grained granite with moderate fracturing.	1.5	5.9	3	142	M	2.61	2.66	.75	Fractures healed.
SD 6	Medium-gray, medium-grained porphyritic granite.	2.0	5.9	10	142	M	2.61	2.64	.9	-----------------------
SD 35A	Medium-gray, medium- to coarse-grained granite.	1.0	6.4	9	154	H	2.57	2.64	1.4	Fresh sample.
[5]SD 41A	Medium-gray, medium-grained porphyritic granite.	1.0	6.4	8	154	H	2.64	2.69	.7	Fresh sample; some minor chlorite.

Table 1.--*Results of density and point-load tests, Lucerne pluton, Maine--Continued*

Sample[1] No.	Description	Degree[2] of weathering and fracturing: 1, 2, 3	Point load index strength I_s (50) (MPa)	No. of samples tested	Compressive strength[3] (MPa)	Strength category: H, M, L[4]	Average bulk density (g/cm^3)	Average grain density (g/cm^3)	Average vertical joint spacing (m)	Remarks
FL 17B	Medium-gray, medium-grained porphyritic granite.	1.5	6.6	5	158	H	2.64	2.69	0.3	----------------------
FL 17C	----do------------------	2.0	6.6	5	158	H	2.61	2.64	.3	Little or no fracturing; some iron oxide staining.
SD 1E	Medium-gray, medium-grained porphyritic granite.	1.5	6.6	4	158	H	2.59	2.64	------------	Some iron oxide staining
SD 11B	Dark-gray, medium-grained porphyritic granite.	1.0	7.5	2	180	H	2.64	2.64	------------	Little or no fracturing; minor iron oxide staining.
[5]SD 4A	Dark-gray, compact, coarse-grained granite with minor fracturing.	1.0	7.9	10	190	H	2.65	2.65	3.5	Fractures well healed.
SD 44	Dark-gray, medium-grained porphyritic granite.	1.0	8.3	9	199	H	2.65	2.66	------------	Little or no fracturing; minor iron oxide staining.
SD 8	Dark-gray, granulated sheared granite.	1.0	8.7	6	209	H	2.64	2.64	2.0	Fractures healed; chlorite.
SD 4B	Light- to medium-gray, coarse-grained, sheared massive granite.	1.0	10.3	12	247	H	2.64	2.61	3.5	Mylonitic.

[1]Sample locations are shown in figure 1.
[2]1 = Fresh, little or no fracturing.
2 = Moderate weathering, may have some fracturing.
3 = Weathered, chalky feldspars, abundant fracturing.
[3]Compressive strength equals I_s (50) times 24 (Bieniawski, 1975).
[4]L = Low strength.
M = Medium strength.
H = High strength.
[5]Has a corresponding uniaxial compressive strength value in table 2.

corrected according to ASTM (L/D) requirements for deviations from the minimum ratio of maximum grain size to sample diameter.

Results of point-load testing are listed in table 1 and uniaxial test results are listed in table 2. Comparison of compressive strengths by the two methods suggests a tendency for slightly higher values from the point-load test. The strength values from the point-load tests are probably more representative than those from the uniaxial tests, because a greater number of samples were used to find average failure strengths. Test values were grouped into three compressive strength categories: low (34-70 MPa), medium (71-150 MPa), and high (above 150 MPa).

Rocks in the low-strength category are coarse grained and characterized by clusters of alkali feldspar grains, coarse-grained quartz and plagioclase, and a few mafic minerals. Some of the samples are weathered and gave abnormally low compressive-strength values, as noted in tables 1 and 2. Rocks in this category usually fracture easily along cleavage planes of the feldspar grains. The sites from which the lowest strength rocks were collected had the most closely spaced joints, averaging 0.7 m. The average bulk density of these samples is relatively low (2.57 g/cm^3) because of the higher proportion of low-density minerals and greater amount of microfracturing.

Medium-strength samples are generally coarse grained to porphyritic and have an average bulk density of 2.60 g/cm^3. The failure surfaces of many samples follow the cleavage planes of feldspar phenocrysts. Joint spacing is greater (average of 1.1 m) than in the low-strength group.

The strongest rocks are mostly medium-grained porphyritic granites that have sparse isolated phenocrysts and little or no fracturing. The average bulk density is the highest of the three groups (2.63 g/cm^3) because of the decrease in fracturing and possibly an increase in ferromagnesium minerals. The rock breaks unevenly across the grains, showing that the minerals are tightly interlocked. A few of the samples are mylonitic and have a green color. They are found in sheared zones within the pluton and near points of contact with surrounding formations. Joint spacing increases to an average of 1.7 m.

Storage Site Selection

From the rock-properties information presented here, a preliminary judgment can be made on the suitability of the Lucerne Granite for excavation of large underground chambers.

Table 2.--*Results of uniaxial compressive strength tests of core samples, Lucerne pluton, Maine*

[Samples are ranked from lowest to highest compressive strength]

Sample No.	Description	Uniaxial compressive strength (MPa)	Comparable compressive strength from point-load tests (MPa)	Type of failure	Remarks
SD 58	Light- to medium-gray, medium-grained porphyritic granite.	70.8	108	Extension	Core sample more weathered than irregular lump sample; slight indication of failure in shear.
SD 52C	Gray-white, coarse-grained granite.	71.7	72	Shear----	Interior of core weathered; core tended to fail in direction of preexisting crystal structure.
SD 60A	Medium-gray, coarse-grained granite.	87.6	84	---do----	Core somewhat weathered.
SD 41C	Pink-gray, coarse- to medium-grained porphyritic granite.	89.7	103	Extension	Failure in core sample exposed preexisting longitudinal weathered fractures; chloritic alteration.
FL 26B	Medium-gray, coarse grained granite.	103.6	118	Shear-----	Slight weathering in core.
FL 26A	Medium- to dark-gray, coarse-grained granite.	104.1	86	---do----	Because of fractures normal to longitudinal axis, upper portion of core shattered on failure. Lump sample weathered and fractured.
SD 41A	Medium-gray, medium-grained porphyritic granite.	123.2	154	---do----	Minor chloritic alteration in core.
SD 4A	Dark-gray, compact, coarse-grained granite.	175.9	199	---do----	Fractures well healed in both samples.

The variation in compressive strength is somewhat surprising in light of the relative homogeneity of many granitic intrusions. Weathering and alteration are mainly responsible for reducing the strength of samples in the low-strength category (30-70 MPa); rock strengths at many of these locations should increase with depth, assuming that the alteration is a superficial condition of the rock. Except for rock near the boundary of the pluton and near the fault zone shown in figure 2, the intact rock strength and joint spacing of the granite at storage depths should permit the excavation of large self-supporting chambers. Most of the granite is either medium or high strength and falls into the "blast to fracture" category (Lee and others, 1977).

For several reasons, the part of the pluton south of the fault zone is preferable to the northern part as a medium for excavation and fluid storage. In general, the rock in the southern part of the pluton is more homogeneous in texture and structure. According to Wones (1976, p. 54), a large area at the north end of the pluton is underlain by porphyritic granite containing miarolitic cavities not present in the "normal" coarse-grained facies to the south. Major joints (fig. 3) trend predominantly N. to N. 10° E. in the south, but there are three strong trends in the north: N. 20° W. to N. 30° W., N. 50° W. to N. 60° W., and N. 40° E. to N. 60° E. The simple joint pattern in the south should be advantageous for tunnel and chamber alinement and excavation. The differences in jointing may reflect different stress regimes. Gross differences in the two parts of the pluton are suggested by Wones. He found that the southern coarse-grained "normal" granite was older than the porphyritic granite and had moved up as much as 1000 m from the core of the pluton along the boundary fault. Excavations should be located well away from this significant zone (fig. 3).

Gravity data of Sweeney (1976) show that a broad, deep mass of granite more than 7 km thick and greater than 100 km^2 in area occurs in the southeast part of the body and that this zone is bounded by shallower, less extensive granite to the north and west. Thus, the southern part of the pluton appears to be thicker and more homogeneous than the northern part.

Finally, in situ stresses should be determined at potential storage sites. This information will allow optimum chamber orientation based on the direction and relative magnitudes of the principal stresses and joint attitudes. Rebound and rockburst, problems encountered in some Maine coastal quarries and indicative of high horizontal stresses, should be assessed in light of stress determinations. Field evidence of these phenomena is lacking in the Lucerne Granite as very little quarrying has been done in this rock.

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