MISCELLANEOUS PAPER C-70-6

TESTS OF ROCK CORES SCOTT STUDY AREA, MISSOURI

by

R. W. Crisp, C. R. Hallford

May 1970

Sponsored by Space and Missile Systems Organization, U. S. Air Force Systems Command

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

ASSOCIATED REPORTS

MP C-69-3	Tests of Rock Cores, Warren Area, Wyoming	March 1969
MP C-69-12	Tests of Rock Cores, Mountain Home, Idaho, and Fairchild, Washington, Areas	September 1969
MP C-69-16	Tests of Rock Cores, Castle Study Area, California	October 1969
MP C-70-4	Tests of Rock Cores, Bergstrom Study Area, Texas	February 1970

TELEPHONE OR VERBAL CONVERSATION RECORD

For use of this form, see AR 340-15; the proponent agency is The Adjutant General's Office.

29 February 1972

SUBJECT OF CONVERSATION

Distribution Statement on Reports

INCOMING CALL		
PERSON CALLING	ADDRESS	PHONE NUMBER AND EXTENSION
PERSON CALLED	OFFICE	PHONE NUMBER AND EXTENSION

OUTGOING CALL		
PERSON CALLING Mr. James M. Polatty	OFFICE Concrete Division	PHONE NUMBER AND EXTENSION
PERSON CALLED Captain B. W. Bullard	ADDRESS Space & Missile Systems Organization	PHONE NUMBER AND EXTENSION

SUMMARY OF CONVERSATION

I called SAMSO and talked to CPT Bullard. CPT Bullard was familiar with the WES reports covering rock tests for SAMSO. I explained the requirements of AR 70-31. He agreed that Statement A should be utilized on all of the SAMSO rock test reports.

James M. Polatty

JAMES M. POLATTY, Chief
Engineering Mechanics Branch
Concrete Division

Copy furnished:
Publications-Distribution

Laura Hanisee said following MP's covering rock tests for SAMSO were to be changed to Statement A :

C-69-3
C-69-12
C-69-16
C-70-4
C-70-6
C-70-7
C-70-9
C-70-10
C-70-11
C-70-14
C-70-16
C-70-17

DA FORM 1 APR 66 751 REPLACES EDITION OF 1 FEB 50 WHICH WILL BE USED.

★ GPO: 1965 O — 343-775/84

MISCELLANEOUS PAPER C-70-6

TESTS OF ROCK CORES SCOTT STUDY AREA, MISSOURI

by

R. W. Crisp, C. R. Hallford

May 1970

Sponsored by Space and Missile Systems Organization, U. S. Air Force Systems Command

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

ABSTRACT

Laboratory tests were conducted on rock core samples received from nine core holes in the Scott Area of Iron, Madison, Saint Francois, and Wayne Counties, Missouri. The results were used to determine the quality and uniformity of the rock to depths of 200 feet below ground surface.

The cores were identified as predominantly rhyolite and dacite porphyry with some granodiorite and small amounts of dolomite, acid metavolcanics, and dark gray volcanic breccia. Specific gravity, Schmidt hardness, compressional and shear wave velocity, and uniaxial compressive strength tests indicated that the highly to critically fractured material, representing approximately 10 percent of the core tested, was of questionable competence. The remainder of the core from this area was found to be relatively competent material.

Based on the results of the tests reported herein, the following conclusions appear warranted:

1. The core was petrographically identified as predominantly rhyolite and dacite porphyry with some granodiorite and small amounts of dolomite, acid metavolcanics, and dark gray volcanic breccia.

2. Based on physical appearance, the following distinct groups of material were represented within the different rock types: intact rock; rock containing fine incipient fractures; moderately fractured

rock; highly to critically fractured rock; and vesicular rock.

3. The highly to critically fractured material exhibited marginal strength characteristics.

4. The moderately fractured to intact material was very competent..

5. The vesicular material exhibited lower strengths than did the moderately fractured material, but was still relatively competent rock.

6. The consistently high compressional wave velocities indicate that the macrofracturing in this area is generally of a tightly closed nature.

7. Results of three-dimensional compressional wave velocity tests conducted on representative specimens indicate that the fractured to intact core is generally quite isotropic. The granodiorite is somewhat anisotropic (3.7 percent variation).

8. The core from this area is generally quite brittle, exhibiting little, if any, hysteresis.

9. Direct and indirect tensile strengths exhibited by the rhyolite and dacite porphyry and granite are very high, but correlate rather well with the relatively high compressive strengths. Direct tensile strength ranged from approximately 5 to 10 percent of the uniaxial compressive strength.

10. Young's moduli exhibited by the dacite and rhyolite porphyry

were consistently high, averaging about 12 million psi. Moduli exhibited by the granite were slightly lower.

11. Evaluation of the area on a hole-to-hole basis indicates that the Scott Area formations sampled and tested generally offer good possibilities as competent hard rock media. The areas represented by Holes ST-CR-18 and -12 are, however, questionable, exhibiting several zones of marginal to poor quality material. Further investigation will be required to fully evaluate the area.

PREFACE

This study was conducted in the Concrete Division of the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Air Force Space and Missile Systems Organization (SAMSO) of the Air Force Systems Command. The study was coordinated with CPT Rupert G. Tart, Jr., SAMSO Project Officer, and Mr. M. V. Anthony of TRW, Inc., Norton Air Force Base, California. The work was accomplished during the period July through August 1969 under the general supervision of Mr. Bryant Mather, Chief, Concrete Division, and under the direct supervision of Messrs. J. M. Polatty, Chief, Engineering Mechanics Branch, W. O. Tynes, Chief, Concrete and Rock Properties Section, and K. L. Saucier, Project Officer. The petrographic analysis was performed by Mr. C. R. Hallford under the direct supervision of Mr. R. V. Tye, Chief, Engineering Science Branch, and Mrs. K. Mather, Chief, Petrography and X-Ray Section. Mr. R. W. Crisp performed the majority of the program analysis and prepared this report with the assistance of Mr. Hallford.

Director of the WES during the investigation and the preparation and publication of this report was COL Levi A. Brown, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
feet per second	0.3048	meters per second
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms (force) per square centimeter
	6.894757	kilonewtons per square meter

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The purpose of this study was to supplement the information being obtained for the area evaluation study by the U. S. Air Force Space and Missile Systems Organization (SAMSO). It was necessary to determine the properties of the specific materials for (1) evaluation of the area as a hard rock medium; (2) utilization in the various computer codes for ground-motion predictions; and (3) as necessary, for design of structures in the medium. Results of tests on cores from Iron, Madison, Saint Francois, and Wayne Counties, near Scott Air Force Base, Missouri, are reported herein.

1.2 OBJECTIVE

The objective of this investigation was to conduct laboratory tests on samples from geographical study areas to determine the integrity and the mechanical behavior of the materials as completely as possible, analyze the data thus obtained, and report the results to appropriate users.

1.3 SCOPE

Laboratory tests were conducted as indicated on the following page on samples received from the field. Table 1.1 gives pertinent information on the various tests.

Tests were conducted to determine the general quality, uniformity, and integrity of the rock in the area sampled. The tests were conducted to determine the following: (1) relative hardness (Schmidt number), (2) specific gravity, (3) unconfined compressive strength (from conventional and cyclic compression tests), (4) dynamic moduli, (5) sonic velocity, and (6) petrography.

1.4 SPECIMENS

Specimens were received from nine holes in the Scott Area. These holes were designated ST-CR-4, -7, -9, -12, -16, -18, -20, -26, and -28. All specimens were NX-size cores (nominal 2-1/8-inch[1] diameter). Test specimens of the required dimensions (Table 1.1) were prepared for the individual tests. Tests were conducted on selected specimens from all holes.

1.5 REPORT REQUIREMENTS

The immediate need for the test results required that data reports be compiled and forwarded to the users as work was completed on each hole. The data reports of the individual test results are included herein as Appendixes A through I.

---

[1] A table of factors for converting British units of measurement to metric units is presented on page 9.

TABLE 1.1 SUMMARY OF TESTS

Test	Specimen Size	Test Equipment	Recording Equipment	Measured Properties	Computed Properties
Relative hardness	1 diam by 2 diam	Schmidt hammer	--	Relative hardness	--
Specific gravity		Scales	--	Specific gravity	Density
Indirect tension		440,000-pound test machine	--	Tensile strength	--
Direct tension		30,000-pound test machine	--	Tensile strength	--
Unconfined compression		440,000-pound test machine	X-Y recorder	Compressive strength	--
Cyclic compression		400,000-pound test machine	X-Y recorder	Compressive strength	Young's, shear, and bulk moduli and Poisson's ratio
Dynamic elastic moduli		Pulse generator, amplifiers	Oscilloscope	Compressional and shear velocities	Young's, shear, and bulk moduli and Poisson's ratio
Sonic velocity		Pulse generator, amplifiers	Oscilloscope	Compressional and shear velocities	--
Petrographic examination	Variable	Microscopes, X-ray diffraction	--	Appearance, texture, and mineralogy	--
Three-dimensional dynamic elastic properties	1 diam by 1 diam	Pulse generator, amplifiers	Oscilloscope	Compressional and shear velocities	Young's, shear, and bulk moduli and Poisson's ratio

CHAPTER 2

TEST METHODS

2.1 SCHMIDT NUMBER

The Schmidt number is a measure of the relative degree of hardness as determined by the degree of rebound of a small mass propelled against a test surface. Twelve readings per specimen were taken. The average of these readings is the Schmidt number, or relative hardness. The hardness is often taken as an approximation of rock quality, and can frequently be correlated with other physical properties such as strength, density, and modulus of elasticity.

2.2 SPECIFIC GRAVITY

The specific gravity of the as-received samples was determined by the loss-of-weight method conducted according to Method CRD-C 107 of the "Handbook for Concrete and Cement."[1] A pycnometer is used to determine the loss of weight of the sample upon submergence. The specific gravity is equal to the weight in air divided by the loss of weight in water.

---

[1] U. S. Army Engineer Waterways Experiment Station, CE; "Handbook for Concrete and Cement"; August 1949 (with quarterly supplements); Vicksburg, Miss.; Unclassified.

2.3 INDIRECT TENSION

The tensile strength was determined by the indirect method, commonly called the tensile splitting or Brazilian method, in which a tensile failure stress is induced in a cylindrical test specimen by a compressive force applied on two diametrically opposite line elements of the cylindrical surface. The test was conducted according to Method CRD-C 77 of the "Handbook for Concrete and Cement."[2]

2.4 DIRECT TENSION

For purposes of comparison, specimens were prepared and tested for tensile strength according to the American Society for Testing and Materials' (ASTM) proposed "Standard Method of Test for Direct Tensile Strength of Rock Core Specimens." Tensile splitting tests were conducted on specimens cut adjacent to the direct tensile test specimens.

For the direct tension tests, the specimens were right circular cylinders, the sides of which were straight to within 0.01 inch over the full length of the specimen and the ends of which were parallel and not departing from perpendicularity to the axis by more than 0.25 degree. Cylindrical metal caps were cemented to the ends of the specimens and provided the means for applying the direct tensile

---

[2] Ibid.

load. The load was applied continuously by a 30,000-pound-capacity universal testing machine and at a constant rate such that failure occurred within 5 to 15 minutes.

2.5 COMPRESSIVE STRENGTH TESTS

The unconfined and cyclic compression test specimens were prepared according to the ASTM and Corps of Engineers' standard method of test for triaxial strength of undrained rock core specimens, CRD-C 147. Essentially, the specimens were cut with a diamond blade saw, and prior to testing the cut surfaces were ground to a tolerance of 0.001 inch across any diameter with a surface grinder. Electrical-resistance strain gages were utilized for strain measurements, two each in the axial (vertical) and horizontal (diametral) directions. Static Young's, bulk, shear, and constrained moduli were computed from strain measurements and were based on tangent moduli computed at 50 percent of the ultimate strength. Stress was applied with a 440,000-pound-capacity universal testing machine.

2.6 DYNAMIC ELASTIC PROPERTIES

Bulk, shear, and Young's moduli, Poisson's ratio, compressive velocity, and shear velocity were determined on selected rock specimens by use of the proposed ASTM "Standard Method of Test for Laboratory Determination of Ultrasonic Pulse Velocities and Elastic Constants of Rock."

Specimens were prepared by cutting the ends of the NX-size cores with a diamond blade saw and grinding these surfaces with a surface grinder to a tolerance of 0.001 inch across any diameter.

The test method essentially consisted of generating a wave in the specimen with a pulse generator unit and measuring, with an oscilloscope, the time required for the compression and shear waves to travel the length of specimen, the resulting wave velocity being the distance traveled divided by the travel time. These compressive and shear velocities, along with the bulk density of the specimen, were used to compute the dynamic elastic properties.

2.7 PETROGRAPHIC EXAMINATION

A limited petrographic examination was conducted on samples selected to be representative of the material received from the several holes. The examination was limited to identifying the rock, determining general condition, identifying mineralogical constituents, and noting any unusual characteristics that may have influenced the test results.

2.8 THREE-DIMENSIONAL DYNAMIC ELASTIC PROPERTIES

Compressional and shear wave velocities, bulk, shear, and Young's moduli, and Poisson's ratio were determined according to the ASTM proposed method described in Section 2.6, except that in the case of the special tests used to determine the degree of anisotropy of the samples, compressional and shear velocities were measured along two mutually perpendicular, diametral (lateral) axes and along the longitudinal axis. This was facilitated by grinding four 1/2-inch-wide strips down the sides of the cylindrical surface at 90-degree angles and generating the compression and shear waves perpendicular to these ground surfaces.

CHAPTER 3

QUALITY AND UNIFORMITY TEST RESULTS

3.1 RHYOLITE PORPHYRY

The entire core received from two holes, ST-CR-7 and -9, and portions of the cores from two others, ST-CR-18 and -26, were petrographically identified as rhyolite porphyry. To facilitate analysis of the data, results of physical tests on these cores were grouped as follows: (1) intact rock, i.e., material free from macroscopic fractures, joints, and/or seams; (2) moderately fractured rock, i.e., rock containing relatively few healed and/or tightly closed fractures; (3) highly to critically fractured rock, i.e., rock containing open fractures, well developed systems of fracture, and critically oriented fractures (fractures inclined with respect to the horizontal at angles at which failing shearing stresses are developed when the specimen is subjected to relatively low axial stresses); and (4) rock containing vesicles. Detailed results are given in Appendixes B, C, F, and H. A summary of the average test results is presented in the following tabulation.

Property	Intact Material	Moderately Fractured Material	Highly to Critically Fractured Material	Vesicular Material
Specific gravity	2.692 (8)	2.667 (4)	2.635 (7)	2.604 (7)
Schmidt number	53.1 (5)	67.0 (4)	53.0 (4)	50.0 (4)
Uniaxial compressive strength, psi	46,170 (8)	33,590 (4)	12,760 (7)	20,030 (7)
Compressional wave velocity, fps	20,320 (8)	20,510 (4)	19,445 (7)	19,765 (7)
Shear wave velocity, fps	11,380 (3)	11,050 (2)	10,120 (2)	10,340 (2)

Note: Number of specimens tested is given in parentheses.

Unconfined compressive strengths exhibited by the rhyolite porphyry were somewhat variable, depending primarily upon the nature and degree of fracturing present. The highly to critically fractured rock exhibited marginal strength characteristics. Although the average compressive strength was 12,760 psi, two of the seven specimens of this type yielded strengths of approximately 8,000 psi or less. A compilation of individual test results is given in Table 3.1. The vesicular material, all of which was located in Hole ST-CR-9, was found to be substantially stronger than the highly to critically fractured material. Compressive strengths were, however, somewhat variable, ranging from 14,550 to 29,090 psi. Predictably, specific gravities exhibited by the vesicular material were lower than those of any other material tested from the Scott Area.

The moderately fractured rhyolite porphyry removed from Hole ST-CR-7 exhibited test results generally very similar to those exhibited by the intact material, indicating that the healed and/or tightly closed fractures had little, if any, detrimental effect on many physical properties. Average uniaxial compressive strengths of the moderately fractured and intact materials were very high, i.e. 33,590 and 46,170 psi, respectively. However, large variations were present within both groups.

The rhyolite porphyry from this area, particularly the moderately fractured and intact rock, is apparently a very brittle material as indicated by the slight hysteresis loop in the stress-strain curves (Appendixes B, C, F, and H). Considerable macrofracturing is present, as evidenced by the photographs included in the petrographic report (see Section 4.4).

3.2 DACITE PORPHYRY

The cores received from Holes ST-CR-4, -20, and -28, and portions of the cores received from Holes ST-CR-12 and -26 were petrographically identified as dacite porphyry. Physical test results were grouped as follows: (1) intact rock, (2) rock containing fine incipient fractures, (3) moderately fractured rock, and (4) highly to critically fractured rock. Detailed results are given in Appendixes A, D, G, H, and I. A summary of the average test results is presented in the following tabulation.

Property	Intact Material	Material Containing Fine Incipient Fractures	Moderately Fractured Material	Highly to Critically Fractured Material
Specific gravity	2.699 (7)	2.675 (5)	2.697 (14)	2.788 (8)
Schmidt number	56.5 (5)	55.7 (4)	56.2 (9)	55.4 (4)
Uniaxial compressive strength, psi	51,165 (7)	45,630 (5)	26,015 (14)	11,435 (8)
Compressional wave velocity, fps	20,730 (7)	20,845 (5)	20,525 (14)	21,120 (8)
Shear wave velocity, fps	11,515 (2)	10,925 (1)	11,790 (3)	11,570 (2)

Note: Number of specimens tested is given in parentheses.

In spite of the varying degrees of fracturing present, physical properties exhibited by the dacite porphyry were, with the exception of uniaxial compressive strength, relatively uniform. Compressive strength, however, was quite variable, ranging from 1,700 to

65,240 psi. Apparently, this large variation was primarily due to the nature and degree of fracturing present in the material.

The lowest compressive strengths observed in this material were, predictably, exhibited by the highly to critically fractured rock. Strengths for cores of this nature generally ranged from 10,000 to 18,000 psi; the only dacite porphyry specimen to fail at less than 10,000 psi was highly fractured and yielded a strength of only 1,700 psi. A compilation of individual test results is given in Table 3.2.

The moderately fractured rock exhibited a variety of compressive strengths ranging from 17,000 to 41,000 psi--rather competent rock. The rock containing fine incipient fractures was substantially stronger than the moderately fractured core and only slightly weaker than the intact material, indicating that fine, tightly closed incipient fractures had little effect on compressive strength.

Generally, the physical properties exhibited by the dacite porphyry were very similar to those exhibited by the rhyolite porphyry. The nature and degree of fracturing apparently affected both materials in the same manner and to the same extent. The dacite porphyry was rather brittle, exhibiting little or no plastic deformation prior to failure. The slight hysteresis detected was apparently caused by sudden slippage along already present fracture surfaces as opposed to energy dissipation in the intact rock. Considerable macrofracturing was detected in the photographs taken during the petrographic examination.

3.3 GRANODIORITE

The core received from Hole ST-CR-16 was identified as granodiorite. This material was generally in one of two conditions--intact or moderately fractured. Results of physical tests were grouped accordingly. Detailed results are given in Appendix E. A summary of the average results is presented in the following tabulation.

Property	Intact Material	Moderately Fractured Material
Specific gravity	2.614 (4)	2.619 (6)
Schmidt number	50.9 (4)	51.5 (5)
Compressive strength, psi	40,000 (4)	29,570 (6)
Compressional wave velocity, fps	17,825 (4)	17,770 (6)
Shear wave velocity, fps	9,570 (2)	--

Note: Number of specimens tested is given in parentheses.

The core received from Hole ST-CR-16 was found to be somewhat variable, but generally quite competent. The intact material was brittle and exhibited negligible hysteresis. The slight reverse curvatures of the stress-strain curves (Appendix E) were indicative of some initial crack closure.

While the moderately fractured core was somewhat weaker than the intact rock, it was still relatively competent, exhibiting compressive strengths ranging from 16,000 to 38,000 psi (Table 3.3). One moderately fractured specimen, No. 21, contained a preexisting shear plane along which failure occurred. It should be noted that while the average uniaxial compressive strengths exhibited by the two groups differed by over 10,000 psi, the two groups did not encompass independent ranges of strength. Instead, strengths yielded by the moderately fractured rock graded into those exhibited by the intact material.

3.4 ACID METAVOLCANICS, BRECCIA, AND DOLOMITE

Of the 201 specimens received from the Scott Area, 25 were petrographically identified as acid metavolcanics, breccia, or dolomite. These materials were taken from Holes ST-CR-12, -18, and -26. Physical properties were determined for 7 of these 25 specimens. Detailed results are given in Appendixes D, F, and H. A summary of the average results is presented in the following tabulation.

Property	Moderately Fractured Acid Metavolcanics	Highly Fractured Acid Metavolcanics	Critically Fractured Breccia	Highly Fractured Dolomite
Specific gravity	2.830 (3)	2.654 (1)	2.651 (1)	2.786 (2)
Schmidt number	62.0 (2)	--	--	44.2 (2)
Compressive strength, psi	33,170 (3)	7,860 (1)	8,520 (1)	7,560 (2)
Compressional wave velocity, fps	21,795 (3)	--	19,010 (1)	16,845 (2)
Shear wave velocity, fps	11,800 (1)	--	9,915 (1)	8,390 (1)

Note: Number of specimens tested is given in parentheses.

With the exception of the acid metavolcanics received from Hole ST-CR-12, these materials were generally found to be highly to critically fractured and incompetent, ranging in uniaxial compressive strength from 5,480 to 9,635 psi. The moderately fractured acid metavolcanics from Hole ST-CR-12 were, however, very competent, exhibiting compressive strengths ranging from 24,520 to 45,450 psi (Table 3.4).

TABLE 3.1 RESULTS OF PHYSICAL TESTS ON RHYOLITE PORPHYRY

Hole No.	Core Piece No.	Approximate Depth	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity	Shear Wave Velocity	Static Moduli: Young's	Static Moduli: Bulk	Static Moduli: Shear	Static Poisson's Ratio	Dynamic Moduli: Young's	Dynamic Moduli: Bulk	Dynamic Moduli: Shear	Dynamic Poisson's Ratio
		feet			psi	fps	fps	10^6 psi	10^6 psi	10^6 psi		10^6 psi	10^6 psi	10^6 psi	
Intact Material:															
ST-CR-9	2	15	2.641	52.9	33,780	19,855	10,345	10.2	6.7	4.1	0.24	10.0	9.8	3.8	0.31
	12	115	2.621	50.7	42,500	20,155	--	--	--	--	--	--	--	--	--
	20a	185	2.622	54.2	65,760	19,810	--	--	--	--	--	--	--	--	--
ST-CR-18	11	104	2.649	52.1	44,850	20,005	--	--	--	--	--	--	--	--	--
	14	127	2.665	--	31,300	21,895	12,800	12.8	6.7	5.4	0.18	14.6	9.4	5.9	0.24
	18	157	2.661	--	52,575	20,720	--	--	--	--	--	--	--	--	--
	19	168	2.651	--	55,000	20,350	--	--	--	--	--	--	--	--	--
ST-CR-26	16	136	3.024	55.6	43,570	19,795	10,995	13.2	10.6	5.8	0.29	12.6	9.4	4.9	0.28
		Avg	2.692	53.1	46,170	20,320	11,380	12.1	8.0	5.1	0.24	12.4	9.6	4.9	0.28
Moderately Fractured Material:															
ST-CR-7	6	71	2.659	66.2	35,150	20,760	11,035	12.2	9.8	4.7	0.29	11.3	9.6	4.4	0.30
	7	75	2.660	66.0	21,180	20,545	--	--	--	--	--	--	--	--	--
	13	132	2.666	67.2	42,270	20,350	--	--	--	--	--	--	--	--	--
	14	141	2.683	68.7	35,760	20,380	11,060	11.8	6.3	5.0	0.19	11.4	9.1	4.4	0.29
		Avg	2.667	67.0	33,590	20,510	11,050	12.0	8.0	4.8	0.24	11.4	9.4	4.4	0.29
Highly to Critically Fractured Material:															
ST-CR-7	4	40	2.652	61.7	15,150	20,435	10,190	--	--	--	--	9.9	10.0	3.7	0.33
	5	61	2.645	--	15,150	20,400	--	--	--	--	--	--	--	--	--
	9	93	2.648	--	17,480	20,390	--	--	--	--	--	--	--	--	--
	12	124	2.657	--	8,090	20,170	--	--	--	--	--	--	--	--	--
ST-CR-18	8	83	2.600	55.0	17,300	17,685	--	--	--	--	--	--	--	--	--
	9	89	2.583	40.3	10,480	17,335	10,050	--	--	--	--	8.6	5.7	3.4	0.25
	13	116	2.659	55.0	5,690	19,700	--	--	--	--	--	--	--	--	--
		Avg	2.635	53.0	12,760	19,445	10,120	--	--	--	--	9.2	7.8	3.6	0.29
Vesicular Material:															
ST-CR-9	3	23	2.624	--	18,550	19,715	--	--	--	--	--	--	--	--	--
	4	35	2.605	--	25,860	19,740	10,255	--	--	--	--	9.7	8.8	3.7	0.32
	13	123	2.601	50.9	14,550	20,010	10,425	11.5	10.1	4.4	0.31	10.0	9.0	3.8	0.31
	14	132	2.605	49.3	23,790	19,725	--	--	--	--	--	--	--	--	--
	16	151	2.613	52.8	23,940	19,855	--	--	--	--	--	--	--	--	--
	17	154	2.568	47.1	29,090	19,285	--	--	--	--	--	--	--	--	--
	18	165	2.614	--	25,450	20,020	--	--	--	--	--	--	--	--	--
		Avg	2.604	50.0	23,030	19,765	10,340	11.5	10.1	4.4	0.31	9.8	8.9	3.7	0.31

TABLE 3.2 RESULTS OF PHYSICAL TESTS ON DACITE PORPHYRY

Hole No.	Core Piece No.	Approximate Depth	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity	Shear Wave Velocity	Static Moduli: Young's	Static Moduli: Bulk	Static Moduli: Shear	Static Poisson's Ratio	Dynamic Moduli: Young's	Dynamic Moduli: Bulk	Dynamic Moduli: Shear	Dynamic Poisson's Ratio
		feet			psi	fps	fps	10^6 psi	10^6 psi	10^6 psi		10^6 psi	10^6 psi	10^6 psi	
Intact Material:															
ST-CR-4	1	10	2.692	57.4	65,240	20,995	11,615	12.6	8.8	5.0	0.26	12.5	9.5	4.9	0.28
	7	61	2.683	--	47,340	21,355	11,415	12.0	7.7	4.8	0.24	12.2	10.2	4.7	0.30
	11	100	2.697	55.3	48,060	20,460	--	--	--	--	--	--	--	--	--
	21	181	2.702	56.2	44,460	20,535	--	--	--	--	--	--	--	--	--
ST-CR-20	10	102	2.730	54.2	52,120	20,940	--	--	--	--	--	--	--	--	--
	16	159	2.712	--	50,075	20,640	--	--	--	--	--	--	--	--	--
ST-CR-26	20	176	2.680	59.8	50,860	20,175	--	--	--	--	--	--	--	--	--
		Avg	2.699	56.5	51,165	20,730	11,515	12.3	8.2	4.9	0.25	12.4	9.8	4.8	0.29
Material Containing Fine Incipient Fractures:															
ST-CR-4	2	19	2.687	--	42,290	21,310	--	--	--	--	--	--	--	--	--
	3	27	2.697	59.6	31,900	20,695	--	--	--	--	--	--	--	--	--
ST-CR-28	10	92	2.663	55.5	57,140	20,790	--	--	--	--	--	--	--	--	--
	16	151	2.669	54.4	44,090	20,730	10,925	10.8	6.3	4.4	0.22	11.2	9.7	4.3	0.31
	18	169	2.659	53.4	52,720	20,705	--	--	--	--	--	--	--	--	--
		Avg	2.675	55.7	45,630	20,845	10,925	10.8	6.3	4.4	0.22	11.2	9.7	4.3	0.31
Moderately Fractured Material:															
ST-CR-4	9	79	2.687	--	21,820	20,280	--	--	--	--	--	--	--	--	--
	13	116	2.692	--	17,320	20,335	--	--	--	--	--	--	--	--	--
ST-CR-20	4	42	2.669	--	37,425	19,340	--	--	--	--	--	--	--	--	--
	7	68	2.731	53.4	21,210	20,495	11,600	10.8	7.5	4.3	0.26	12.5	8.8	5.0	0.26
	9	91	2.713	54.3	23,105	20,655	--	--	--	--	--	--	--	--	--
	11	112	2.734	--	26,365	21,085	11,915	9.5	5.2	4.0	0.19	13.2	9.4	5.2	0.27
	12	119	2.722	55.3	19,090	20,715	--	--	--	--	--	--	--	--	--
	17	166	2.712	--	34,240	20,725	--	--	--	--	--	--	--	--	--
	21	200	2.709	61.0	21,970	20,805	--	--	--	--	--	--	--	--	--
ST-CR-26	14	127	2.675	57.5	24,690	20,300	--	--	--	--	--	--	--	--	--
	22	196	2.749	55.8	41,290	20,930	--	--	--	--	--	--	--	--	--
ST-CR-28	4	39	2.649	55.8	25,890	20,680	11,850	12.8	8.7	5.1	0.25	12.6	8.6	5.0	0.26
	11	101	2.655	57.2	28,730	20,440	--	--	--	--	--	--	--	--	--
	13	122	2.659	55.8	21,090	20,565	--	--	--	--	--	--	--	--	--
		Avg	2.697	56.2	26,015	20,525	11,790	11.0	7.1	4.5	0.23	12.8	8.9	5.1	0.26
Highly to Critically Fractured Material:															
ST-CR-4	14	125	2.684	--	13,100	22,260	--	--	--	--	--	--	--	--	--
ST-CR-12	1	8	2.762	51.8	18,080	19,850	--	--	--	--	--	--	--	--	--
	6	50	2.804	--	10,210	21,725	--	--	--	--	--	--	--	--	--
	8	66	2.897	--	12,360	20,400	11,425	11.1	--	--	--	13.3	11.0	5.1	0.30
	9	76	2.746	64.5	10,360	21,550	11,720	12.5	--	--	--	13.1	10.4	5.1	0.29
	11	96	2.757	51.9	11,330	21,690	--	--	--	--	--	--	--	--	--
	13	109	2.920	53.2	1,700	21,050	--	--	--	--	--	--	--	--	--
ST-CR-26	11	104	2.736	--	14,340	20,420	--	--	--	--	--	--	--	--	--
		Avg	2.788	55.4	11,435	21,120	11,570	11.8	--	--	--	13.2	10.7	5.1	0.30

TABLE 3.3 RESULTS OF PHYSICAL TESTS ON GRANODIORITE

Hole No.	Core Piece No.	Approximate Depth	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity	Shear Wave Velocity	Static Moduli: Young's	Static Moduli: Bulk	Static Moduli: Shear	Static Poisson's Ratio	Dynamic Moduli: Young's	Dynamic Moduli: Bulk	Dynamic Moduli: Shear	Dynamic Poisson's Ratio
		feet			psi	fps	fps	10^6 psi	10^6 psi	10^6 psi		10^6 psi	10^6 psi	10^6 psi	
Intact Material:															
ST-CR-16	1	11	2.600	47.5	33,350	17,580	9,365	9.1	6.7	3.4	0.27	8.0	6.7	3.1	0.30
	4	38	2.620	50.3	40,280	17,600	--	--	--	--	--	--	--	--	--
	9	86	2.621	53.4	43,930	18,280	9,780	10.4	7.6	4.1	0.27	8.8	7.3	3.4	0.30
	16	155	2.616	52.3	42,430	17,840	--	--	--	--	--	--	--	--	--
		Avg	2.614	50.9	40,000	17,825	9,570	9.8	7.2	3.8	0.27	8.4	7.0	3.2	0.30
Moderately Fractured Material:															
ST-CR-16	2	18	2.594	53.6	36,140	16,920	--	--	--	--	--	--	--	--	--
	3	28	2.601	--	16,430	16,790	--	--	--	--	--	--	--	--	--
	12	116	2.616	52.0	37,800	17,930	--	--	--	--	--	--	--	--	--
	15	144	2.617	50.0	22,140	18,110	--	--	--	--	--	--	--	--	--
	20	192	2.624	49.4	38,570	17,970	--	--	--	--	--	--	--	--	--
	21	199	2.664	52.6	26,360	18,910	--	--	--	--	--	--	--	--	--
		Avg	2.619	51.5	29,570	17,770	--	--	--	--	--	--	--	--	--

TABLE 3.4 RESULTS OF PHYSICAL TESTS ON ACID METAVOLCANICS, BRECCIA, AND DOLOMITE

Hole No.	Core Piece No.	Approximate Depth	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity	Shear Wave Velocity	Static Moduli Young's	Static Moduli Bulk	Static Moduli Shear	Static Poisson's Ratio	Dynamic Moduli Young's	Dynamic Moduli Bulk	Dynamic Moduli Shear	Dynamic Poisson's Ratio
		feet			psi	fps	fps	10^6 psi	10^6 psi	10^6 psi		10^6 psi	10^6 psi	10^6 psi	
Moderately Fractured Acid Metavolcanics:															
ST-CR-12	15	127	2.836	59.7	29,550	20,880	11,800	12.5	--	--	--	13.5	9.6	5.3	0.27
	19	158	2.824	--	24,520	22,310	--	--	--	--	--	--	--	--	--
	20	166	2.831	64.3	45,450	22,190	--	--	--	--	--	--	--	--	--
		Avg	2.830	62.0	33,170	21,795	11,800	12.5	--	--	--	13.5	9.6	5.3	0.27
Highly Fractured Acid Metavolcanics:															
ST-CR-26	2	19	2.654	--	7,860	--	--	--	--	--	--	--	--	--	--
Critically Fractured Breccia:															
ST-CR-26	6	56	2.651	--	8,520	19,010	9,915	8.7	4.4	3.7	0.17	9.2	8.2	3.5	0.31
Highly Fractured Dolomite:															
ST-CR-18	2	38	2.798	52.1	5,480	20,480	--	--	--	--	--	--	--	--	--
	4	55	2.775	36.3	9,635	13,215	8,390	5.9	4.7	2.3	0.29	6.1	3.0	2.6	0.16
		Avg	2.786	44.2	7,560	16,845	8,390	5.9	4.7	2.3	0.29	6.1	3.0	2.6	0.16

CHAPTER 4

SPECIAL TESTS

4.1 ELASTIC MODULI

Samples representative of the different materials in each hole were selected for deformation moduli tests for the data reports. Results of the moduli tests are presented in Table 4.1. Dynamic moduli presented in these data reports were determined by the seismic pulse method according to the ASTM proposed "Standard Method of Test for Laboratory Determination of Ultrasonic Pulse Velocities and Elastic Constants of Rock." After the dynamic tests had been completed, portions of most specimens were prepared for static testing. Static moduli were computed from measurements taken from electrical-resistance strain gages affixed to the specimens. The tangent modulus of elasticity and Poisson's ratio were computed at 50 percent of ultimate strength. Static moduli were not determined for some of the more highly fractured specimens since electrical-resistance strain gages applied to this type of material generally yield very erratic results.

The rhyolite and dacite porphyry exhibited, with the exception of the highly fractured material, consistently high moduli. Dynamic and static results were in close agreement. Those specimens containing tightly closed fractures (moderately fractured material and material containing fine incipient fractures) generally exhibited Young's moduli only slightly lower than those exhibited by the intact rock, indicating that prior to catastrophic failure very little slippage occurred along the fractures. Jaeger[1] states that "the effective Young's modulus of a body containing closed cracks is less than its intrinsic Young's modulus if the surfaces of the cracks slide past one another."

Moduli exhibited by the intact granodiorite were somewhat lower than those exhibited by the porphyry, but static and dynamic results were again in exceptionally close agreement. No moduli were determined for the fractured granodiorite.

Because acid metavolcanic, breccia, and dolomite specimens were relatively scarce, little data were available for analysis and comparison. Generally, however, the moderately fractured acid metavolcanics tended toward high moduli that were comparable to those exhibited by the porphyry. The highly to critically fractured breccia and dolomite exhibited the lowest static moduli of all the specimens tested from this area.

---

[1] J. C. Jaeger and N. G. W. Cook; "Fundamentals of Rock Mechanics"; 1969; Methuen and Company, Ltd.; London; Unclassified.

4.2 COMPARATIVE TENSILE TESTS

Eight NX-size-diameter rock specimens were selected to represent the variation of rock type present in the cores received from the drill holes in the Scott Area. The specimens were prepared and tested for tensile strength according to the ASTM proposed "Standard Method of Test for Direct Tensile Strength of Rock Core Specimens." For comparative purposes, tensile splitting tests were conducted on specimens cut adjacent to the direct tensile test specimens.

Results of the tensile strength tests are given in Table 4.2. Specimens 4-4, 16-13, 20-18, and 28-14 failed through the bonding agent during the initial test attempts. Specimens ST-CR-7-13 and ST-CR-9-8 exhibited direct tensile strengths exceeding the strength of the bonding agent. Therefore, direct tensile strength of these two specimens could not be determined.

The tensile strengths of the competent porphyry and granite are relatively high in comparison with those of other materials. A literature review yielded limited results of direct tensile strength data. However, one author[2] reported very few tensile strengths exceeding 1,000 psi for a variety of rock types tested. Significantly,

---

[2] R. G. Wuerker; "The Shear Strength of Rocks"; Mining Engineering, October 1959, Vol 11, Pages 1022-1026; Unclassified.

the porphyry and granite materials exhibiting rather large tensile strengths also exhibited very high compressive strengths.

The tensile splitting (indirect) strengths of the competent rock are exceptionally high (generally twice as great as the direct tensile strengths). The indirect tensile strength should be greater than the direct tensile strength because in the direct tensile strength test, the specimen has a better opportunity to fail at the point of minimum strength. Thus, in assessing competency of a rock medium, one would normally utilize the direct tensile strength, as it is the more conservative result.

The direct and indirect tensile strength results are comparable for the welded tuff, but the direct tensile strength of the marl is sufficiently low to void tensile strength as a significant physical property of this material.

4.3 ANISOTROPY TESTS

Compressional and shear velocity tests were conducted on eight specimens from the Scott Area, with one velocity being determined in the axial direction and two others being determined on mutually perpendicular diametral (lateral) axes, as previously described in Section 2.8. Results of the velocity determinations are presented in Table 4.3.

A convenient method for determining the degree of anisotropy is to examine the maximum percent deviation from the average of the compressional wave velocity, but the point of division between isotropy and anisotropy is difficult to define. The proposed ASTM test method states that the equations for computation of dynamic elastic moduli should not be used if "any of the three compressional wave velocities vary by more than 2 percent from their average value. The error in Young's modulus (E) and shear modulus (G) due to both anisotropy and experimental error then does not exceed 6 percent." On this basis, seven of the eight specimens tested were determined to be isotropic; the medium-grained granodiorite from Hole ST-CR-16 was determined to be anisotropic.

Computations of dynamic elastic moduli and constants were made on the seven specimens exhibiting compressional wave deviations of less than 2 percent. Results are presented in Table 4.4. In evaluating these results, due consideration should be given to the fact that the highly fractured rock representative of portions of some core from this area could not be prepared for the special tests. This fractured material would probably have exhibited lower velocities and a larger compressive deviation.

To evaluate the effect of anisotropy on a rock mass, the state of stress expected or applied should be determined. The effect of elastic anisotropy on the stress distribution is greatest for a uniaxial state of stress, a state that exists in very little massive rock. Obert[3] indicates that if the stress field is hydrostatic and the ratio of moduli due to anisotropy is approximately two, the maximum difference between stress for the isotropic case and that for the anisotropic case would be only 10 to 15 percent. He further states that

> It can be inferred that for most rock, the effects of elastic anisotropy are no larger than the normal variations in rock strength and, hence, they can be neglected. The most likely exceptions to this generalization would be strongly foliated metamorphic rocks, such as micaceous schists...where the moduli of elasticity often differ by a factor greater than two.[3]

4.4 PETROGRAPHIC EXAMINATION

Nine boxes of NX-size cores from holes in Iron, St. Francois, Madison, and Wayne Counties, Missouri, were received for testing in July 1969. Each box contained about 15 feet of core material representing several depths to 200 feet.

The contents of each box were inspected in order that representative material from all significant rock types could be selected for petrographic examination. Inspection of the cores and logs indicated the results presented in the following paragraphs.

---

[3] Leonard Obert and W. I. Durall; "Rock Mechanics and the Design of Structures in Rock"; John Wiley and Sons, New York, N. Y.; 1967; Unclassified.

4.4.1 Hole ST-CR-4 (SAMSO-7 DC-1). The entire core was blue-gray porphyritic dacite, with inclusions of chlorite. Steeply dipping joints were closed and usually coated with chlorite. The core sections, which were very fresh, showed very little difference in degree of weathering and alteration.

4.4.2 Hole ST-CR-26 (SAMSO-7 DC-2). At least five rock types were present in this core. They were a green, fine-grained, acid metavolcanic; a dark red and black breccia; a reddish-brown porphyry; a blue-gray porphyry; and a black, fine-grained basalt. All the sections were severely fractured and jointed, with partings varying from nearly vertical to horizontal.

Pieces 2, 3, and 15 were the light green acid metavolcanic rock and contained many high-angle and horizontal open fractures. Pieces 1, 5, 6, 7, 18, 19, and 21 were dark breccia or volcanic agglomerate. The fragments included were black and red, and the ground mass was reddish-brown. All pieces contained closed high-angle and vertical fractures. Pieces 10, 11, 13, 14, 20, and 22 were reddish-brown porphyry. Pieces 10, 11, 13, and 14 were severely fractured, and Pieces 20 and 22 were massive, with almost no visible fractures. Pieces 4, 9, and 16 were blue-gray porphyry. All of these pieces were intact and were logged as parts of large inclusions in the breccia and the rhyolite. Pieces 12 and 17 were dark, fine-grained, very massive basaltic rocks. Piece 8 was part of an aplite dike cutting the breccia; the aplite is a minor constituent in this hole.

4.4.3 Hole ST-CR-9 (SAMSO-7 DC-3). The entire core was brownish-red porphyry with a nearly horizontal flow structure and many vesicles parallel to the flow structure. There were few visible fractures present in the core, but microfractures were apparent under magnification.

4.4.4 Hole ST-CR-16 (SAMSO-7 DC-4). The entire core was light red, medium-grained, granitic rock. Pieces 2, 3, 12, 13, 14, 19, and 20 contained steeply dipping closed fractures, and the rest of the core was intact. Pieces 1, 2, and 3 were slightly weathered.

4.4.5 Hole ST-CR-18 (SAMSO-7 DC-5). This core was composed of dolomite and porphyry. The dolomite was light gray rock ranging from poorly crystalline, highly fractured rock to massive marble. The other rock type was reddish-brown porphyry that was predominantly intact.

Pieces 1 through 7 were dolomite, with Pieces 4 through 7 being finely crystalline. The remainder of the core was porphyry. Pieces 8 through 10 were more weathered than the remainder of the porphyry.

4.4.6 Hole ST-CR-20 (SAMSO-7 DC-6). The entire core was brownish-gray highly fractured porphyry. The fractures were randomly oriented, and most had been sealed with chlorite.

4.4.7 Hole ST-CR-12 (SAMSO-7 DC-7). The two rock types were acid metavolcanic and brownish-gray porphyry. Both rocks contained tightly closed vertical to steeply dipping fractures. Pieces 1 through 14 were porphyry. The rock appeared to be severely sheared and tightly sealed with chlorite. The rest of the core was light green, acid metavolcanic rock that intruded and included the porphyry.

4.4.8 Hole ST-CR-28 (SAMSO-7 DC-8). The entire core was grayish-red porphyry, severely fractured and sheared, with a steeply dipping flow structure. Fractures ranged from fine, sealed partings to open, high-angle fractures.

4.4.9 Hole ST-CR-7 (SAMSO-7 DC-9). The entire core was dark gray, vesicular porphyry, showing horizontal flow structure including elongated, filled and empty vesicles.

Sealed and open fractures were present; Pieces 1, 2, 3, 4, 8, 9, 10, 11, and 12 contained open fractures, and the remaining pieces contained sealed fractures.

The 17 core sections chosen for petrographic examination were as follows:

CD Serial No. SAMSO-7	Hole No.	Piece No.	Approximate Depth	Rock Description
			feet	
DC-1	ST-CR-4	1	10	Blue-gray porphyry
DC-2	ST-CR-26	7	64	Dark reddish-brown breccia
		12	113	Blue-gray porphyry
		15	136	Green metavolcanic

(Continued)

CD Serial No. SAMSO-7	Hole No.	Piece No.	Approx-imate Depth	Rock Description
			feet	
DC-2 (Cont'd)	ST-CR-26	17	156	Green metavolcanic
		22	196	Mixed zone
DC-3	ST-CR-9	3	23	Brownish-red porphyry with leached zone and contact with blue-gray porphyry
DC-4	ST-CR-16	8	77	Granite
DC-5	ST-CR-18	1	25	Poorly crystalline, fractured dolomite
		5	64	Light gray dolomitic marble
		22	195	Reddish-brown porphyry
DC-6	ST-CR-20	13	127	Brownish-gray porphyry
DC-7	ST-CR-12	4	38	Brownish-gray porphyry
		14	118	Severely sheared brownish-gray porphyry
		21	179	Light green acid metavolcanic
DC-8	ST-CR-28	8	73	Grayish-red porphyry
DC-9	ST-CR-7	11	113	Vesicular dark green porphyry

4.5 TEST PROCEDURE

Each of the 17 pieces of core was sawed axially, and one sawed surface of each piece was polished and photographed. Composite samples were obtained from the whole length or from selected portions from the unpolished halves of each piece. The samples were ground to pass a No. 325 sieve (44μ). X-ray diffraction (XRD) patterns were made of each sample as a tight-packed powder. The samples X-rayed are listed below:

SAMSO-7	ST-CR-	Piece	Description of X-Ray Sample
DC-1	4	1	Entire length was sampled
DC-2	26	7	Matrix of breccia only
		12	Entire length was sampled
		17	Entire length was sampled
DC-3	9	3	Reddish-brown rock, leached rock, and blue-gray rock were sampled separately
DC-4	16	8	Entire length was sampled
DC-5	18	1	Entire length was sampled
		5	Entire length was sampled
		22	Entire length was sampled
DC-6	20	13	Entire length was sampled
DC-7	12	4	Entire length was sampled
		14	Entire length was sampled
		21	Green rock sampled; inclusion omitted
DC-8	28	8	Entire length was sampled
DC-9	7	11	Entire length was sampled

When it was possible, coatings, fracture fillings, and inclusions were separated and ground to pass a No. 325 sieve (44μ). These samples were slurried with water on a glass slide and X-rayed in the air-dried condition.

All X-ray diffraction patterns were made using an XRD-5 diffractometer with nickel-filtered copper radiation. Polished and broken surfaces of each piece were examined with a stereomicroscope. Small portions of the powdered samples were tested with dilute hydrochloric acid and with a magnet to determine whether carbonate minerals or magnetite were present. Thin sections were prepared from Pieces 12, 15, and 22 of Core 26; Pieces 4 and 21 of Core 12; and Piece 13 of Core 20. A polarizing microscope was used to examine the thin sections.

4.6 RESULTS

The relation of the cores examined to the geologic units in the area is shown in Table 4.5.[4,5] All of the rocks examined except the dolomites were Precambrian. The groups represented are the Middlebrook and Van East groups of extrusive and intrusive felsites, and the younger Bevos group of granitic intrusives; the Middlebrook is regarded as the oldest. Snyder and Wagner[5] suggest that this area

---

[4] William C. Hughes; "Precambrian Rock Units in Missouri"; Guidebook to the Geology of the St. Francois Mountain Area, Report of Investigations No. 26; 1961; State of Missouri Geological Survey; Unclassified.

[5] F. G. Snyder and R. E. Wagner; "Precambrian of Southeastern Missouri, Status and Problems"; Guidebook to the Geology of the St. Francois Mountain Area, Report of Investigations No. 26; 1961; State of Missouri Geological Survey; Unclassified.

has been repeatedly folded, faulted, and intruded. The sheared condition of many of the cores reflects such a history, and repeated fracturing at different angles is believed to explain some of the variations in compressive strength in groups of rocks of similar composition and texture. The rock types found are discussed below.

4.6.1 Dacite Porphyry. Cores SAMSO-7 DC-1, -6, -8, and parts of Cores DC-2 and -7 (Figures 4.1 through 4.4) were logged as blue-gray rhyolite porphyry. X-ray diffraction and examination of thin sections indicate that very little potassium feldspar is present in these cores. The bulk composition of this rock is quartz, plagioclase feldspar (near oligoclase), chlorite, biotite, and magnetite (Table 4.6). The phenocrysts are plagioclase feldspar and quartz; by composition, the rock is classified as dacite porphyry in the Shand[6] system. Piece 4 from Hole DC-1 (at right in Figure 4.1) is a representative sample. In thin section, the rock is composed of severely fractured phenocrysts of plagioclase and quartz in a very finely crystalline ground mass of quartz and plagioclase. Chlorite is found in sealed fractures and as an alteration product of biotite. Unaltered magnetite is disseminated throughout the rock. Variations

[6] S. J. Shand; "Eruptive Rocks"; Third Edition, 1947; John Wiley and Sons, New York, N. Y.; Unclassified.

in compressive strength of this rock are probably due primarily to variation in nature and degree of fracturing present in the core.

4.6.2 Rhyolite Porphyry. All of Cores DC-3, -7, and -9 and parts of Cores DC-2 and -5 (Figures 4.5 through 4.8) were described in field logs as rhyolite porphyries. X-ray diffraction patterns and thin section analysis indicate that these rocks are rhyolite porphyry, containing quartz and equal amounts of potassium and plagioclase feldspar. Piece 22 of DC-2 (Figure 4.8) and Piece 22 of DC-5 (Figure 4.5) represent this rock; they are described below. The bulk composition is quartz, plagioclase (near oligoclase), and potash feldspar, with minor amounts of biotite, chlorite, and magnetite (Table 4.6). Examination of the thin section of DC-2, Piece 22, indicated that the rhyolite porphyry resembles the dacite in composition except that the rhyolite contains orthoclase as phenocrysts and orthoclase in the ground mass (Figure 4.8). The rhyolite porphyries have fewer phenocrysts and better developed flow structure than the dacite porphyries and contain many vesicles elongated parallel to the flow structure (Figures 4.5 and 4.6). The cores are essentially unweathered. Variations in compressive strength are believed to result from different orientation and different degrees of sealing of joints and fractures.

4.6.3 Light Gray Dolomite. This rock made up the top 80 feet of DC-5 and was logged as highly fractured marl. X-ray diffraction examinations of Pieces 1 and 5 showed the rock to be dolomite, ranging from a highly fractured, porous, poorly crystalline rock in Piece 1 to massive, dolomitic marble in Piece 5 (Figure 4.9). The upper 50 feet of dolomite was porous rock that had a bulk composition of dolomite and minor clay mica in thin horizontal bands defining bedding planes. The remainder of the rock was dolomitic marble with a bulk composition of dolomite, epidote, and illite. The dolomitic marble exhibited higher compressive strength values than did the porous dolomite, probably because the marble was less porous than the dolomite and did not contain fractures at critical angles.

4.6.4 Dark Gray Breccia. This rock was found only in DC-2, Pieces 1, 5, 6, 7, 18, 19, and 21. The matrix was dacitic at the top, containing only plagioclase feldspar at the top of the hole but increasing in potassium feldspar to the composition of rhyolite with increasing depth. The included fragments were rounded basalt except near the bottom of the hole, where the breccia contained a lower proportion of fragments and of basalt fragments. However, some granitic fragments were present. Piece 7 of DC-2 (Figure 4.10) represented the breccia. This rock was sheared and fractured, but the fractures were usually sealed with chlorite, epidote, and quartz. There was a great deal of magnetite present in most of the pieces.

4.6.5 Pink Granodiorite. All of the core in DC-4 was logged as hornblende granite. Examination of the sample indicated that it was medium-grained, biotite, chlorite granodiorite. Chlorite was present as an alteration product of biotite. Piece 8 of DC-4 (Figure 4.11) was representative of this type. The bulk composition was plagioclase, orthoclase, quartz, biotite, and chlorite. About one-third of the pieces of the core contained fractures, most of which were sealed with chlorite. Differences in compressive strength were apparently due to the fractures, as the rock was otherwise homogeneous.

4.6.6 Green Metavolcanics. SAMSO-7 DC-2 Sections 2, 3, 15, and 17 and DC-7 Sections 15 through 21 belonged to this group. The rocks ranged from acidic green highly fractured rocks with well-developed flow structure to massive, structureless, dark green basaltic rocks. The green rock is logged as welded tuff (Sections 14 through 23) in the field log of SAMSO-7 DC-7 (ST-CR-12) and as low-grade metamorphics in DC-2 (ST-CR-26) (Sections 2, 3, and 15). Section 21 of DC-7 (on right in Figure 4.3) was representative of this group. The bulk composition was quartz, plagioclase, chlorite, biotite, and magnetite. The rock was uniformly fine-grained and contained both open and closed fractures. The greenstone intruded and included a felsitic rock (Figure 4.3). The rock in DC-7 was more massive than the rock in DC-2, which accounts for the higher compressive strengths of the volcanics in DC-7.

4.7 SUMMARY

Petrographic examination of 17 sections of core from nine holes in the St. Francois Mountain area of southeastern Missouri indicated that six rock types were represented: dacite porphyry, rhyolite porphyry, dark gray volcanic breccia, acid metavolcanics, granodiorite, and dolomite. The dacite and rhyolite porphyries were the most abundant types in the cores (Table 4.5). Differences in compressive strength and elastic properties among the rocks of each type appear to have arisen from the number of fractures, whether the fractures were open or recemented, and the inclination of the fractures present in each test specimen. All of the rock types represented are described in the preceding paragraphs. The relations of the rock types to the geologic units of the area are summarized in Table 4.5, and the mineral compositions of the rocks are presented in Table 4.6.

TABLE 4.1 ELASTIC MODULI TEST RESULTS

Group Description	Static Moduli			Static Poisson's Ratio	Dynamic Moduli			Dynamic Poisson's Ratio
	Young's	Bulk	Shear		Young's	Bulk	Shear	
	10^6 psi	10^6 psi	10^6 psi		10^6 psi	10^6 psi	10^6 psi	
Rhyolite Porphyry:								
Intact	12.1	8.0	5.1	0.24	12.4	9.6	4.9	0.28
Moderately fractured	12.0	8.0	4.8	0.24	11.7	9.4	4.6	0.29
Vesicular	11.5	10.1	4.4	0.31	9.6	8.5	3.7	0.31
Highly to critically fractured	--	--	--	--	9.2	7.8	3.6	0.29
Dacite Porphyry:								
Intact	12.3	8.2	4.9	0.29	12.4	9.8	4.8	0.29
Containing fine incipient fractures	10.8	6.3	4.4	0.31	11.2	9.7	4.3	0.31
Moderately fractured	11.0	7.1	4.5	0.26	12.8	8.9	5.1	0.26
Highly to critically fractured	11.8	--	--	--	13.2	10.7	5.1	0.30
Granodiorite:								
Intact	9.8	7.2	3.8	0.27	8.4	7.0	3.2	0.30
Moderately fractured	--	--	--	--	--	--	--	--
Acid Metavolcanics:								
Moderately fractured	12.5	--	--	--	13.5	9.6	5.3	0.27
Highly fractured	--	--	--	--	--	--	--	--
Breccia:								
Critically fractured	8.7	4.4	3.7	0.17	9.2	8.2	3.5	0.31
Dolomite:								
Highly fractured	5.9	4.7	2.3	0.29	6.1	3.0	2.6	0.16

TABLE 4.2 TENSILE STRENGTH DETERMINATIONS

Hole No.	Specimen No.	Depth	Tensile Strength			Core Log Description
			Splitting	Direct	Direct/ Splitting	
		feet	psi	psi	percent	
4	4	30	2,220	1,250	56	Felsite porphyry w/healed fractures
7	13	132	3,080	a	--	Rhyolite porphyry
9	8	74	2,785	a	--	Rhyolite porphyry
12	17	138	485	450	93	Welded tuff w/healed fractures
16	13	128	2,795	1,330	48	Hornblende granite
18	3	48	470	80	17	Gray marl
20	18	175	3,310	1,880	57	Latite porphyry
28	14	132	2,590	1,250	48	Rhyolite porphyry w/healed fractures
		Avg	2,800[b]	1,430[b]	52[b]	

[a] Direct tensile strengths exceeded tensile strength of bonding agent.
[b] Welded tuff and gray marl values were not used in figuring averages.

TABLE 4.3 VELOCITY DETERMINATIONS

		Velocity	
		Compression[a]	Shear[a]
		fps	fps
Hole ST-CR-4, Specimen 4:			
Dacite porphyry		20,035	11,375
Depth: 30 feet		19,735	11,285
Specific gravity: 2.711		19,985	11,370
Compressive deviation:[b] 0.9 pct			
	Avg	19,920	11,345
Hole ST-CR-16, Specimen 13:			
Granodiorite		17,485	11,050
Depth: 128 feet		18,195	9,820
Specific gravity: 2.633		18,785	10,810
Compressive deviation:[b] 3.7 pct			
	Avg	18,155	10,560
Hole ST-CR-9, Specimen 8:			
Vesicular rhyolite porphyry		18,925	10,870
Depth: 74 feet		18,900	11,025
Specific gravity: 2.622		19,055	11,060
Compressive deviation:[b] 0.5 pct			
	Avg	18,960	10,985
Hole ST-CR-20, Specimen 18:			
Dacite porphyry		20,440	11,920
Depth: 175 feet		20,270	11,800
Specific gravity: 2.707		20,075	11,660
Compressive deviation:[b] 0.9 pct			
	Avg	20,260	11,795
Hole ST-CR-18, Specimen 3:			
Moderately fractured, porous dolomite		13,770	8,060
Depth: 48 feet		13,380	6,550
Specific gravity: 2.670		13,575	7,560
Compressive deviation:[b] 1.4 pct			
	Avg	13,575	7,390
Hole ST-CR-12, Specimen 17:			
Fractured acid metavolcanic		19,725	11,765
Depth: 138 feet		19,875	11,765
Specific gravity: 2.746		19,605	12,095
Compressive deviation:[b] 0.7 pct			
	Avg	19,735	11,875
Hole ST-CR-28, Specimen 14:			
Dacite porphyry with vertical healed fracture		19,605	11,750
Depth: 132 feet		19,565	11,480
Specific gravity: 2.676		19,815	11,990
Compressive deviation:[b] 0.8 pct			
	Avg	19,660	11,740
Hole ST-CR-7, Specimen 13:			
Rhyolite porphyry		19,645	12,030
Depth: 132 feet		20,025	11,970
Specific gravity: 2.702		20,385	11,780
Compressive deviation:[b] 1.9 pct			
	Avg	20,020	11,925

[a] First velocity listed is in axial (longitudinal) direction; other two are on mutually perpendicular diametral (lateral) axes.

[b] Maximum percent deviation from the average of the compression wave velocity.

TABLE 4.4 DYNAMIC ELASTIC PROPERTIES

Hole/ Specimen	Moduli			Poisson's Ratio	Hole/ Specimen	Moduli			Poisson's Ratio
	Young's	Bulk	Shear			Young's	Bulk	Shear	
	10^6 psi	10^6 psi	10^6 psi			10^6 psi	10^6 psi	10^6 psi	
4/4	11.9	8.4	4.7	0.26	12/17	12.5	7.6	5.1	0.22
	11.6	8.0	4.7	0.26		12.6	7.8	5.1	0.23
	11.9	8.3	4.7	0.26		12.9	7.0	5.4	0.19
Avg	11.8	8.2	4.7	0.26	Avg	12.7	7.5	5.2	0.21
9/8	10.4	7.1	4.2	0.25	28/14	12.1	7.2	5.0	0.22
	10.6	6.9	4.3	0.24		11.7	7.5	4.8	0.24
	10.7	7.1	4.3	0.25		12.6	7.2	5.2	0.21
Avg	10.6	7.0	4.3	0.25	Avg	12.1	7.3	5.0	0.22
20/18	12.9	8.3	5.2	0.24	7/13	12.6	7.0	5.3	0.20
	12.6	8.2	5.1	0.24		12.7	7.6	5.2	0.22
	12.3	8.1	5.0	0.25		12.6	8.4	5.0	0.25
Avg	12.6	8.2	5.1	0.24	Avg	12.6	7.7	5.2	0.22
18/3	5.8	3.7	2.3	0.24					
	4.1	4.4	1.5	0.34					
	5.2	3.9	2.0	0.28					
Avg	5.0	4.0	1.9	0.29					

TABLE 4.5 RELATION OF CORES EXAMINED TO AREAL GEOLOGIC UNITS

CD Serial No. SAMSO-7	Field No. ST-CR-	Rock Type or Types[a]		Geologic Unit	
DC-1	4	All sections	Dacite porphyry	Pilot Knob felsite	Intrusives and extrusives of the Middlebrook group
DC-6	20	All sections		Unassigned Middlebrook	
DC-8	28	All sections		Pilot Knob felsite	
DC-2	26	Sections 10, 11, 13, 14, 20, 22		Unassigned Middlebrook	
DC-7	12	Sections 1-14		Pilot Knob felsite	
DC-3	9	All sections	Rhyolite porphyry	Stout's Creek rhyolite	Intrusives and extrusives of the Van East group
DC-9	7	All sections		Stout's Creek rhyolite	
DC-2	26	Sections 4, 9, 16		Unassigned Van East group	
DC-5	18	Sections 8-23		Annapolis rhyolite	
DC-4	16	All sections	Granodiorite	Silvermine granite	Bevos group
DC-5	18	Sections 1-7	Dolomite	Davis formation (?)	
DC-2	26	Sections 1, 5, 6, 7, 18, 19, 21	Breccia	Middlebrook or Van East group	
DC-2	26	Sections 2, 3, 15, 17	Acid metavolcanics	Middlebrook or Van East group, probably Middlebrook group	
DC-7	12	Sections 15-21			

[a] According to U. S. Army Engineer Waterways Experiment Station identification using Shand's system for igneous rocks.

TABLE 4.6 BULK COMPOSITION OF CORES SAMSO-7 DC-1 THROUGH DC-9 AS DETERMINED BY X-RAY DIFFRACTION

M = major constituent, more than 20 percent; A = accessory mineral, less than 20 percent; P = present, trace; X = not detected; M* = plagioclase, about 50 percent of rock; M^1 = plagioclase content ≃ quartz content ≃ orthoclase content ≃ 30 percent of rock.

Mineral	SAMSO-7 DC-1 (1)	SAMSO-7 DC-2 (7)	SAMSO-7 DC-2 (12)	SAMSO-7 DC-2 (17)	SAMSO-7 DC-3 (3A)	SAMSO-7 DC-3 (3C)	SAMSO-7 DC-4 (8)	SAMSO-7 DC-5 (1)	SAMSO-7 DC-5 (5)	SAMSO-7 DC-5 (22)	SAMSO-7 DC-6 (13)	SAMSO-7 DC-7 (4)	SAMSO-7 DC-7 (14)	SAMSO-7 DC-7 (21)	SAMSO-7 DC-8 (8)	SAMSO-7 DC-9 (11)
Quartz	M	M	M	M	M	M	M	X	X	M	M	M	M	M	M	M
Plagioclase	M*	M*	M*	M^1	M^1	M^1	M^1	X	X	M^1	M*	M*	M*	M	M*	M^1
Orthoclase	P	A	P	M	M	M	M	X	X	M	A	A	A	X	A	M
Biotite	A	A	A	P	A	A	A	X	X	A	M	A	P	A	P	X
Chlorite	A	A	A	A	X	X	M	X	X	X	A	A	A	M	A	X
Hornblende	X	A	P	P	X	X	X	X	X	X	X	X	X	X	X	X
Magnetite	A	A	A	A	A	P	A	X	X	A	A	A	A	A	A	A
Epidote	X	X	X	P	X	X	X	A	P	X	X	X	X	X	X	X
Dolomite	X	X	X	X	X	X	X	M	M	X	X	X	X	X	X	X
Illite	X	X	X	X	X	X	X	A	X	X	X	X	X	X	X	X
Rock type[a]	Dacite	Dacite breccia	Dacite	Rhyolite	Rhyolite	Rhyolite	Granodiorite	Dolomite	Dolomite	Rhyolite	Dacite	Dacite	Dacite	Acid metavolcanic	Dacite	Rhyolite

[a]As determined by use of Shand's system for igneous rocks.

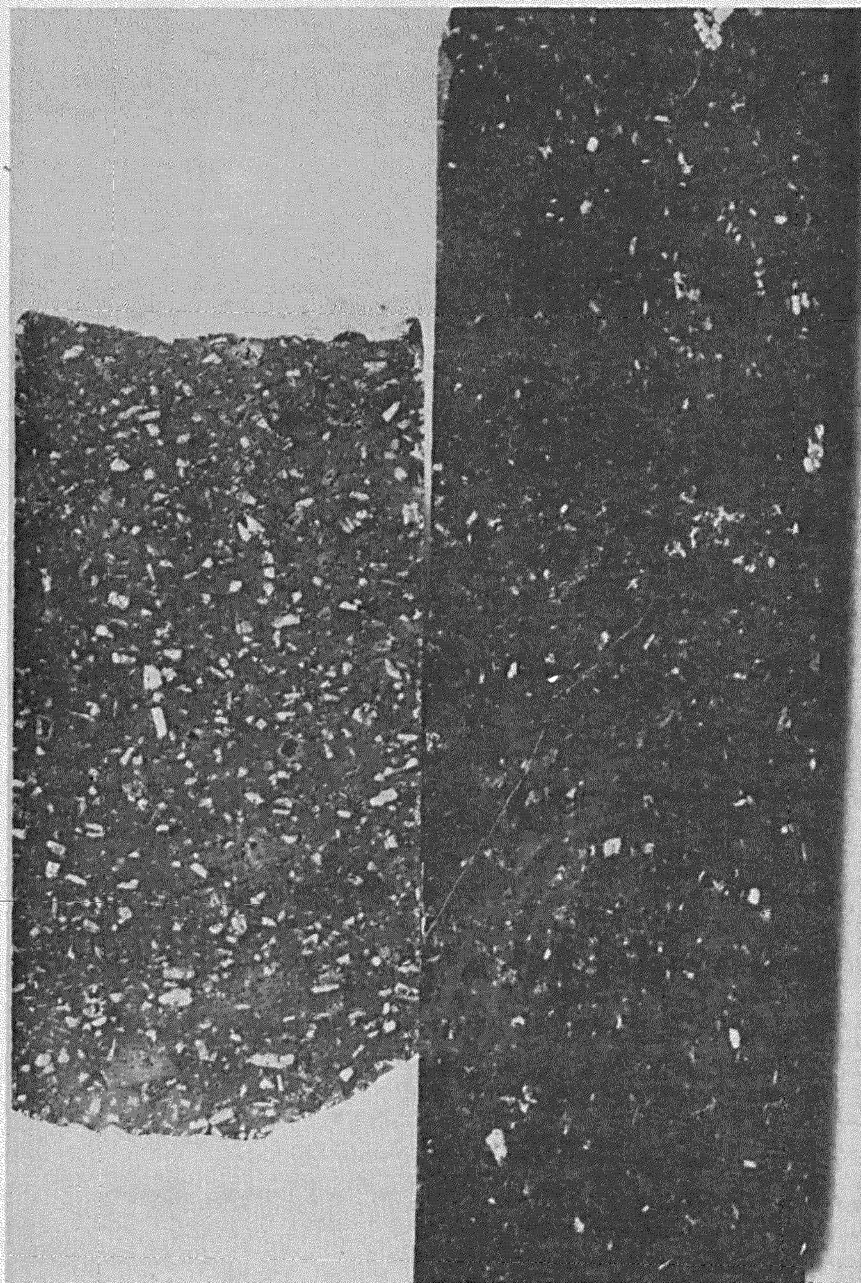


Figure 4.1 Photograph of Core SAMSO-7 DC-1 (1) and DC-1 (4). SAMSO-7 DC-1 (1) (left) is dacite porphyry with abundant pale phenocrysts of plagioclase and quartz. SAMSO-7 DC-1 (4) (right) is sheared dacite porphyry; the light lines are fractures. Phenocrysts are less abundant. Actual size.

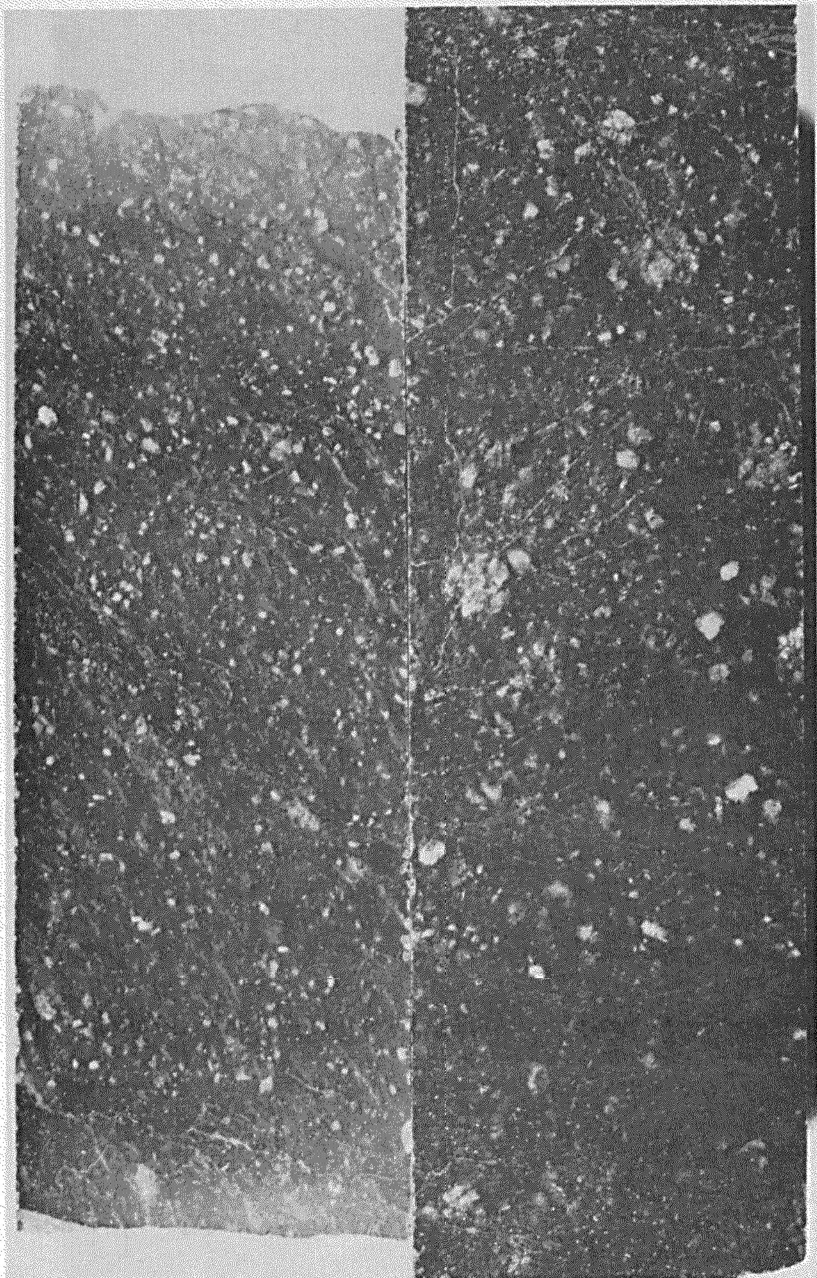


Figure 4.2 Photograph of Cores SAMSO-7 DC-8 (8) (left) and DC-6 (13) (right). The cores are sheared dacite porphyry. The narrow pale lines are sealed fractures, and the minute white flecks are light reflected from magnetite grains. Dark zones in DC-8 (8) are altered regions along fractures. The abundant phenocrysts show little crystal shape. Actual size.

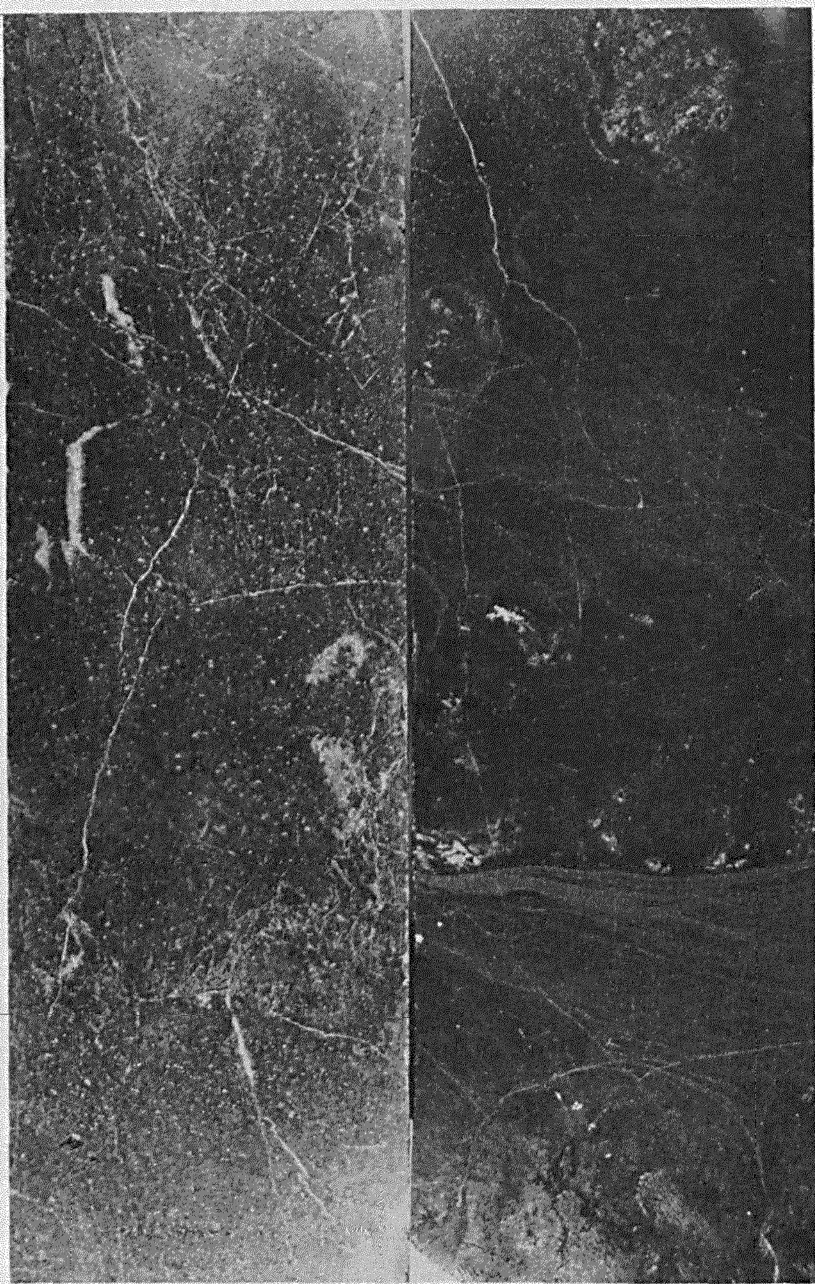


Figure 4.3 Photograph of Cores SAMSO-7 DC-7 (14) (left) and DC-7 (21) (right). DC-7 (14) is highly sheared dacite porphyry; white lines are sealed fractures, and minute white specks are magnetite. The original texture has been destroyed. DC-7 (21) is metavolcanic with dark rhyolite inclusions (upper portion of lower half and upper right) in the greenstone. In the lower quarter, flow structure is shown by streaks of gray magnetite. Pale lines are sealed fractures. Actual size.

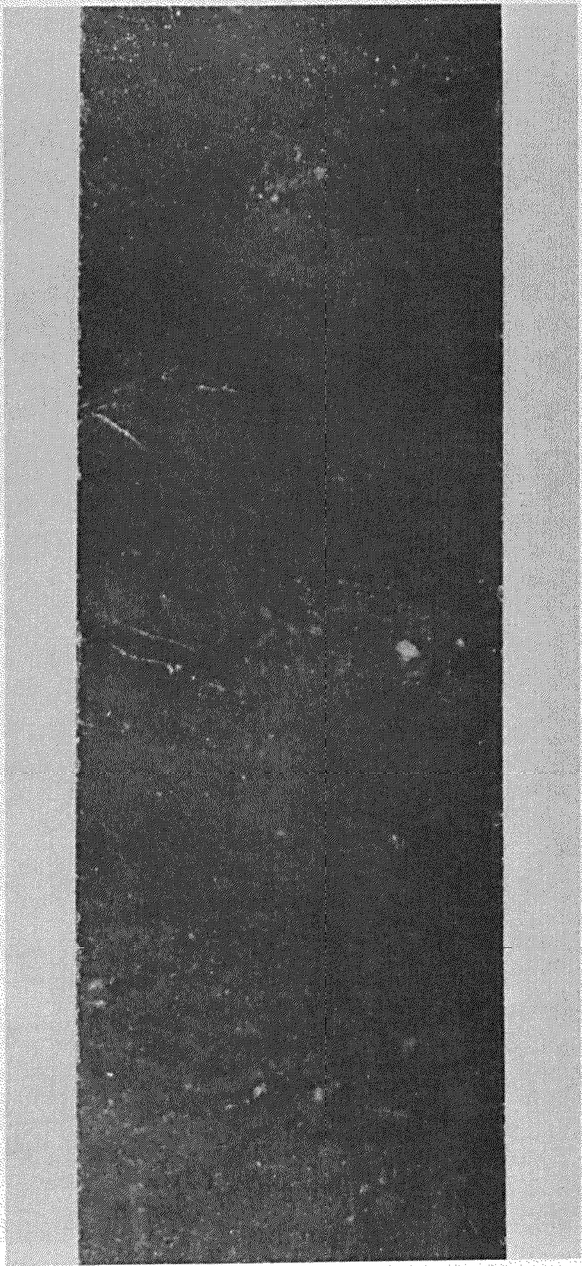


Figure 4.4 Photograph of Core SAMSO-7 DC-2 (13). Core is severely sheared dacite porphyry with most of the texture destroyed. Dark blurred areas have been subjected to intense cataclastic shearing and comminution (mylonitization).

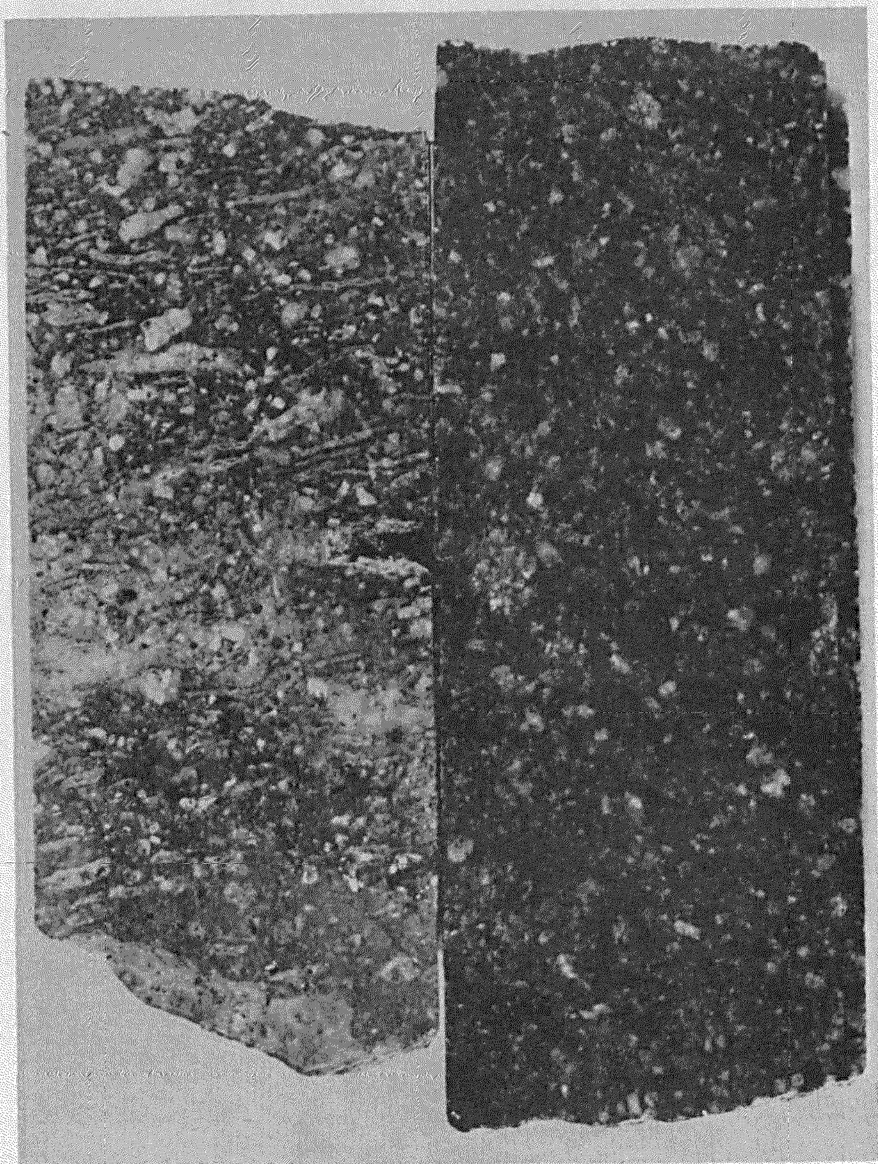


Figure 4.5 Photograph of Cores SAMSO-7 DC-3 (3) (left) and DC-5 (22) (right). The cores are rhyolite porphyry. Core DC-3 (3) shows flow structure expressed by abundant filled vesicles and some empty ones. Core DC-5 (22) has been highly sheared and then sealed. No flow structure can be recognized. Actual size.

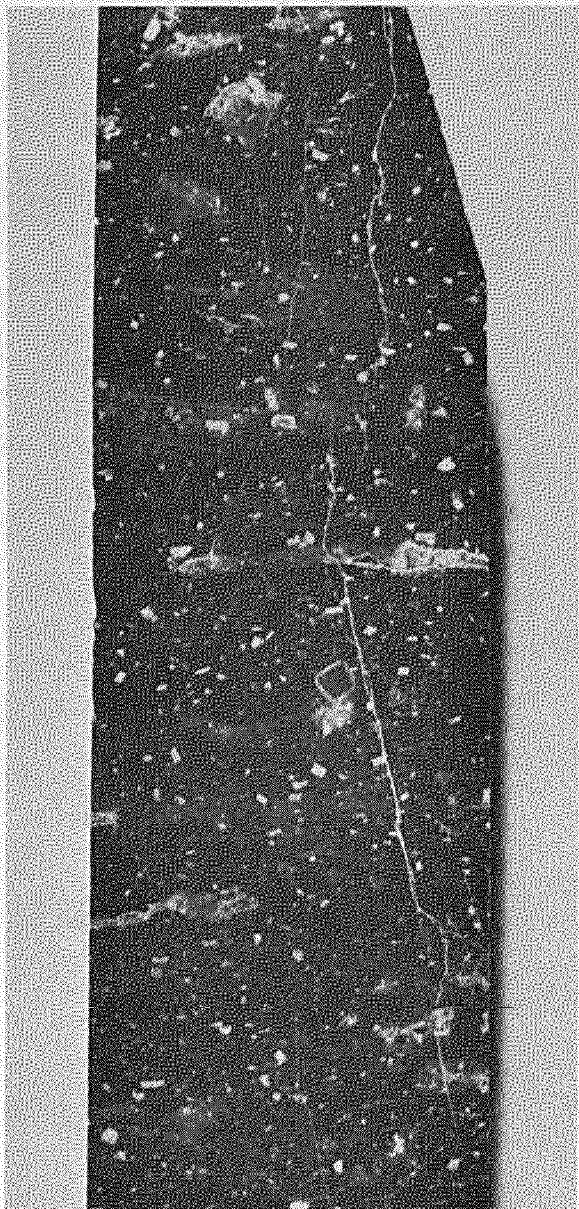


Figure 4.6 Photograph of Core SAMSO-7 DC-9 (11). The core is rhyolite porphyry and shows a well-developed flow structure normal to the long axis of the core. The flow structure is expressed by oriented phenocrysts of quartz, plagioclase, and orthoclase, and filled vesicles. The fractures are sealed. Actual size.

Figure 4.7 Photograph of Core SAMSO-7 DC-2 (17). The core is rhyolite porphyry and shows several sets of shear fractures subparallel to the long axis of the core as light-colored lines.

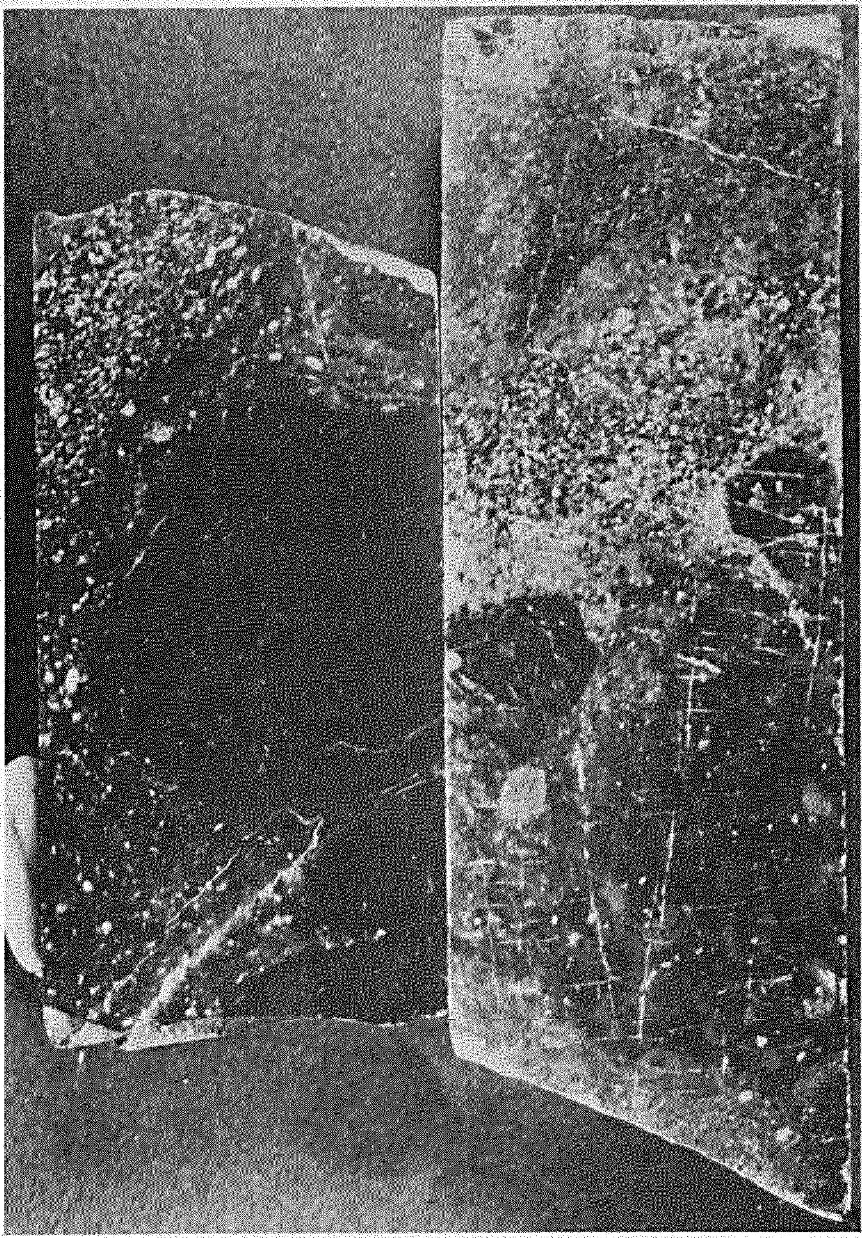


Figure 4.8 Photograph of Cores SAMSO-7 DC-2 (15) (left) and DC-2 (22) (right). Piece at left is rhyolite porphyry with marked flow structure including a partly assimilated basalt fragment. In the piece at the right, the lower half is amygdaloidal rhyolite intruded by porphyritic rhyolite (upper half), which contains partly assimilated dark inclusions. The fracturing of the rock in the lower half antedated the intrusion of the upper rock.

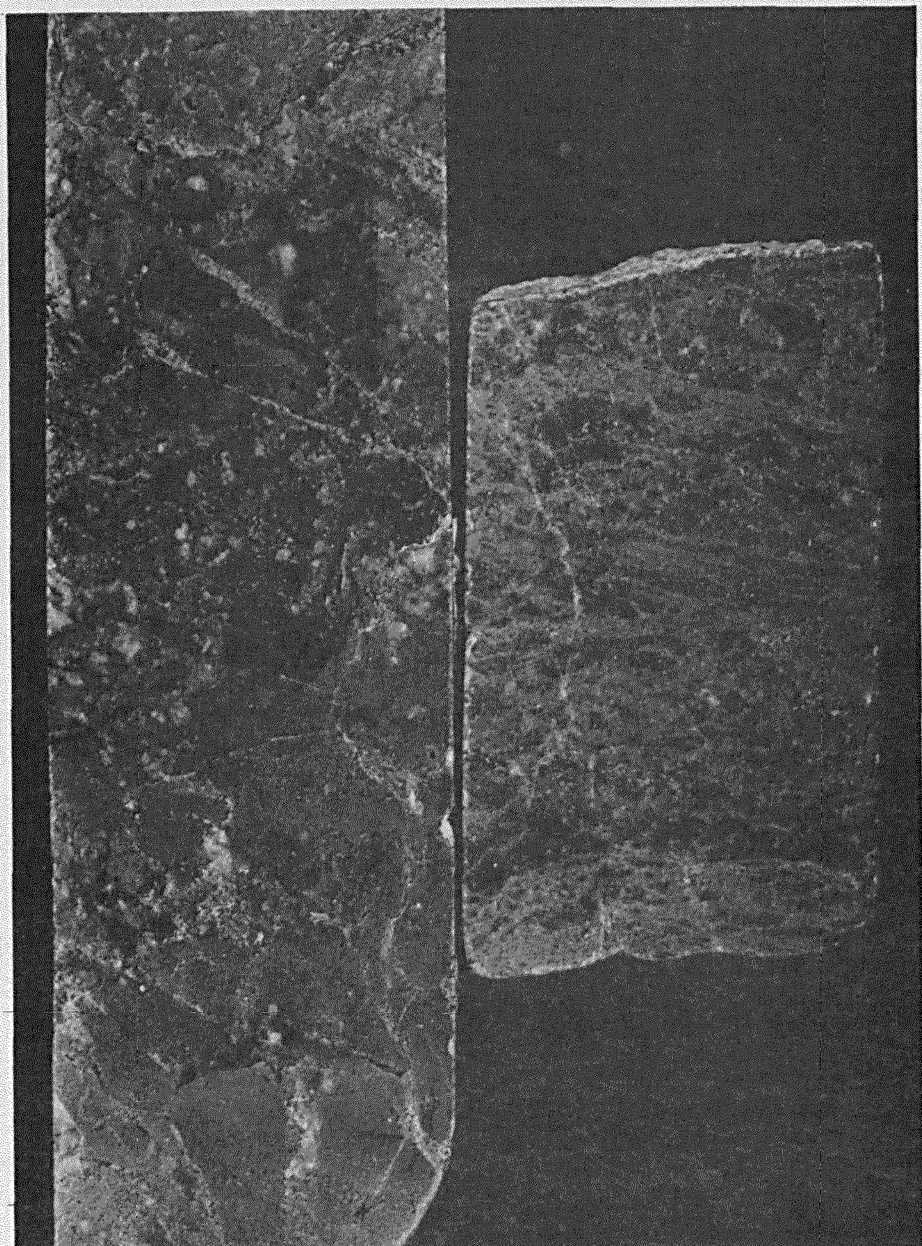


Figure 4.9 Photograph of Cores SAMSO-7 DC-5 (1) (left) and DC-5 (5) (right). Porous dolomite DC-5 (1) at left shows many fractures, either open or partially filled with clay mica (illite), and dark areas containing epidote. Dolomitic marble in DC-5 (5) is the metamorphic equivalent of the rock at the left. The porosity has been reduced, and the fractures are sealed.

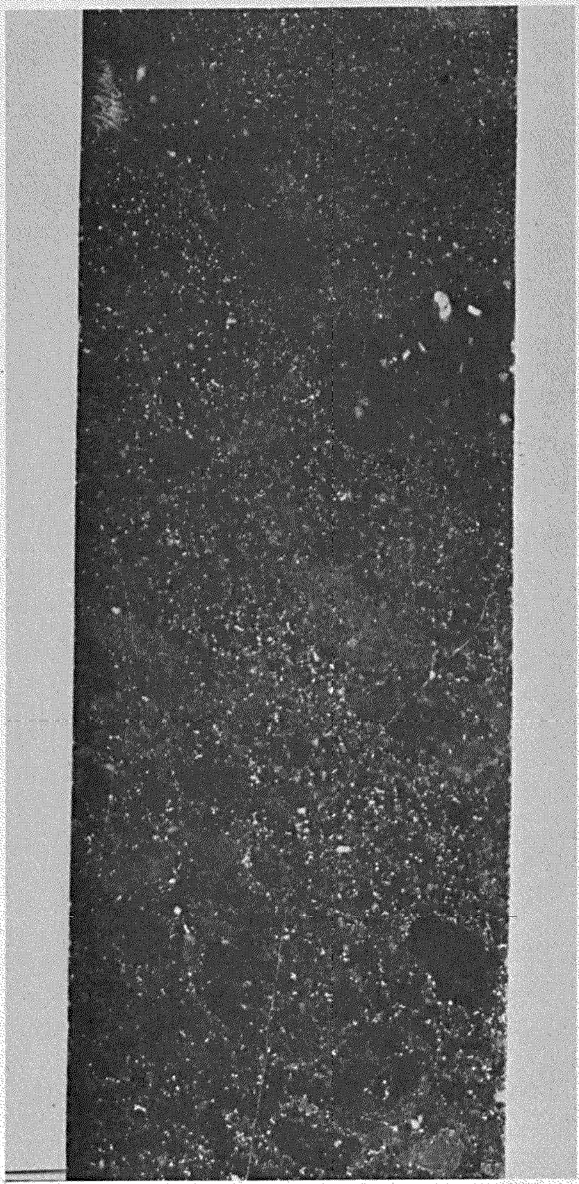


Figure 4.10 Photograph of Core SAMSO-7 DC-2 (7). The core is igneous breccia and shows rounded fragments in a matrix containing magnetite (minute white specks). A few sealed fractures appear as pale narrow lines.

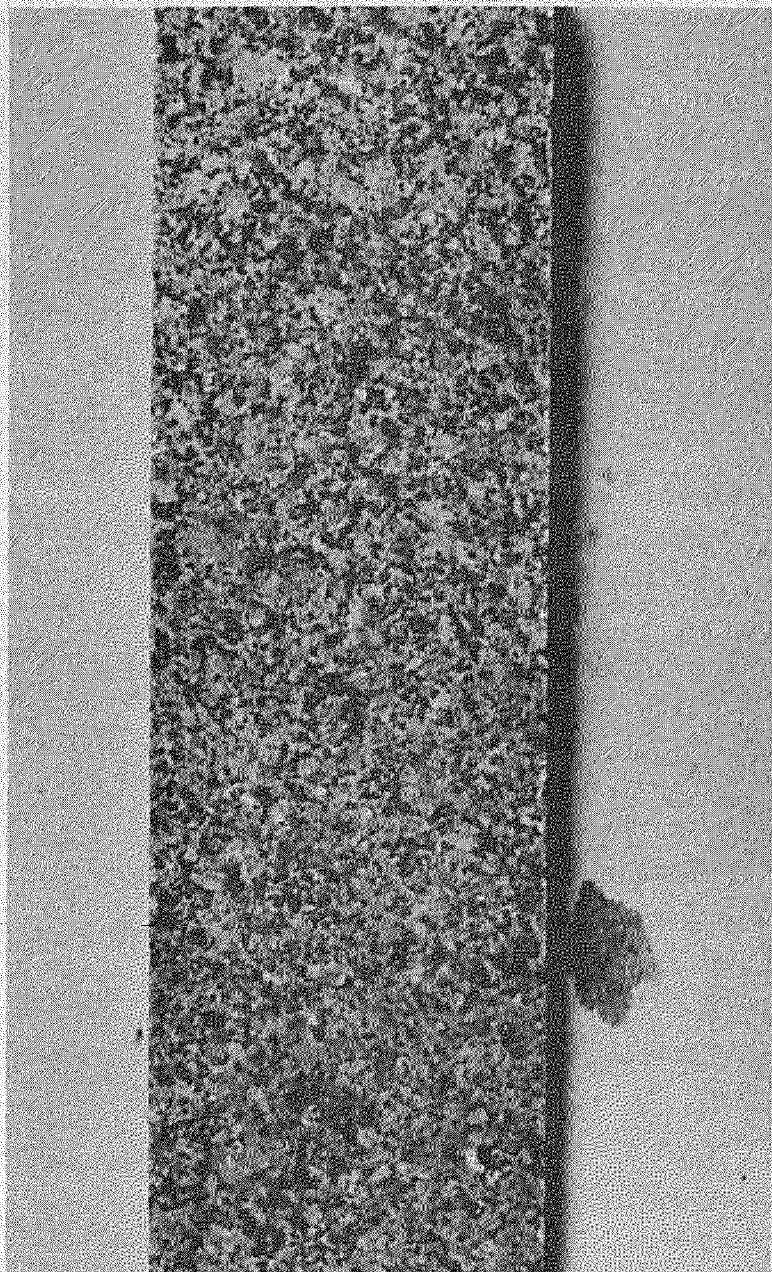


Figure 4.11 Photograph of Core. SAMSO-7 DC-4 (8). The core is equigranular granodiorite with dark blobs of biotite and chlorite.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

Evaluation of the test results from the Scott Area cores on a hole-to-hole basis indicates that Holes ST-CR-4, -16, -9, and -20 contain good rock throughout the entire depth tested. The rock quality chart (Figure 5.1), which is based on compressive strength divided into three categories (good, marginal, and poor), indicates further that Holes ST-CR-26, -18, and -28 contain zones of poor rock near the surface, i.e., less than 50 feet, and that Holes ST-CR-26, -18, and -7 contain zones of marginal quality to depths of 130 feet. Significantly, only one hole, ST-CR-12, contained poor quality rock at any depth greater than 50 feet. The locations of the drill holes are shown in Figure 5.2.

It is noted in the petrographic report (Section 4.4) that much geologic shearing and fracturing has occurred in the area. However, most of the fractures had been sealed with chlorite. Apparently, the strength of the rock samples was dependent primarily on the effectiveness of this chlorite seal.

5.2 CONCLUSIONS

Based on the results of tests of rock core specimens received from the Scott Area, the following conclusions appear warranted:

1. The core was petrographically identified as predominantly rhyolite and dacite porphyry with some granodiorite and small amounts of dolomite, acid metavolcanics, and dark gray volcanic breccia.

2. Based on physical appearance, several distinct groups of material were represented within the different rock types: intact rock; rock containing fine incipient fractures; moderately fractured rock, i.e., material containing a relatively small number of healed and/or tightly closed fractures; highly to critically fractured rock, i.e., rock containing open fractures and critically oriented fractures (inclined at 30 to 70 degrees with respect to the horizontal); and rock containing vesicles.

3. The highly to critically fractured material, comprising approximately 10 percent of the test specimens, exhibited marginal strength characteristics.

4. The moderately fractured to intact material was very competent.

5. The vesicular material from Hole ST-CR-9 exhibited lower strengths than did the moderately fractured material, but was still relatively competent rock.

6. The consistently high compressional wave velocities indicate that the macrofracturing is generally of a tightly closed nature.

7. Results of three-dimensional compressional wave velocity tests conducted on representative specimens indicate that the

fractured to intact core is generally quite isotropic. The granodiorite is somewhat anisotropic (3.7 percent variation). Due consideration should be given to the fact that the highly fractured material not represented in these tests would probably exhibit larger compressive deviations indicative of greater degrees of anisotropy.

8. The core is generally quite brittle, exhibiting little, if any, hysteresis.

9. Direct and indirect tensile strengths exhibited by the rhyolite and dacite porphyry and granite are very high, but correlate rather well with the relatively high compressive strengths. Direct tensile strength was found to range from approximately 5 to 10 percent of the uniaxial compressive strength.

10. Young's moduli exhibited by the dacite and rhyolite porphyry were consistently high, averaging about 12 million psi. Moduli exhibited by the granite were slightly lower.

11. Evaluation of the core on a hole-to-hole basis indicates that Holes ST-CR-4, -9, -16, and -20 yielded good competent rock throughout the depths represented. As illustrated in the rock quality chart, Holes ST-CR-18, -26, and -28 contained zones of incompetent material near the surface, i.e. less than 50 feet. Only Hole ST-CR-12 yielded core of poor to marginal quality at depths greater than 50 feet. Further investigation will be required to fully evaluate the area.

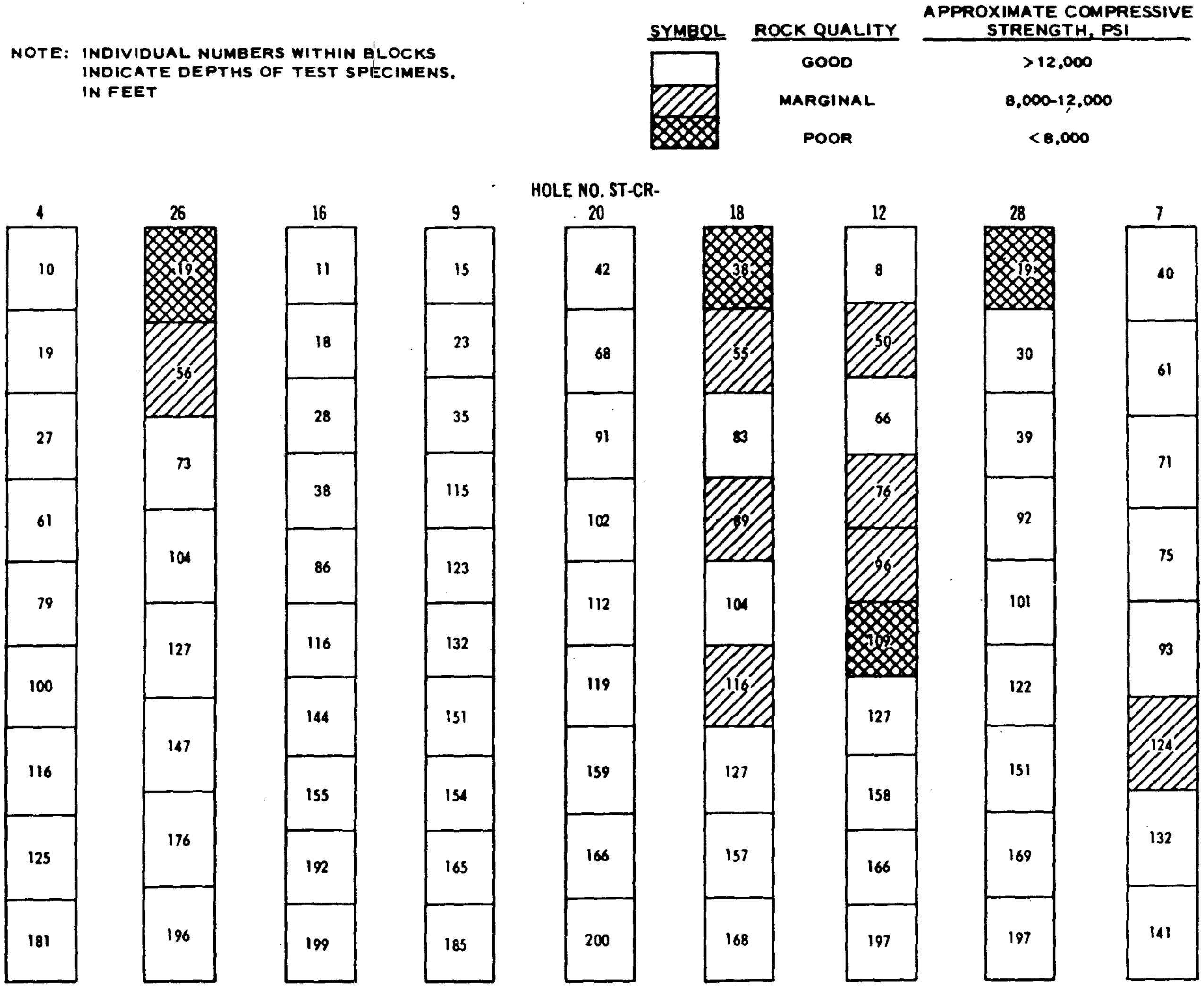


Figure 5.1 Depth versus quality for individual holes.

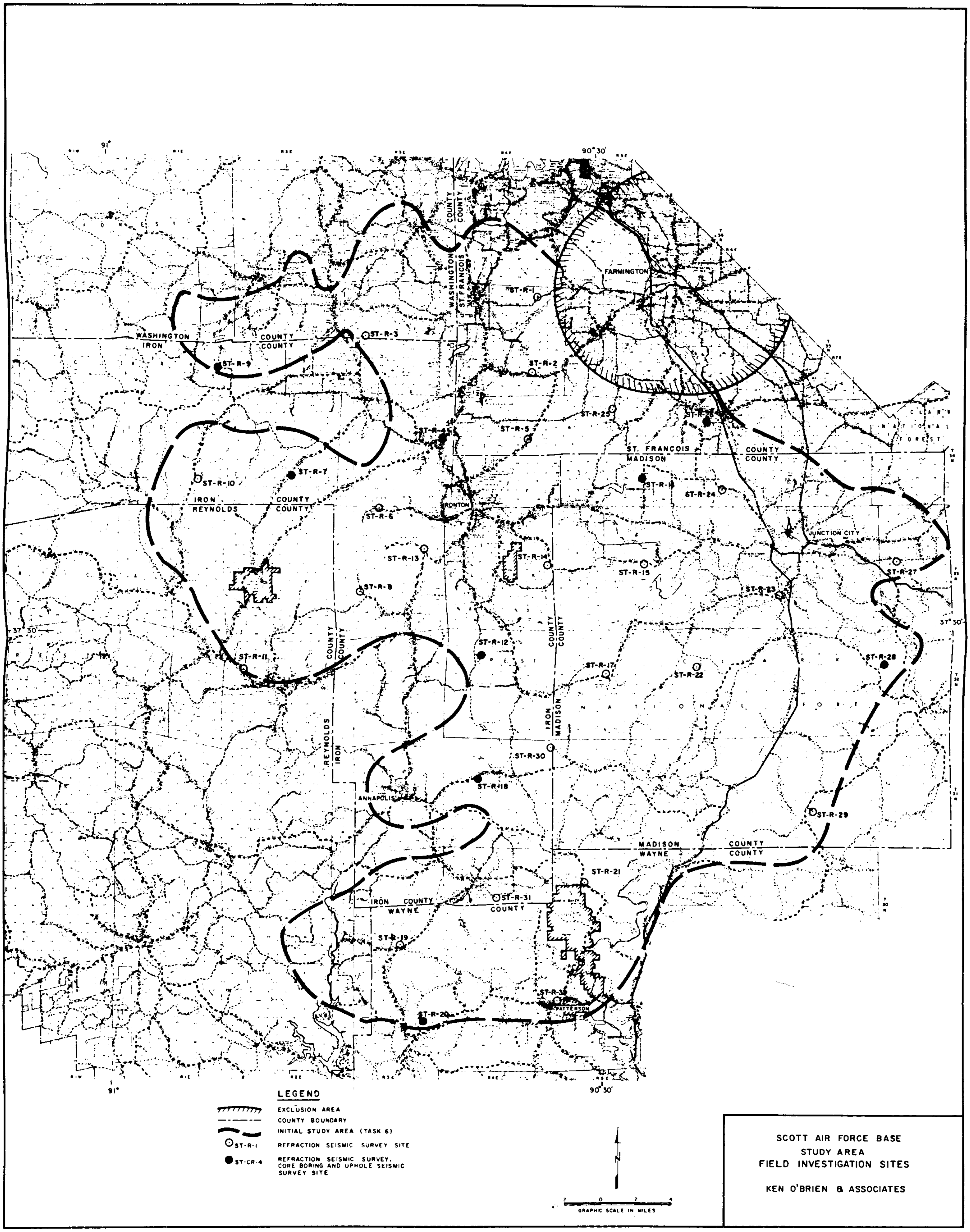


Figure 5.2 Locations of drill holes.

APPENDIX A

DATA REPORT

Hole ST-CR-4

14 July 1969

Hole Location: Iron County, Missouri

Township T34N, Range R3E, Section 13

2800' E/WL 1300' S/NL NE 1/4 NW 1/4

Core

1. The following core was received on 7 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	10
2	19
3	27
4	30
5	39
6	51
7	61
8	71
9	79
10	88
11	100
12	108
13	116
14	125
15	133
16	141
17	151
18	155
19	162
20	171
21	181
22	192
23	200

Description

2. The samples received were gray to gray-green rock identified as felsite porphyry and rhyolite porphyry by the field log received with the core. Piece No. 1 appeared to be an olivine inclusion. Piece Nos. 2, 4, 6, 9, 10, 13, 14, 16, 20, 22, and 23 contained seams and/or tightly closed fractures.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
1	Gray, Intact	10	2.692	57.4	65,240	20,995
2	Black, Intact**	19	2.687	--	42,290	21,310
3	Black, Intact**	27	2.697	59.6	31,900	20,695
7	Black, Intact	61	2.683	--	47,340	21,355
9	Gray, Fractured	79	2.687	--	21,820	20,280
11	Gray, Intact	100	2.697	55.3	48,060	20,460
13	Gray, Fractured	116	2.692	--	17,320	20,335
14	Gray, Fractured	125	2.684	--	13,100	22,260
21	Gray, Intact	181	2.702	56.2	44,460	20,535
Average of Fractured Specimens			2.688	--	17,410	20,960
Average of Black (Intact) Specimens			2.689	59.6	40,510	21,120
Average of Gray (Intact) Specimens			2.697	56.3	52,585	20,665

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Specimens discovered to have very small macrocracks which may have initiated failure.

4. In spite of the pre-existing fracturing present in some of the specimens, tests indicated the rock to be competent to very competent material. The rather high strengths for fractured rock may be attributed to the fact that almost all of the fractures were vertical or nearly vertical and tightly closed. The compressive wave velocities for these same specimens were also rather high for fractured rock, this again being attributed to the vertical nature of the fractures. The compressive waves must cross the fracture (unlikely in the case of vertical fractures) in order to experience a decrease in velocity.

5. All of the intact specimens showed high compressive strengths, indicating that the rock was very competent. One specimen, No. 1, was identified by the field log to be an olivine inclusion.

Moduli of deformation

6. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 1 and 7. Stress-strain curves are given in plates 1 and 2. Specimen 7 was cycled at 20,000 psi and specimen 1 at 30,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6			Shear Velocity, fps	Poisson's Ratio
	Young's	Bulk	Shear		
		Dynamic Tests			
1	12.5	9.5	4.9	11,615	0.28
7	12.2	10.2	4.7	11,415	0.30

(Continued)

(Continued)

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Static Tests			
1	12.6	8.8	5.0	--	0.26
7	12.0	7.7	4.8	--	0.24

All of the rock tested herein is apparently rather rigid material exhibiting no hysteresis under the cyclic stresses applied.

Conclusions

7. The core received for testing from hole ST-CR-4 was identified as felsite porphyry and rhyolite porphyry by the field log received with this core. All of the core was gray to gray-green colored; some fracturing was present. Specimen No. 1 was an olivine inclusion. In spite of the lower physical test results obtained on the fractured specimens, as given below, compressive strengths indicated that even the fractured rock was relatively competent. Compressive velocities did not reflect the reduced strength in the fractured rock, apparently due to vertical, tightly closed nature of the fractures.

Property	Fractured	Black (Intact)	Gray (Intact)
Specific Gravity	2.688	2.689	2.697
Schmidt No.	--	59.6	56.3
Compressive Strength, psi	17,410	40,510	52,585
Compressional Wave Velocity, fps	20,960	21,120	20,665
Young's Modulus, psi x 10^6	--	12.0	12.6

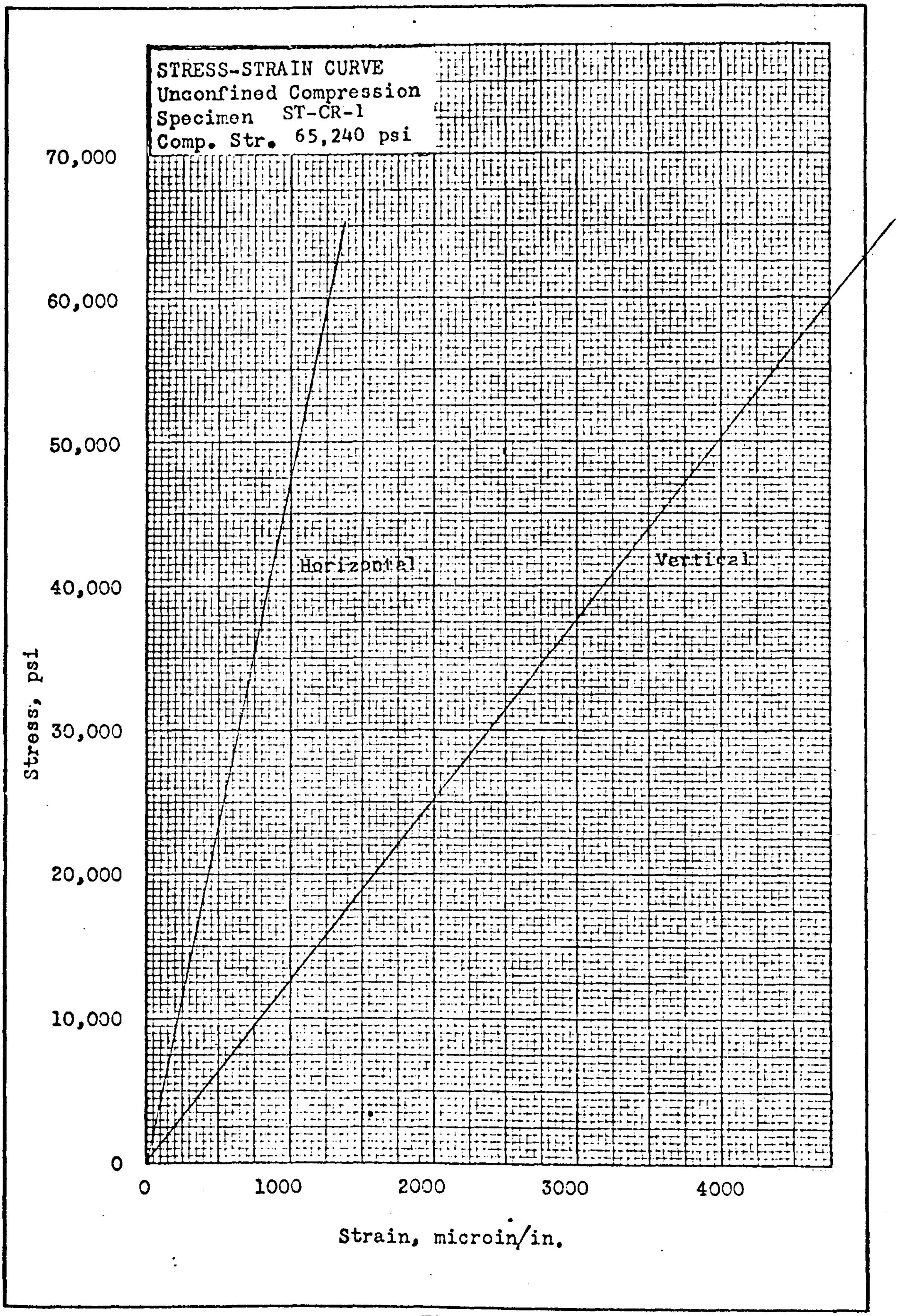
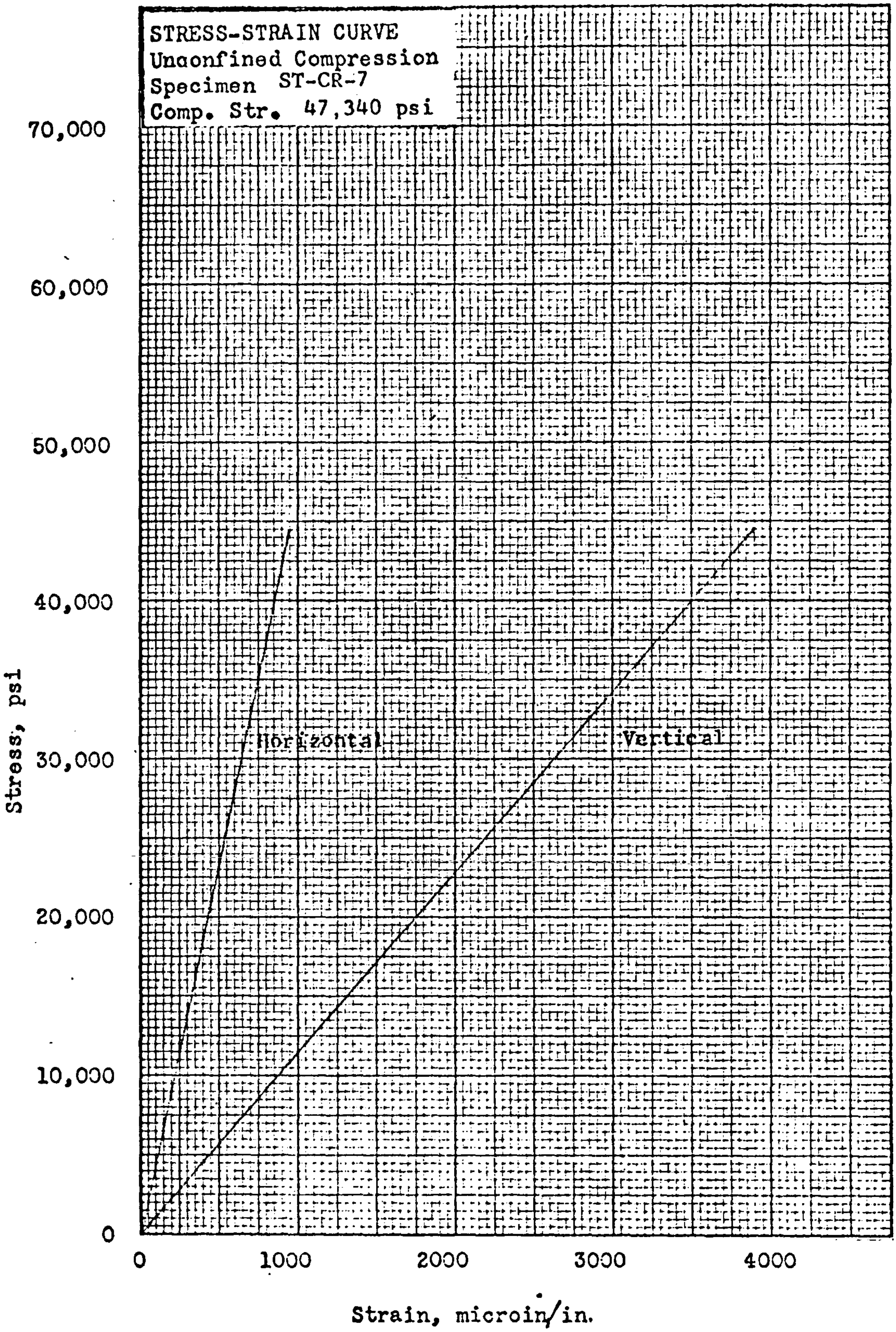

STRESS-STRAIN CURVE
Unconfined Compression
Specimen ST-CR-1
Comp. Str. 65,240 psi
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
Strain, microin/in.

PLATE 1



STRESS-STRAIN CURVE
Unconfined Compression
Specimen ST-CR-7
Comp. Str. 47,340 psi
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
Strain, microin/in.

PLATE 2

APPENDIX B

DATA REPORT

Hole ST-CR-7

15 August 1969

Hole Location: Iron County, Missouri

Township 34N, Range 2E, Section 27

Core

1. The following core was received on 6 August 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	16
2	22
3	26
4	40
5	61
6	71
7	75
8	82
9	93
10	103
11	113
12	124
13	132
14	141
15	147

Description

2. The samples received were blue-gray-colored rock identified as rhyolite porphyry by the field log received with the core. All specimens contained fractures, either open or sealed. The fractures described as open actually appeared to have some void space between the intact pieces. The voids were not continuous, however, as sufficient adhesion was present between the intact pieces to permit preparation and testing of the samples as an integral specimen. The sealed fractures were very tightly sealed cracks with no evidence of void space.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
4	Rock with Open Fractures	40	2.652	61.7	15,150	20,435
5	Rock with Open Fractures	61	2.645	--	15,150	20,400
6	Rock with Sealed Fractures	71	2.659	66.2	35,150	20,760
7	Rock with Sealed Fractures	75	2.660	66.0	21,180	20,545
9	Rock with Open Fractures	93	2.648	--	17,480	20,390
12	Rock with Open Fractures	124	2.657	--	8,090	20,170
13	Rock with Sealed Fractures	132	2.666	67.2	42,270	20,350
14	Rock with Sealed Fractures	141	2.683	68.7	35,760	20,380
Average Rock with Open Fractures (4)			2.650	61.7	13,970	20,350
Average Rock with Sealed Fractures (4)			2.667	67.0	33,590	20,510

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

4. The group composed of specimens containing sealed fractures exhibited a much larger average compressive strength, a slightly greater average compressional wave velocity, and a somewhat larger average Schmidt number. The average compressional wave velocity would probably have better reflected the large difference in compressive strength had the majority of the fracturing not been of a vertical or high-angle nature.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 6 and 14. Stress-strain curves are given in plates 1 and 2. Specimens 6 and 14 were cycled at 20,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
4	9.9	10.0	3.7	10,190	0.33
6	11.3	9.6	4.4	11,035	0.30
14	11.4	9.1	4.4	11,060	0.29
		Static Tests			
6	12.2	9.8	4.7	--	0.29
14	11.8	6.3	5.0	--	0.19

All of the rock tested herein is apparently rather rigid material exhibiting little hysteresis.

Conclusions

6. The core received for testing from hole ST-CR-7 was identified as blue-gray rhyolite porphyry by the field log received with the core. All of the specimens contained fractures, some open and some sealed. The group of specimens containing sealed fractures exhibited an unconfined compressive strength almost 20,000 psi greater than the group containing open fractures. However, since most of the fracturing was of a high-angle nature, this larger compressive strength was not reflected by compressional wave velocities. All of the material was quite rigid.

Property	Rock with Open Fractures	Rock with Sealed Fractures
Specific Gravity	2.650	2.667
Schmidt No.	61.7	67.0
Compressive Strength, psi	13,970	33,590
Compressional Wave Velocity, fps	20,350	20,510
Young's Modulus, psi x 10^6	--	12.0

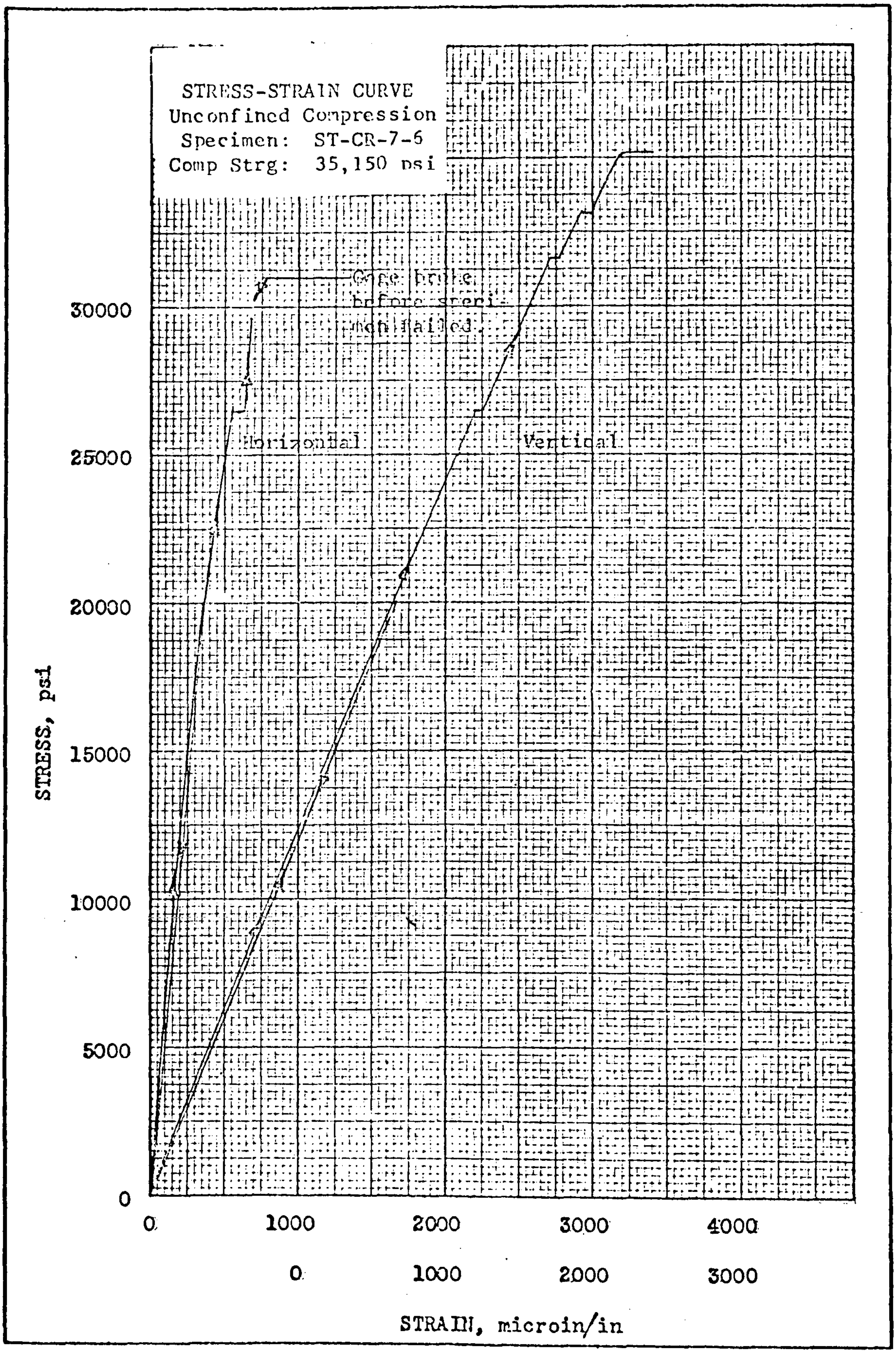

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: ST-CR-7-6
Comp Strg: 35,150 psi
Gage broke before specimen failed.
Horizontal
Vertical
STRESS, psi
0
5000
10000
15000
20000
25000
30000
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 1

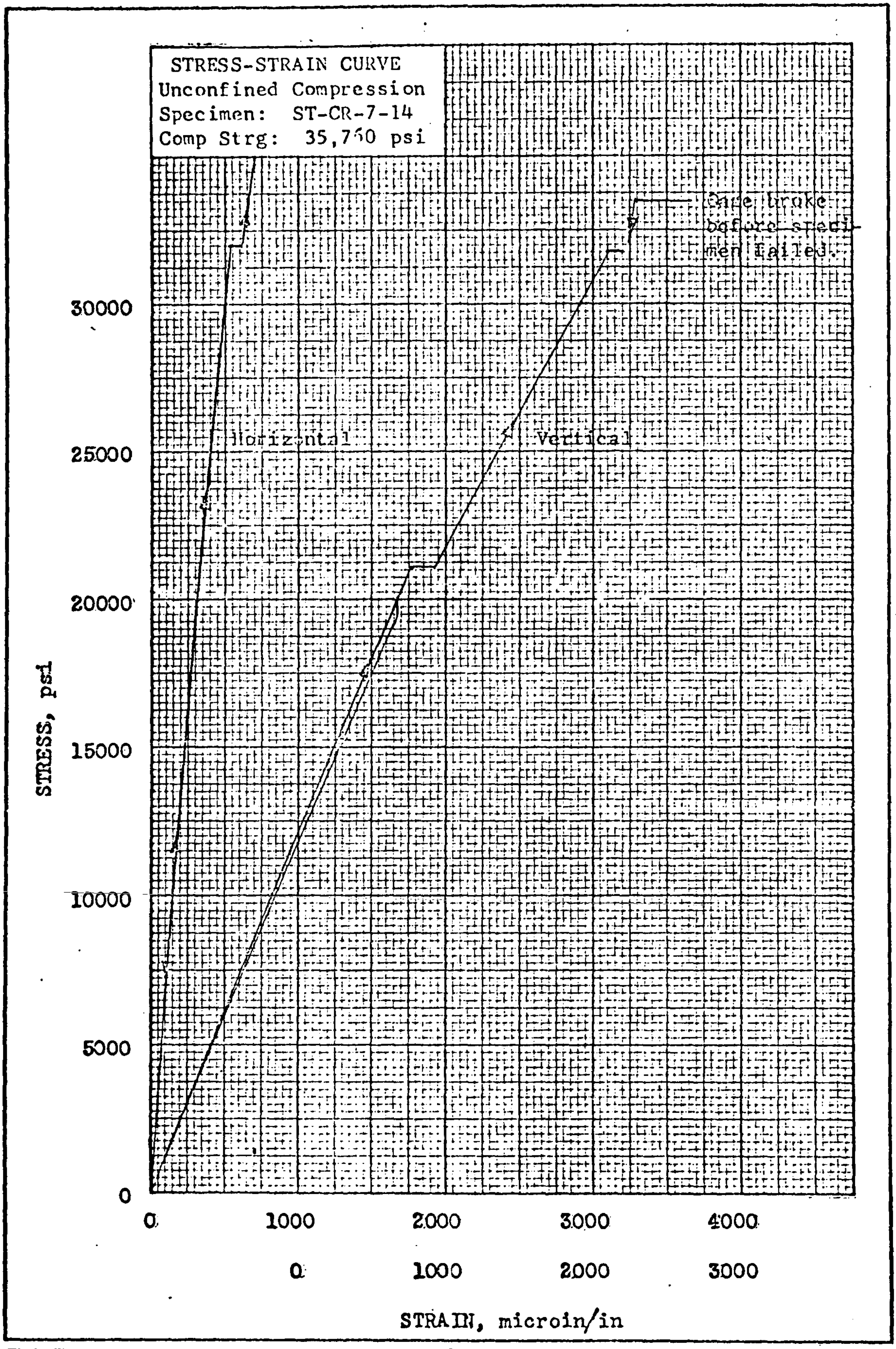

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: ST-CR-7-14
Comp Strg: 35,760 psi
Gage broke before specimen failed.
Horizontal
Vertical
STRESS, psi
30000
25000
20000
15000
10000
5000
0
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 2

APPENDIX C

DATA REPORT

Hole ST-CR-9

24 July 1969

Hole Location: Iron County, Missouri

Township 35N, Range 1E, Section 25

1980' E/WL, 1670' S/NL, SE 1/4 NW 1/4

Core

1. The following core was received on 14 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	5
2	15
3	23
4	35
5	44
6	55
7	65
8	74
9	88
10	93
11	104
12	115
13	123
14	132
15	141
16	151
17	154
18	165
19	174
20	185
21	190
22	200

Description

2. The samples received were pinkish-gray to blue-gray rock identified as rhyolite porphyry by the field log received with the core. Piece Nos. 1, 3, 4, 5, 6, 8, 9, 10, 11, 13, 14, 15, 17, and 18 contained fractures or vesicles or a combination of the two. Piece Nos. 2, 7, 16, 18, 19, 20, 21, and 22 were relatively dense and contained no visible fractures.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
2	No Visible Fractures	15	2.641	52.9	33,780	19,855
3	Fractures and Vesicles	23	2.624	--	18,550	19,715
4	Fractures and Vesicles	35	2.605	--	25,860	19,740
12	No Visible Fractures	115	2.621	50.7	42,500	20,155
13	Scattered Zones of Vesicles	123	2.601	50.9	14,550	20,010
14	Fractures and Vesicles	132	2.605	49.3	23,790	19,725
16	Scattered Zones of Vesicles	151	2.613	52.8	23,940	19,855
17	Scattered Zones of Vesicles	154	2.568	47.1	29,090	19,285
18	Scattered Zones of Vesicles	165	2.614	--	25,450	20,020
20	No Visible Fractures	185	2.622	54.2	16,210	19,810
20a	No Visible Fractures**		--	--	55,760	--
Average of All Specimens			2.611	51.1	29,040	19,815

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Another specimen was cut adjacent to No. 20 and tested in an attempt to determine the validity of the compressive strength value first observed. The compressive strength yielded by No. 20a indicated that specimen No. 20 contained some hidden zone of weakness.

4. Although the specimens tested were originally grouped according to visible physical characteristics, results of the quality and uniformity tests did not substantiate such a grouping. The test results were, therefore, evaluated as a single group.

5. Compressive strength was quite variable throughout the group, ranging from 16,210 to 33,780 psi. Generally, higher strengths were observed in specimens which contained no visible fractures while moderate to lower compressive strengths were observed in those specimens containing fractures and/or vesicles.

6. The compressive wave velocities for all specimens tested were relatively uniform, indicating that much of the fracturing was vertical or nearly vertical and tightly closed. The vertical fracturing was reflected in the general mode of failure, vertical splitting.

Moduli of deformation

7. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 2 and 13. Stress-strain curves are given in plates 1 and 2. Specimen 2 was cycled at 15,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
2	10.0	9.0	3.8	10,345	0.31
4	9.7	8.8	3.7	10,255	0.32
13	10.0	9.0	3.8	10,425	0.31
		Static Tests			
2	10.2	6.7	4.1	--	0.24
13	11.5	10.1	4.4	--	0.31

8. The erratic behavior of the stress-strain curves was probably due to the vertical splitting nature of failure which caused large, rather sudden lateral strains, accompanied in one case by significant vertical strain relief.

Conclusions

9. The core received from hole ST-CR-9 was identified as pinkish-gray to blue-gray rhyolite porphyry by the field log received with the core. The material tested was rather variable, ranging from relatively competent to very competent. Generally, the specimens containing vesicles and/or fractures were less competent than those containing no visible fractures. The very erratic behavior of the stress-strain curves was due to the vesicular and fractured nature of the material and the vertical splitting nature of the failure.

Property	Average of All Specimens
Specific Gravity	2.611
Schmidt No.	51.1
Compressive Strength, psi	29,040
Compressional Wave Velocity, fps	19,815
Young's Modulus, psi x 10^6	10.8

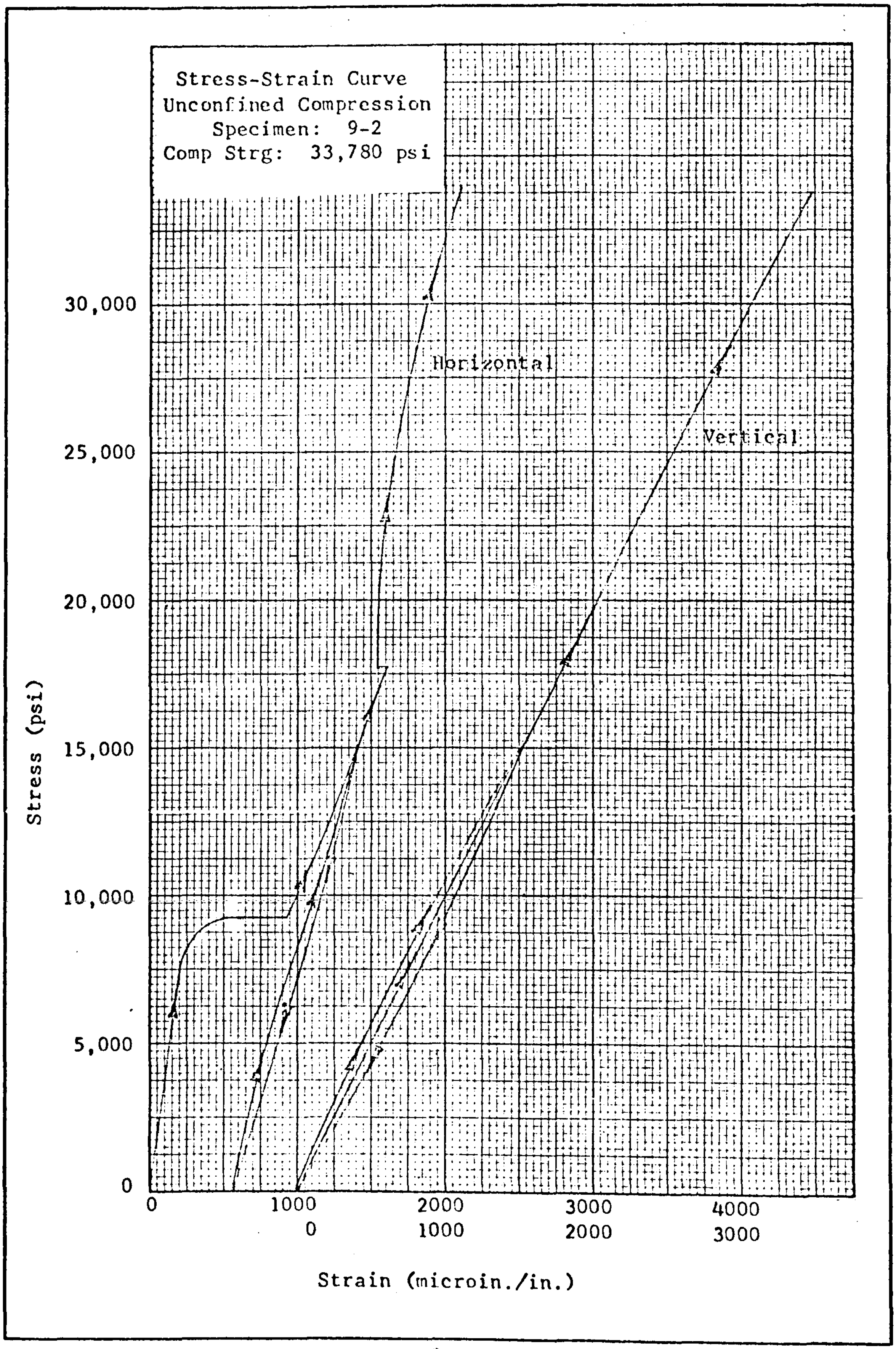
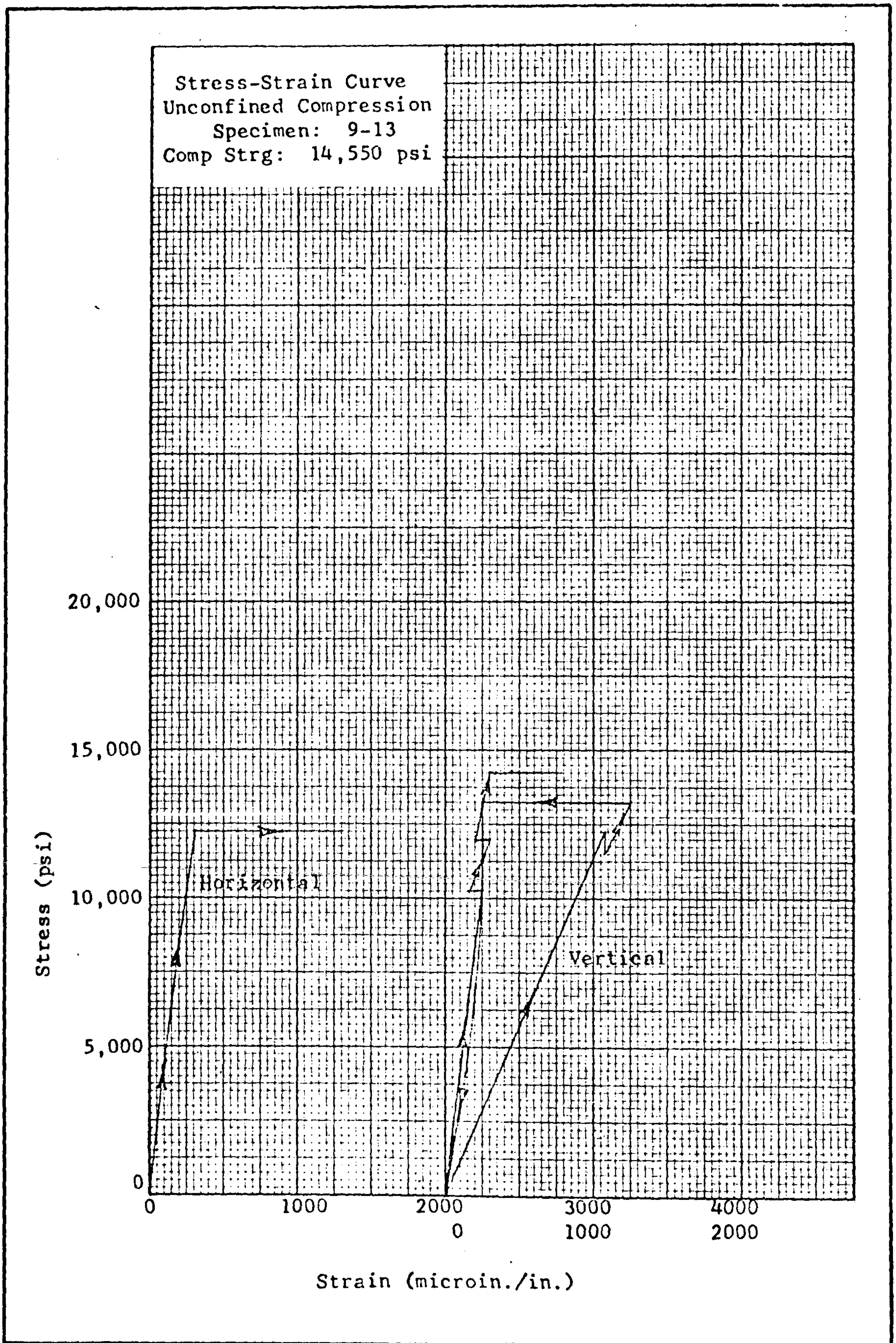

Stress-Strain Curve
Unconfined Compression
Specimen: 9-2
Comp Strg: 33,780 psi
Horizontal
Vertical
Stress (psi)
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1000
2000
3000
4000
0
1000
2000
3000
Strain (microin./in.)

PLATE 1



Stress-Strain Curve
Unconfined Compression
Specimen: 9-13
Comp Strg: 14,550 psi
Stress (psi)
20,000
15,000
10,000
5,000
0
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
Strain (microin./in.)

PLATE 2

APPENDIX D

DATA REPORT

Hole ST-CR-12

1 August 1969

Hole Location: Iron County, Missouri

Township 32N, Range 4E, Section 8

1620' W/EL, 1850' S/NL, SW 1/4 NE 1/4

Core

1. The following core was received on 28 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	8
2	18
3	28
4	38
5	41
6	50
7	59
8	66
9	76
10	86
11	96
12	106
13	109
14	118
15	127
16	131
17	138
18	147
19	158
20	166
21	179
22	187
23	197

Description

2. The samples received were blue-gray to brown-gray rock identified by the field log received with the core as rhyolite porphyry over the upper 110 ft and welded tuff over the lower 90 ft of the hole. All specimens contained some fractures and/or seams, some oriented at critical angles.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
1	Healed, High Angle Fractures	8	2.762	51.8	18,080	19,850
6	Healed, High Angle Fractures	50	2.804	--	10,210	21,725
8	Healed, Vertical and Horizontal Fractures	66	2.897	--	12,360	20,400
9	Healed, High Angle Fractures	76	2.746	64.5	10,360	21,550
11	Healed, High Angle Fractures	96	2.757	51.9	11,330	21,690
13	Healed, Critical Angle Fractures	109	2.920	53.2	1,700	21,050
15	Tightly Closed Fractures	127	2.836	59.7	29,550	20,880
19	Tightly Closed Fractures	158	2.824	--	24,520	22,310
20	Tightly Closed, Vertical Fractures	166	2.831	64.3	45,450	22,190
23	Healed, Vertical Fractures	197	2.853	--	14,320	22,035
Average Specimens with Tightly Closed Fractures (3)			2.830	62.0	33,170	21,795
Average Specimens with Healed Fractures (7)			2.820	55.4	11,190	21,185

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

The significant result of the above tests is the very low compressive strength obtained on specimen 13 in which the fracture was oriented at an apparent critical angle, thus indicating the possibilities of obtaining such strengths when the fractures, although healed, are oriented at critical angles to the applied stress.

Moduli of deformation

4. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 8 and 15. Stress-strain curves are given in plates 1 and 2. Specimen No. 8 was cycled at 8000 psi and No. 15 at 20,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6			Shear Velocity, fps	Poisson's Ratio
	Young's	Bulk	Shear		
		Dynamic Tests			
8	13.3	11.0	5.1	11,425	0.30
9	13.1	10.4	5.1	11,720	0.29
15	13.5	9.6	5.3	11,800	0.27
		Static Tests			
8	11.1	--	--	--	--
15	12.5	--	--	--	--

5. All of the rock tested herein is apparently rather rigid material exhibiting slight hysteresis. Values for the static bulk and shear moduli and the static Poisson's ratio could not be reasonably determined for

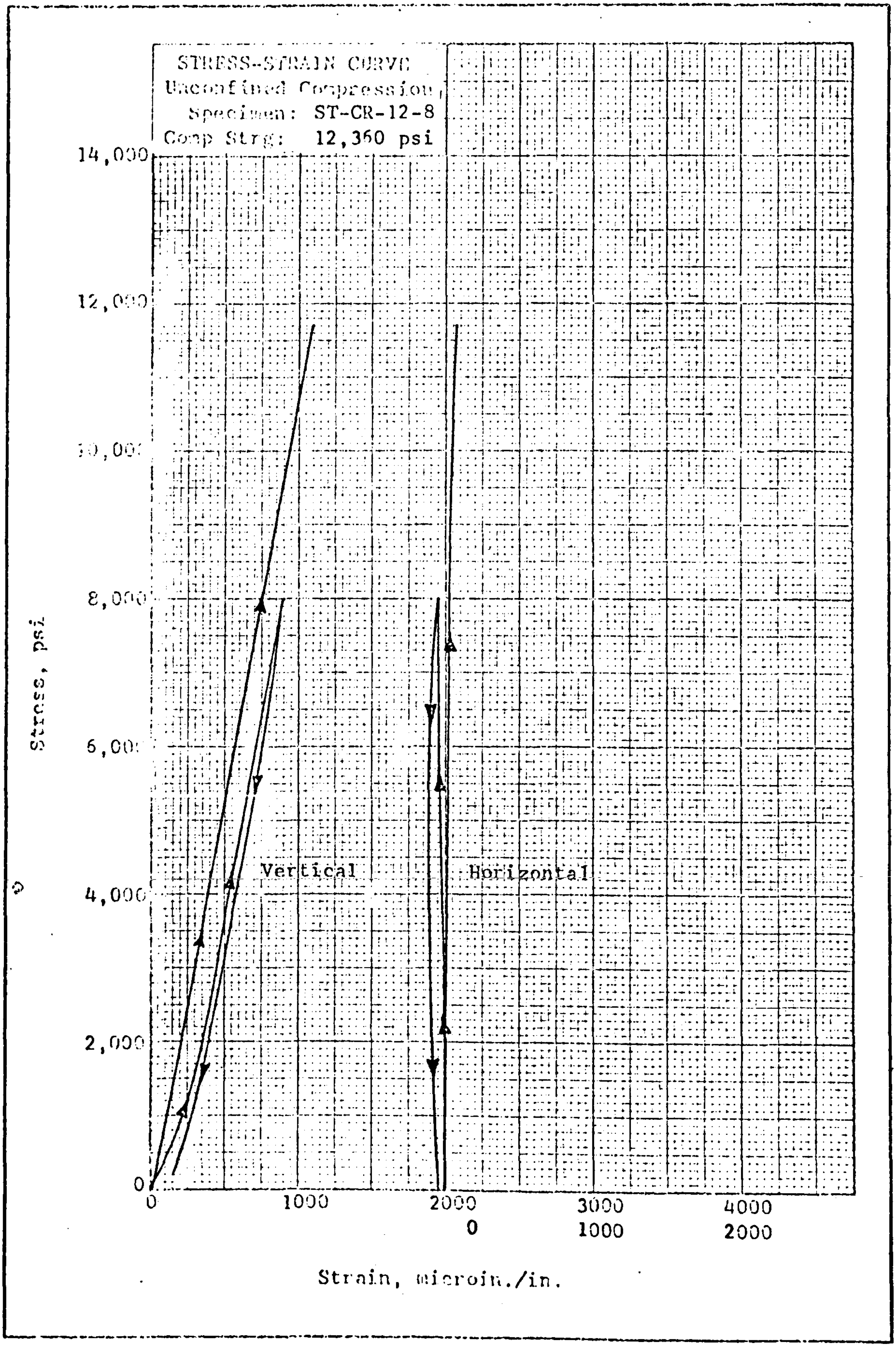
specimen Nos. 8 and 15 due to the erratic behavior of the horizontal strain gages. This behavior was probably due to the location of the horizontal gages over healed, high-angle fractures which closed slightly upon loading.

Conclusions

6. The core received from hole ST-CR-12 was identified by the field log as blue-gray rhyolite porphyry over the upper 110 ft of the hole and brown-gray welded tuff over the remaining 90 ft. Some fracturing, much of it healed, was present in all of the specimens. The rock from this hole was noticeably denser than the rock from the other holes in the Scott Area. Average compressive wave velocities were also greater.

Property	Specimens with Tightly Closed Fractures	Specimens with Healed Fractures
Specific Gravity	2.830	2.820
Schmidt No.	62.0	55.4
Compressive Strength, psi	33,170	11,190
Compressional Wave Velocity, fps	21,795	21,185
Young's Modulus, psi x 10^6	12.5	11.1

7. Generally, the group of specimens containing healed fractures exhibited considerably lower compressive strengths than did the group containing tightly closed fractures, the healing material apparently acting as a lubricant rather than an adhesive. Only in the case of the specimen containing healed, critically oriented fractures was the material very weak (compressive strength of 1700 psi).



STRESS-STRAIN CURVE
Unconfined Compression,
Specimen: ST-CR-12-8
Comp Strg: 12,360 psi
14,000
12,000
8,000
6,000
4,000
2,000
0
Stress, psi
Vertical
Horizontal
0
1000
2000
3000
4000
0
1000
2000
Strain, microin./in.

PLATE 1

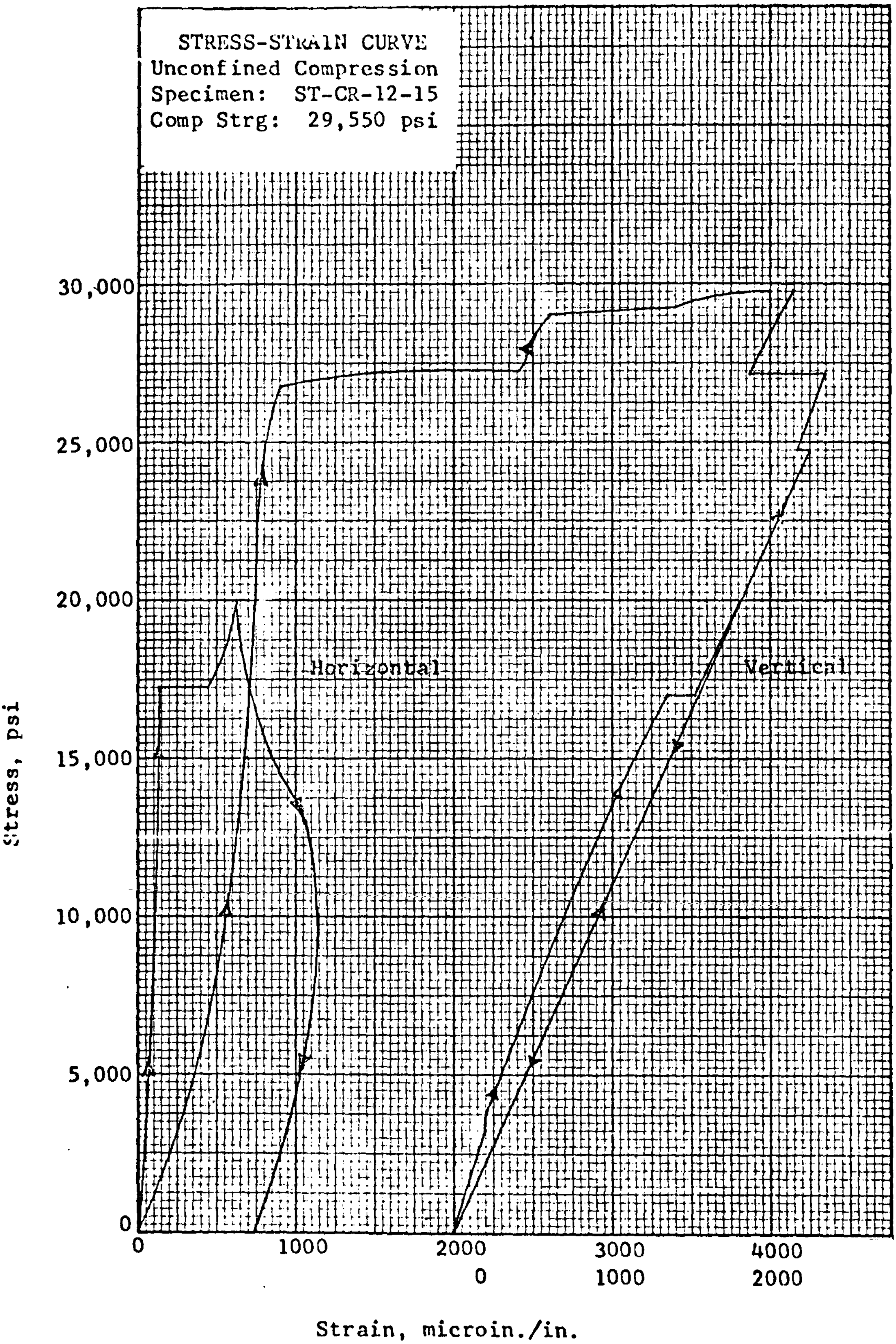

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: ST-CR-12-15
Comp Strg: 29,550 psi
30,000
25,000
20,000
15,000
10,000
5,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
Strain, microin./in.

PLATE 2

APPENDIX E

DATA REPORT

Hole ST-CR-16

22 July 1969

Hole Location: Madison County, Missouri

Township 34N, Range 5E, Section 26

2680' E/WL, 2080' S/NL, SE 1/4 NW 1/4

Core

1. The following core was received on 13 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	11
2	18
3	28
4	38
5	47
6	56
7	65
8	77
9	86
10	98
11	108
12	116
13	128
14	138
15	144
16	155
17	164
18	172
19	184
20	192
21	199

Description

2. The samples received were pink rock identified as hornblende granite by the field log received with the core. Piece Nos. 1, 2, and 3 appeared to be slightly weathered. Piece Nos. 2, 3, 5, and 7 contained seams and/or tightly closed fractures.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
1	Slightly Weathered	11	2.600	47.5	33,350	17,580
2	Slightly Weathered, Fractured	18	2.594	53.6	36,140	16,920
3	Slightly Weathered, Fractured	28	2.601	--	16,430	16,790
4	Intact	38	2.620	50.3	40,280	17,600
9	Intact	86	2.621	53.4	43,930	18,280
12	Fractured	116	2.616	52.0	37,800	17,930
15	Fractured	144	2.617	50.0	22,140	18,110
16	Intact	155	2.616	52.3	42,430	17,840
20	Fractured	192	2.624	49.4	38,570	17,970
21	Intact**	199	2.664	52.6	26,360	18,910
Average of All Specimens			2.617	51.2	33,745	17,795

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Specimen contained, according to field log, a bluish-green zone of clorization or saussuritzation.

4. The specimens from this hole were grouped for testing according to visible physical characteristics as given in the second column of the tabulation in paragraph 3. However, such a grouping did not reflect significant differences in the core samples. Accordingly, the test results for the entire hole were considered together.

5. Compressive strength varied considerably, ranging from 16,430 psi for one slightly weathered, fractured specimen to 43,930 psi for an intact specimen. There was no particular manner of variation, as evidenced by the fact that two of the apparently weathered specimens exhibited higher compressive strengths than one of the intact specimens. In spite of the considerable variation, all specimens tested were indicative of rather competent material. The compressive wave velocities were relatively uniform; the three lowest velocities were obtained on the three weathered specimens.

Moduli of deformation

6. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 1 and 9. Stress-strain curves are given in plates 1 and 2. Specimen No. 1 was cycled at 20,000 psi, and No. 9 was cycled at 25,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
1	8.0	6.7	3.1	9365	0.30
9	8.8	7.3	3.4	9780	0.30
		Static Tests			
1	9.1	6.7	3.4	--	0.27
9	10.4	7.6	4.1	--	0.27

All of the rock tested herein is apparently rather competent material exhibiting slight hysteresis.

Conclusions

7. The core received for testing from hole ST-CR-16 was identified as pink hornblende granite by the field log received with the core. The core was relatively uniform in appearance; some weathering and macro-fracturing were present; however, test results did not reflect the effect of weathering or fracturing. There was considerable variation in compressive strength as indicated by a range in compressive strength of approximately 28,000 psi. All of the rock was competent material and much was very competent.

Property	Average for All Specimens Tested
Specific Gravity	2.617
Schmidt No.	51.2
Compressive Strength, psi	33,745
Compressional Wave Velocity, fps	17,795
Young's Modulus, psi x 10^6	9.8

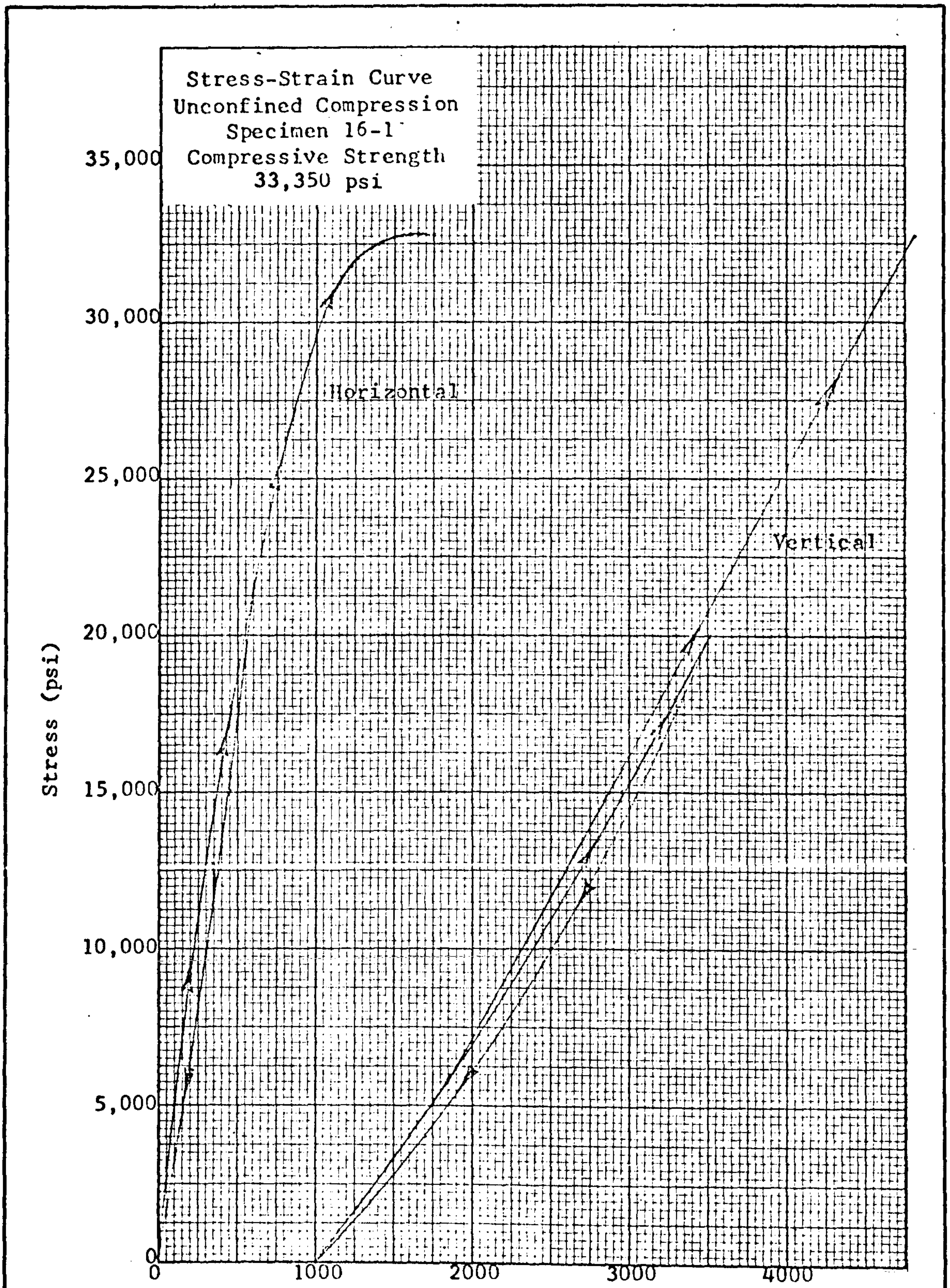

Stress-Strain Curve
Unconfined Compression
Specimen 16-1
Compressive Strength
33,350 psi
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Stress (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain (μin./in.)

PLATE 1

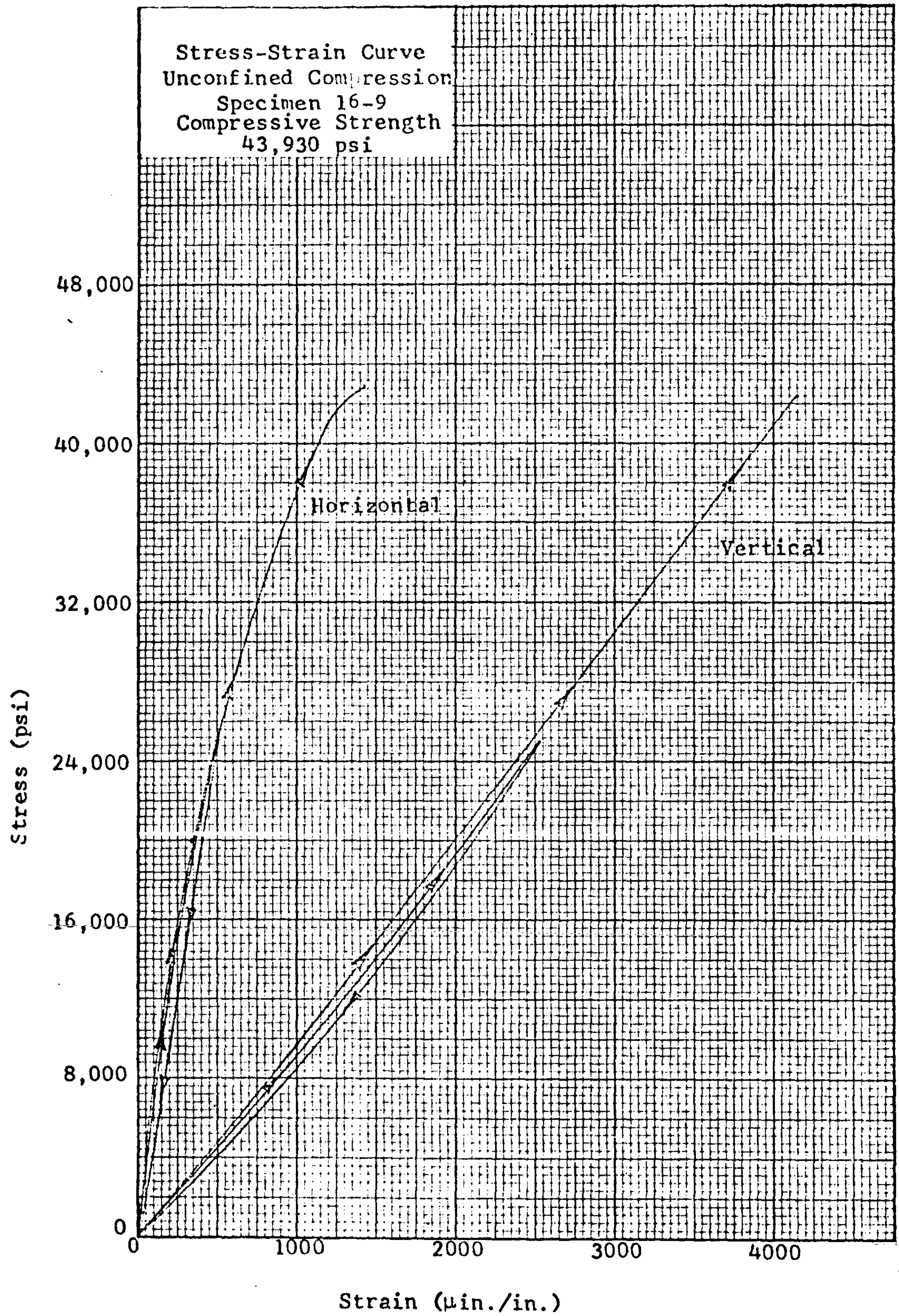

Stress-Strain Curve
Unconfined Compression
Specimen 16-9
Compressive Strength
43,930 psi
48,000
40,000
32,000
24,000
16,000
8,000
0
Stress (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
Strain (μin./in.)

PLATE 2

APPENDIX F

DATA REPORT

Hole ST-CR-18

29 July 1969

Hole Location: Iron County, Missouri

Township 31N, Range 4E, Section 17

290' W/EL, 1000' S/NL, NE 1/4 NE 1/4

Core

1. The following core was received on 18 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	25
2	38
3	48
4	55
5	64
6	71
7	77
8	83
9	89
10	94
11	104
12	112
13	116
14	127
15	131
16	136
17	148
18	157
19	168
20	176
21	183
22	195
23	199

Description

2. The samples received were quite variable in appearance. According to the field log received with the core, the rock was identified as gray to gray-yellow marl in the upper regions of the hole and maroon rhyolite and rhyolite porphyry in the lower regions. All pieces contained seams and/or fractures, some of which were inclined at critical angles.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
2	Highly Fractured Marl	38	2.798	52.1	5,480**	20,480
4	Fractured Marl	55	2.775	36.3	9,635	13,215
8	Fractured Transitional Rock	83	2.600	55.0	17,300	17,685
9	Fractured, Gray Igneous Porphyry	89	2.538	40.3	10,480	17,335
11	Red Porphyry	104	2.649	52.1	44,850	20,005
13	Fractured Red Porphyry	116	2.659	55.0	5,690**	19,700
14	Red Porphyry	127	2.665	--	31,300	21,895
18	Red Porphyry	157	2.661	--	52,575	20,720
19	Red Porphyry	168	2.651	--	55,000	20,350
Average Fractured Marl and Transitional Rock			2.668	46.0	10,725	17,180
Average Red Porphyry***			2.657	53.6	45,930	20,535

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Specimen contained several critical angle fractures along which failure occurred, resulting in low compressive strength.

*** Excluding specimen No. 13, which failed along several very weak critical angle fractures.

4. Test results were divided into two groups according to field log descriptions of the specimens: red porphyry and fractured marl and transitional rock. The red porphyry contained tightly closed macrofractures.

The two groups exhibited drastically different average compressive strengths, with the red porphyry generally exhibiting three to four times the strength of the marl and transitional material. The only exception was one red porphyry specimen containing several critical angle fractures which failed cleanly along the fractures at a relatively low stress. This same specimen exhibited a compressive wave velocity somewhat lower than the other specimens in the group, probably due to the fracture.

5. The compressive wave velocities for specimens from this hole varied significantly, unlike the velocities from holes ST-CR-4, ST-CR-9, ST-CR-16, ST-CR-20, and ST-CR-26. This variation can be attributed to the wide range of composition and condition characteristic of the specimens from hole ST-CR-18, especially the material identified as marl. Generally, the wave velocities exhibited by the specimens of fractured marl and transitional rock were quite variable and significantly lower than the velocities exhibited by the red porphyry.

Moduli of deformation

6. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 4 and 14. Stress-strain curves are given in plates 1 and 2. Specimen No. 4 was cycled at 3000 psi, and No. 14 was cycled at 30,000 psi. Results are given below.

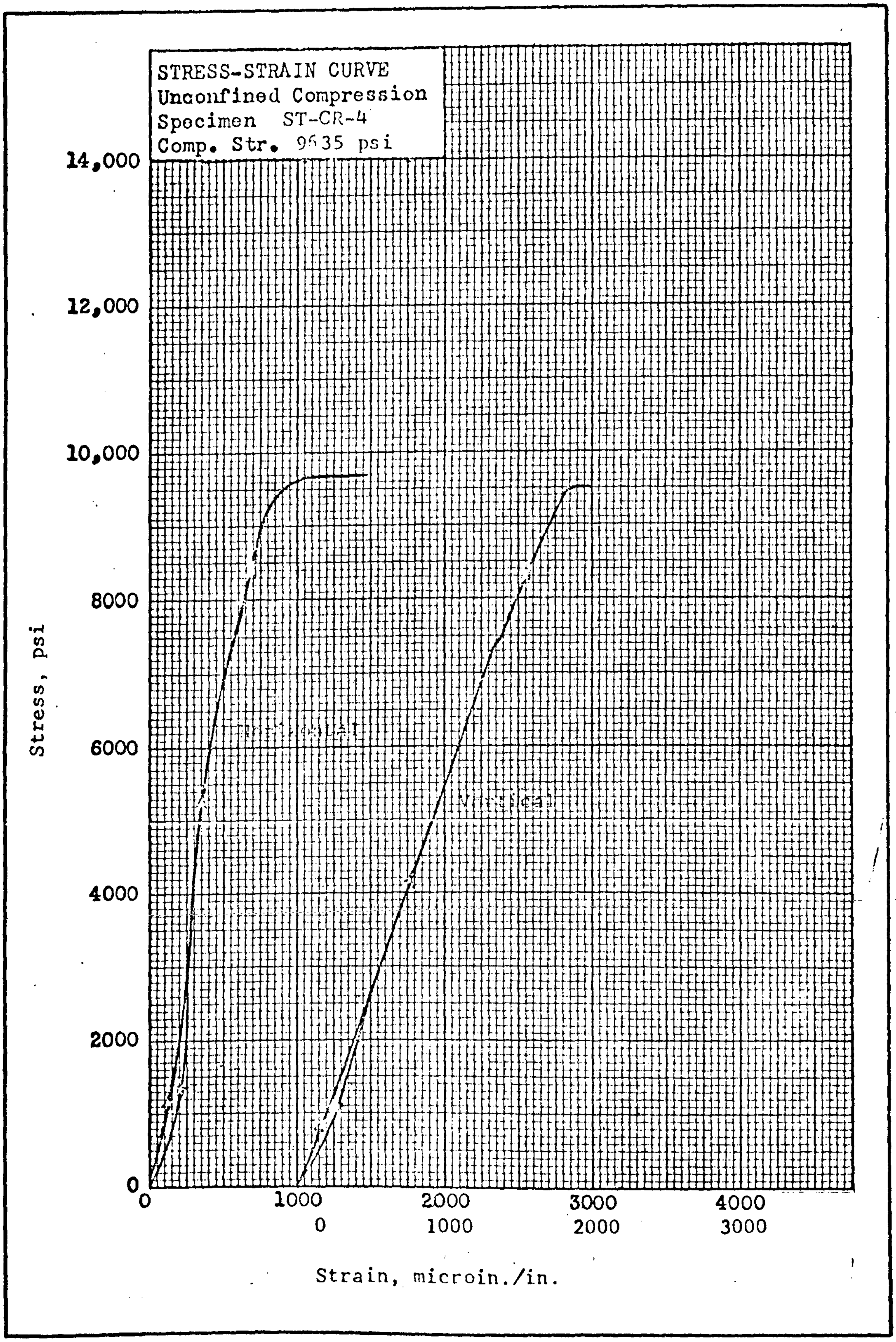
Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
			Dynamic Tests		
4	6.1	3.0	2.6	8,390	0.16
9	8.6	5.7	3.4	10,050	0.25
14	14.6	9.4	5.9	12,800	0.24
			Static Tests		
4	5.9	4.7	2.3	--	0.29
14	12.8	6.7	5.4	--	0.18

All of the rock tested herein is apparently rather variable material exhibiting slight hysteresis.

Conclusions

7. The core received from hole ST-CR-18 was identified by the field log as gray to gray-yellow marl, and maroon rhyolite and rhyolite porphyry. All pieces contained some fractures and/or seams. Considerably lower compressive strengths were obtained from the specimens of marl and transitional material, the group generally consisting of quite variable material. One highly fractured specimen of marl and one critically fractured specimen of red porphyry were especially weak, yielding strengths of only 5000 psi each.

Property	Fractured Marl and Transitional Rock	Fractured Red Porphyry
Specific Gravity	2.668	2.657
Schmidt No.	53.6	53.6
Compressive Strength, psi	10,725	45,930
Compressional Wave Velocity, fps	17,180	20,535
Young's Modulus, psi x 10^6	5.9	12.8



STRESS-STRAIN CURVE
Unconfined Compression
Specimen ST-CR-4
Comp. Str. 9635 psi
14,000
12,000
10,000
8000
6000
4000
2000
0
Stress, psi
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 1

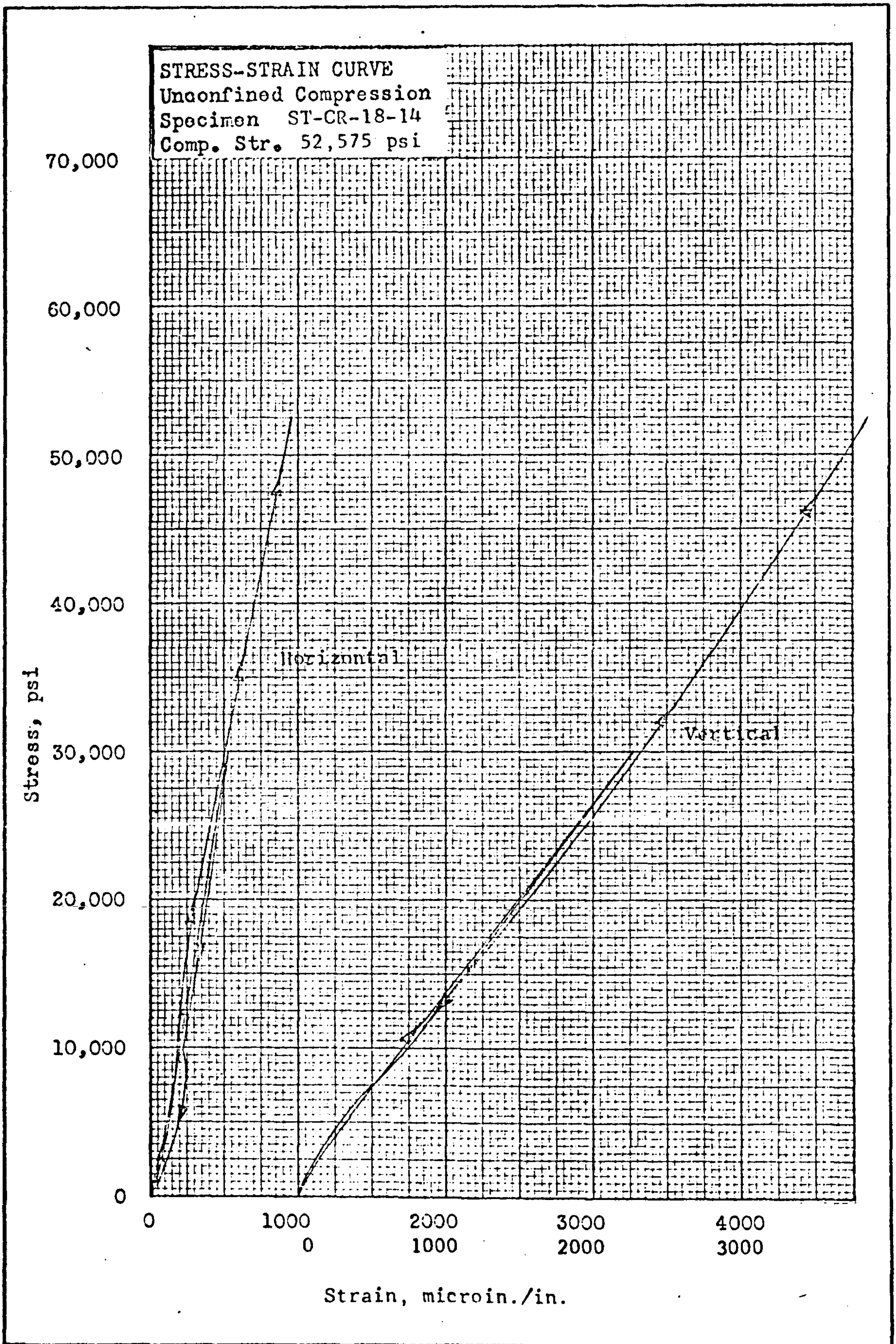

STRESS-STRAIN CURVE
Unconfined Compression
Specimen ST-CR-18-14
Comp. Str. 52,575 psi
Stress, psi
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 2

APPENDIX G

DATA REPORT

Hole ST-CR-20

25 July 1969

Hole Location: Wayne County, Missouri

Township 29N, Range 3E, Section 24

750' E/WL, 950' S/NL, NE 1/4 NW 1/4

Core

1. The following core was received on 1 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	18
2	30
3	36
4	42
5	50
6	61
7	68
8	80
9	91
10	102
11	112
12	119
13	127
14	139
15	148
16	159
17	166
18	175
19	186
20	194
21	200

Description

2. The samples received were green-gray rock identified as latite porphyry by the field log received with the core. Piece Nos. 3, 4, 6, 9, 11, 14, 17, 19, and 21 contained seams and/or fractures, most of which were tightly closed.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
4	Fractured	42	2.669	--	37,425	19,340
7	Unfractured**	68	2.731	53.4	21,210	20,495
9	Fractured	91	2.713	54.3	23,105	20,655
10	Unfractured	102	2.730	54.2	52,120	20,940
11	Fractured	112	2.734	--	26,365	21,085
12	Unfractured**	119	2.722	55.3	19,090	20,715
16	Unfractured	159	2.712	49.2****	50,075	20,640
17	Fractured	166	2.712	--	34,240	20,725
21	Fractured	200	2.709	61.0	21,970	20,805
Average	Fractured Specimens***		2.713	56.0	26,200	20,545
Average	Unfractured Specimens		2.721	54.2	51,100	20,790

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Specimens discovered after test to have very small macrocracks, some of which were critically oriented and may have initiated failure.

*** Includes the two specimens previously classified as unfractured which were, subsequent to testing, found to contain small macrocracks.

**** Deleted from average due to probable unreliability caused by irregular shape of specimen.

4. The specimens were divided into two groups: fractured specimens which contained visible seams and/or fractures and unfractured specimens which contained no visible fractures. Two specimens originally thought to be unfractured were later found to contain tightly closed macrofractures. The test results for these two specimens were accordingly grouped with the results for the fractured specimens.

5. Unconfined compressive tests indicated that the unfractured rock was considerably stronger than the rock containing seams or fractures, the average unfractured strength being nearly twice the average fractured strength. Both of the unfractured specimens displayed conical type failures while the remainder of the specimens failed by splitting vertically.

6. Compressive wave velocities for all specimens tested were relatively relatively uniform, indicating that much of the fracturing was nearly vertical or tightly healed. The average compressive wave velocity for the unfractured group was slightly higher than the average for the fractured group.

Moduli of deformation

7. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 7 and 11. Stress-strain curves are given in plates 1 and 2. Specimen No. 7 was cycled at 20,000 psi, while No. 11 was cycled at 15,000 psi. Results are given below.

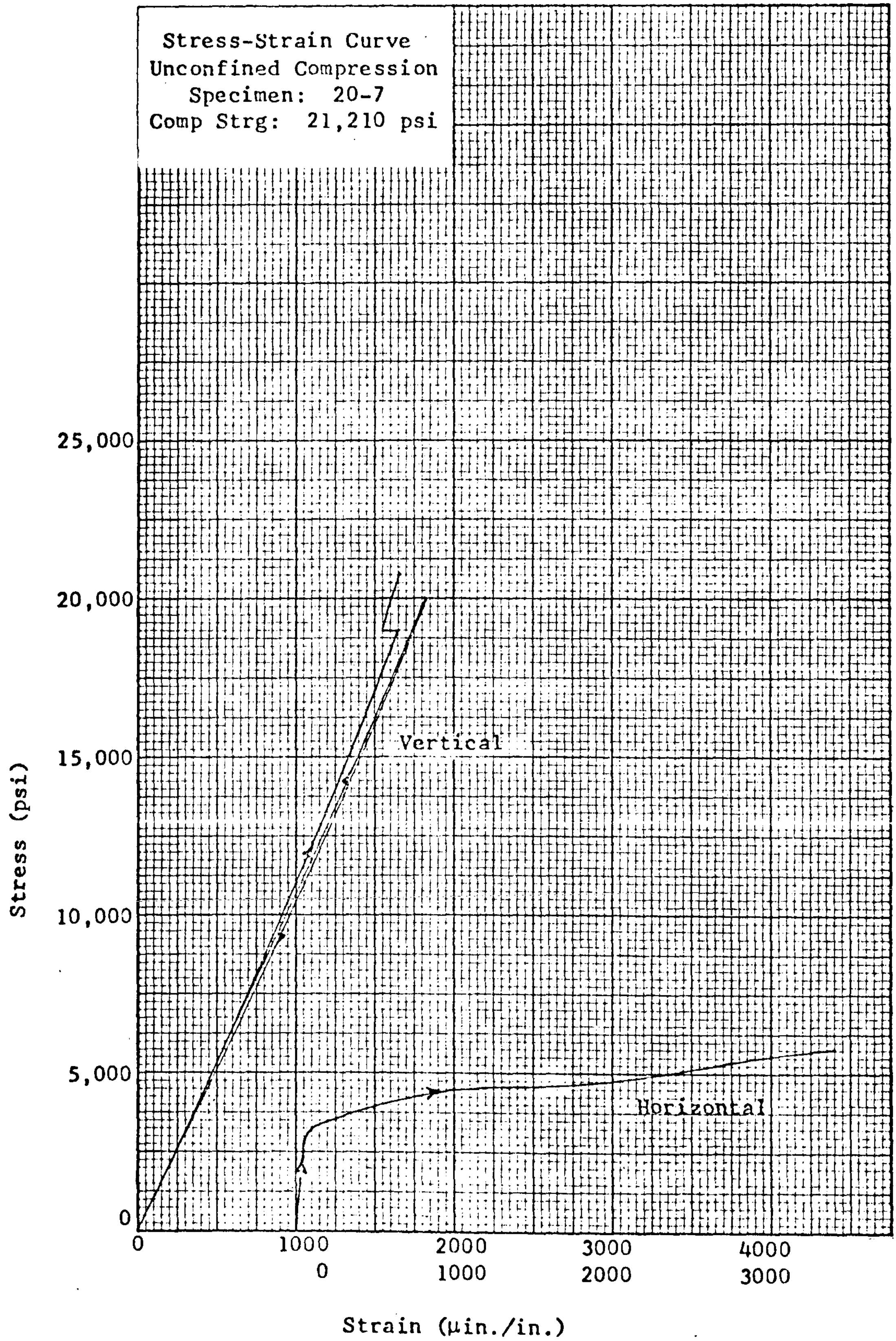
Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
7	12.5	8.8	5.0	11,600	0.26
11	13.2	9.4	5.2	11,915	0.27
		Static Tests			
7	10.8	7.5	4.3	--	0.26
11	9.5	5.2	4.0	--	0.19

All of the rock tested herein is apparently rather rigid material. The hysteresis exhibited by specimen No. 11 was due to slippage along already present cracks.

Conclusions

8. The core received from hole ST-CR-20 was identified as green-gray latite porphyry by the field log received with the core. Some macrofracturing was present in many of the specimens, with most fractures being tightly closed or healed. Considerably lower compressive strengths were obtained from the fractured specimens. Despite the fracturing, rather competent material is indicated.

Property	Fractured	Unfractured
Specific Gravity	2.713	2.721
Schmidt No.	56.0	54.2
Compressive Strength, psi	26,200	51,100
Compressional Wave Velocity, fps	20,545	20,790
Young's Modulus, psi x 10^6	10.0-12.0	--



Stress-Strain Curve
Unconfined Compression
Specimen: 20-7
Comp Strg: 21,210 psi
Stress (psi)
0
5,000
10,000
15,000
20,000
25,000
Vertical
Horizontal
0
1000
2000
3000
4000
0
1000
2000
3000
Strain (µin./in.)

PLATE 1

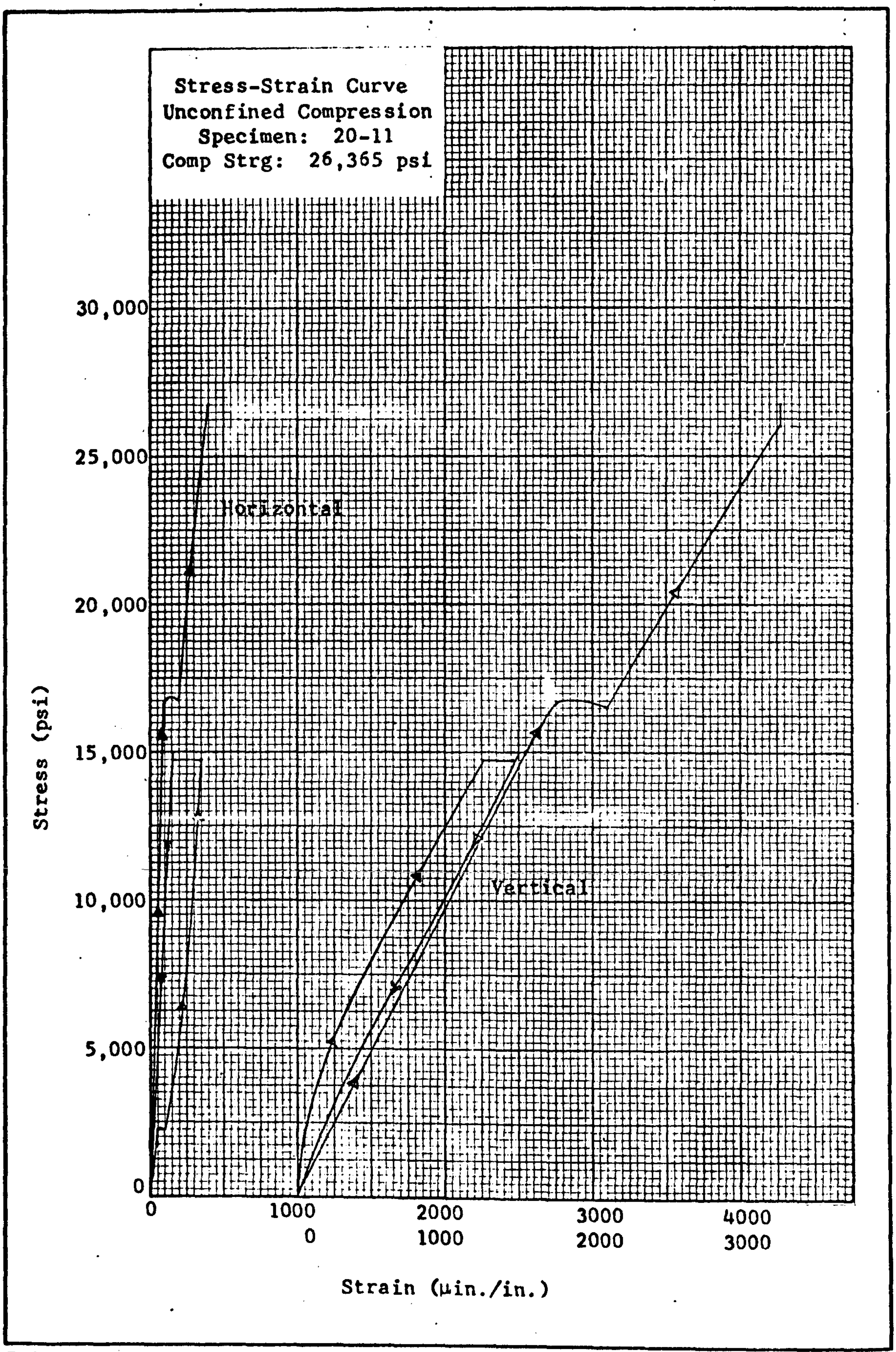

Stress-Strain Curve
Unconfined Compression
Specimen: 20-11
Comp Strg: 26,365 psi
30,000
25,000
20,000
15,000
10,000
5,000
0
Stress (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain (μin./in.)

PLATE 2

APPENDIX H

DATA REPORT

Hole ST-CR-26

16 July 1969

Hole Location: St. Francois County, Missouri

Longitude: 90° 23' West

Latitude: 30° 40' North

Township 34N, Range 6E, Section 8

750' W/EL, 2000' S/NL, SE 1/4 NE 1/4

Core

1. The following core was received on 1 July 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	13
2	19
3	32
4	36
5	47
6	56
7	64
8	73
9	83
10	95
11	104
12	113
13	118
14	127
15	136
16	147
17	155
18	166
19	172
20	176
21	186
22	196

Description

2. The samples received were pinkish- to gray-colored rock identified as low-grade metamorphics by the field log received with the core. Piece Nos. 1, 2, and 3 appeared somewhat weathered. Piece Nos. 1, 2, 3, 4, 5, 6,

7, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 21, and 22 contained seams and/or fractures, most of which were tightly closed.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
2	Highly Fractured	19	2.654	--	7,860	**
6	Critical Angle Fractured	56	2.651	--	8,520	19,010
8	Fractured, Contained Pink Granitic Material	73	2.703	53.2	24,290	20,075
11	Fractured	104	2.736	--	14,340	20,420
14	Fractured	127	2.675	57.5	24,690	20,300
16	Intact Rock	147	3.024	55.6	43,570	19,795
20	Intact, Contained Pink Granitic Material	176	2.680	59.8	50,860	20,175
22	Some Fracturing***, Failed through Rock	196	2.749	55.8	41,290	20,930
~~Average Critically Fractured (2)~~			2.653	--	8,190	19,010
Average Fractured (3)			2.705	55.4	21,105	20,265
Average Intact (3)			2.818	57.1	45,240	20,300

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Compressive wave test not performed. Specimen required capping for unconfined compression test--capping material would have rendered questionable results of velocity test.

*** Though specimen was partially fractured, fractures apparently had little effect on results of compressive strength test or mode of failure. Specimen failed through intact rock, not along fractures.

4. The results were grouped according to compressive strength which was dependent on the original condition of the specimens and the modes of failure. The highly fractured rock near the surface is apparently rather poor material and contains fractures at critical angles for compression testing (45 to 50 deg with the horizontal), e.g., specimen No. 6. The specimens which contained relatively high angle fracturing exhibited somewhat higher compressive strengths and were reasonably competent. Specimens which were either intact or vertically fractured and failed through rock represented quite competent material.

5. The compressive wave velocities for all specimens tested were relatively uniform, indicating that much of the fracturing was vertical or near vertical and tightly closed.

Moduli of deformation

6. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 6 and 16. Stress-strain curves are given in plates 1 and 2. Specimen 16 was cycled at 20,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
6	9.2	8.2	3.5	9,915	0.31
16	12.6	9.4	4.9	10,995	0.28
		Static Tests			
6	8.7	4.4	3.7	--	0.17
15	13.2	10.6	5.8	--	0.29

Slight hysteresis is evident in the stress-strain relationships.

Conclusions

7. The core received from hole ST-CR-26 was identified as low-grade metamorphics by the field log received with the core. All of the core was pinkish-to gray-colored with the pink material described by the log as granitic material. Some macrofracturing was present in many of the samples. Considerably lower physical test results were obtained on the highly fractured samples from the first 50 ft of depth. The remainder of the samples tested indicated relatively competent material, especially those which were not influenced by the macrofractures. The compressive velocity for sample 6 did not reflect its low compressive strength, apparently due to the vertical, tightly closed nature of the fractures.

Property	Critically Fractured	Fractured	Intact and Failing Through Rock
Specific Gravity	2.653	2.705	2.818
Schmidt No.	--	55.4	57.1
Compressive Strength, psi	8,190	21,105	45,240
Compressional Wave Velocity, fps	19,010	20,265	20,300
Young's Modulus, psi x 10^6	8.7	--	13.2

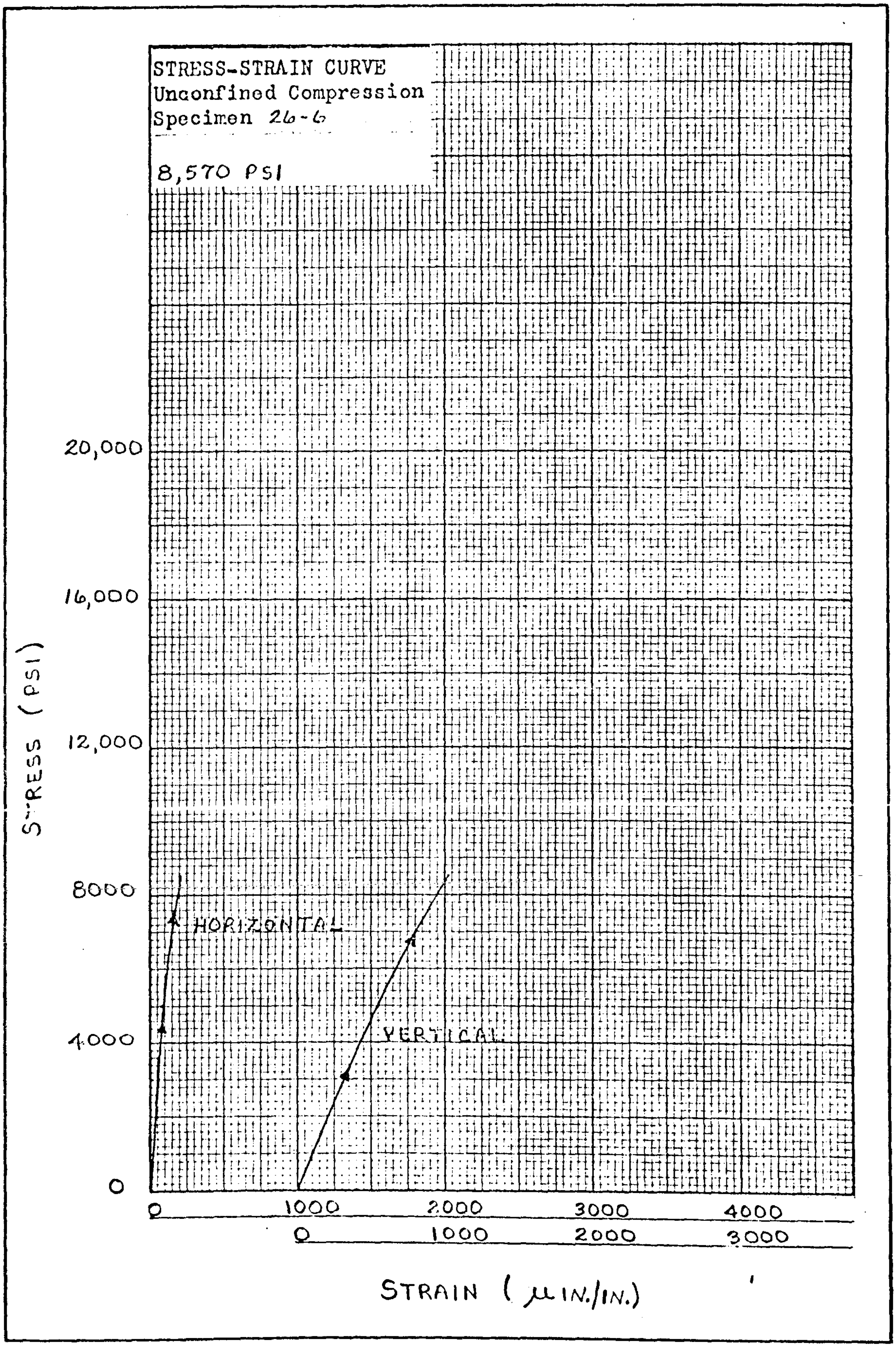

STRESS-STRAIN CURVE
Unconfined Compression
Specimen 26-6
8,570 PSI
20,000
16,000
12,000
8000
4000
0
HORIZONTAL
VERTICAL
STRESS (PSI)
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN (μ IN./IN.)

PLATE 1

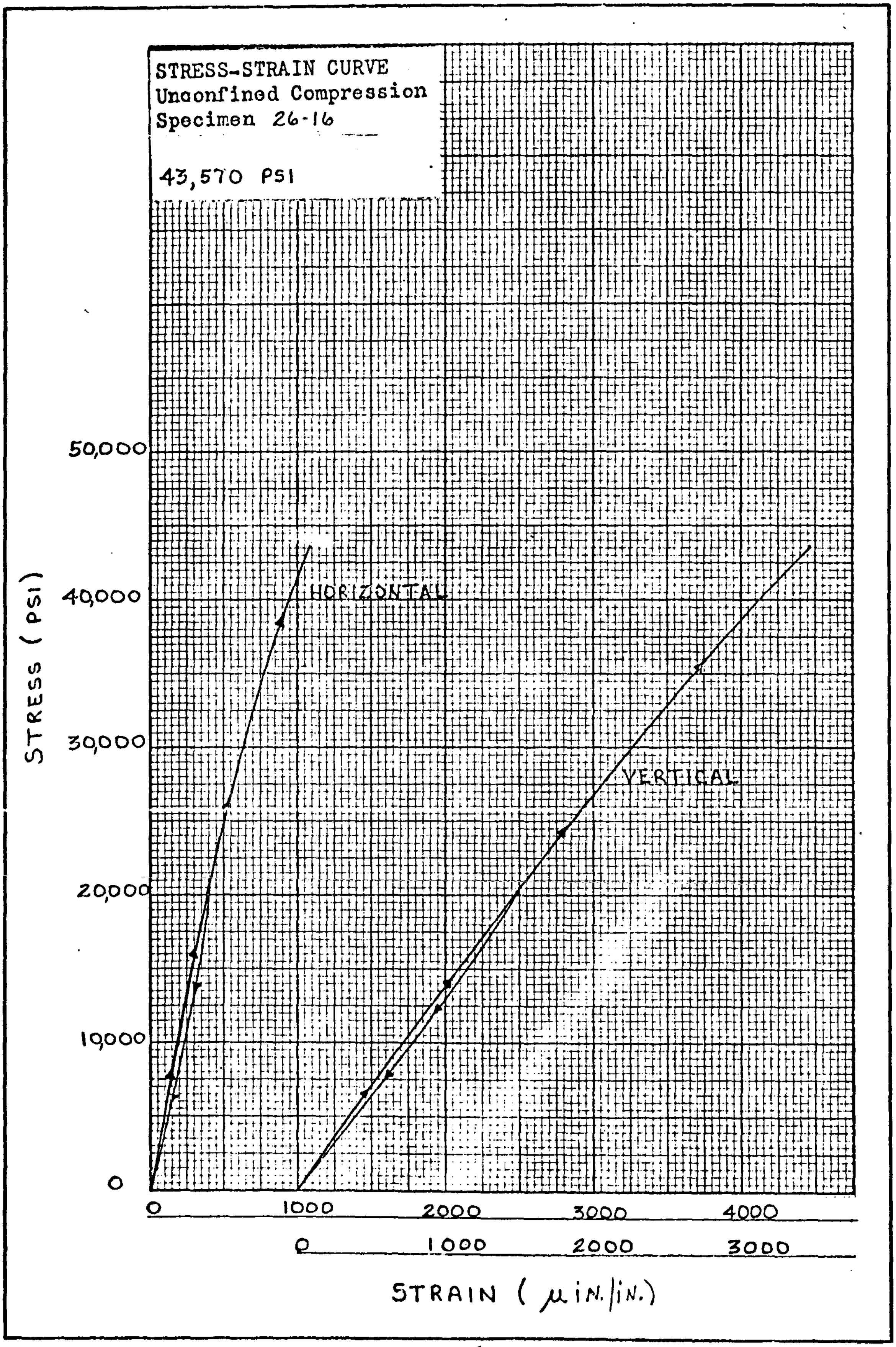

STRESS-STRAIN CURVE
Unconfined Compression
Specimen 26-16
43,570 PSI
HORIZONTAL
VERTICAL
STRESS (PSI)
50,000
40,000
30,000
20,000
10,000
0
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN (μIN./IN.)

PLATE 2

APPENDIX I

DATA REPORT

Hole ST-CR-28

8 August 1969

Hole Location: Madison County, Missouri

Township 32N, Range 8E, Section 7

550' E/WL, 50' N/SL, SW 1/4 SW 1/4

Core

1. The following core was received on 4 August 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	9
2	19
3	30
4	39
5	48
6	59
7	63
8	73
9	82
10	92
11	101
12	112
13	122
14	132
15	141
16	151
17	160
18	169
19	180
20	188
21	197

Description

2. The samples received were pinkish-gray to gray-colored rock identified as rhyolite porphyry by the field log received with the core. All pieces contained fractures.

Quality and uniformity tests

3. To determine variations within the hole, specific gravity, Schmidt number, compressive strength, and compressional wave velocity were determined on specimens prepared from representative samples as given below:

Sample No.	Description	Core Depth	Sp Gr	Schmidt No.*	Comp Strg, psi	Comp Wave Vel, fps
2	Pronounced Critical Angle Fracturing	19	2.658	63.2	5,500**	20,515
3	Pronounced Fracturing	30	2.658	--	22,430	20,675
4	Moderate Fracturing	39	2.649	55.8	25,890	20,680
10	Fine Incipient Fracturing	92	2.663	55.5	57,140	20,790
11	Moderate Fracturing	101	2.655	57.2	28,730	20,440
13	Moderate Fracturing	122	2.659	55.8	21,090	20,565
16	Fine Incipient Fracturing	151	2.669	54.4	44,090	20,730
18	Fine Incipient Fracturing	169	2.659	53.4	52,720	20,705
21	Pronounced Fracturing	197	2.665	56.3	20,580	20,470
Specimen Failing Along Critical Angle Fracture (1)			2.658	63.2	5,500	20,515
Average of Specimens with Fine Incipient Fractures (3)			2.664	54.4	51,320	20,740
Average of Specimens with Pronounced and Moderate Fracturing (5)			2.657	56.3	23,745	20,565

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

** Specimen failed along pronounced critical angle fracture.

4. Results were grouped according to the nature of fracturing present in the specimens prior to testing. The three groups thus formed exhibited quite different average compressive strengths and different modes of failure. The group containing fine, tightly closed incipient fractures yielded a high compressive strength (average 51,320 psi), and all specimens in this group exhibited conical failure surfaces. The group of specimens containing moderate to pronounced fracturing yielded moderately high compressive strengths (average 23,745 psi) and generally failed by splitting vertically. The specimen containing a pronounced critical angle fracture failed along this fracture and exhibited a low compressive strength of only 5500 psi.

5. Compressive wave velocities exhibited by all specimens tested were surprisingly uniform, ranging only from 20,440 to 20,790 fps. This unusual uniformity was probably due to the vertical, tightly closed nature of many of the fractures and relatively uniform composition of specimens throughout the hole.

Moduli of deformation

6. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 4 and 16.

Stress-strain curves are given in plates 1 and 2. Specimen No. 4 was cycled at 10,000 psi and No. 16 at 20,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6			Shear Velocity, fps	Poisson's Ratio
	Young's	Bulk	Shear		
		Dynamic Tests			
2	12.6	8.4	5.0	11,840	0.25
4	12.6	8.6	5.0	11,850	0.26
16	11.2	9.7	4.3	10,925	0.31
		Static Tests			
4	12.8	8.7	5.1	--	0.25
16	10.8	6.3	4.4	--	0.22

All of the rock tested herein is apparently rather rigid material exhibiting slight hysteresis.

7. The rather erratic behavior of the vertical strain gages on specimen No. 4 was probably due to the location of the gages over high-angle fractures which slipped upon loading of the specimen.

Conclusions

8. The core received from hole ST-CR-28 was identified as pinkish-gray to gray-colored rhyolite porphyry by the field log received with the core. Some fracturing was present in all specimens, ranging from pronounced fracturing at critical angles to fine, incipient fracturing. The nature of the fracturing appeared to determine both the strength of the specimen and its mode of failure. The stronger specimens were those which contained very fine, incipient fractures and exhibited conical failure surfaces. The weaker specimens contained more pronounced

fractures and failed by splitting vertically or shearing along critical angle fractures. Compressive wave velocities were unusually uniform, a reflection on the vertical, tightly closed nature of much of the fracturing.

Property	Specimen Failing Along Critical Angle Fracture	Specimens With Fine Incipient Fractures	Specimens With Pronounced to Moderate Fracturing
Specific Gravity	2.658	2.664	2.657
Schmidt No.	63.2	54.4	56.3
Compressive Strength, psi	5,500	51,320	23,745
Compressive wave velocity, fps	20,515	20,740	20,565
Young's Modulus, psi x 10^6	--	10.8	12.8

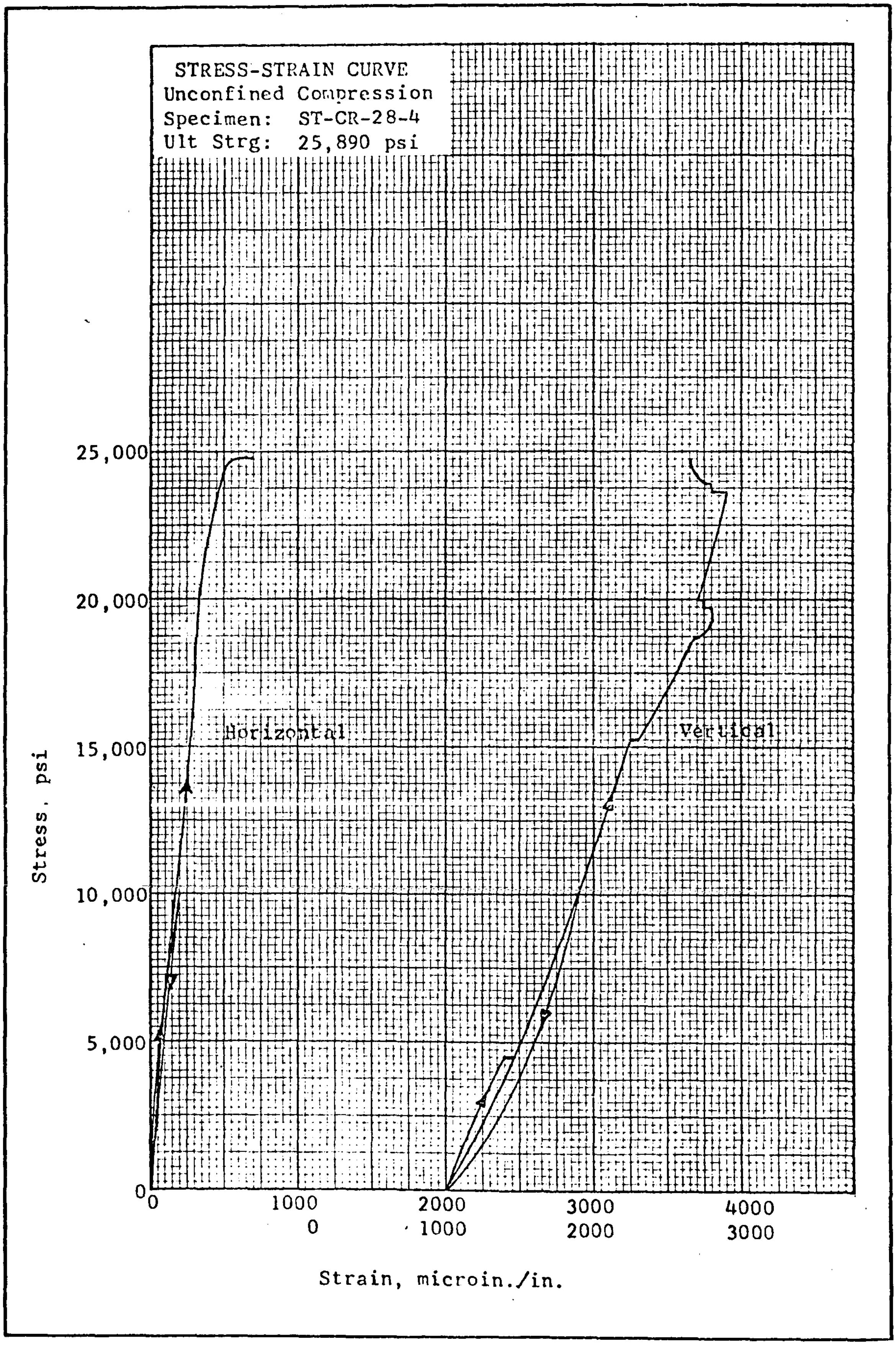

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: ST-CR-28-4
Ult Strg: 25,890 psi
Horizontal
Vertical
Stress, psi
25,000
20,000
15,000
10,000
5,000
0
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 1

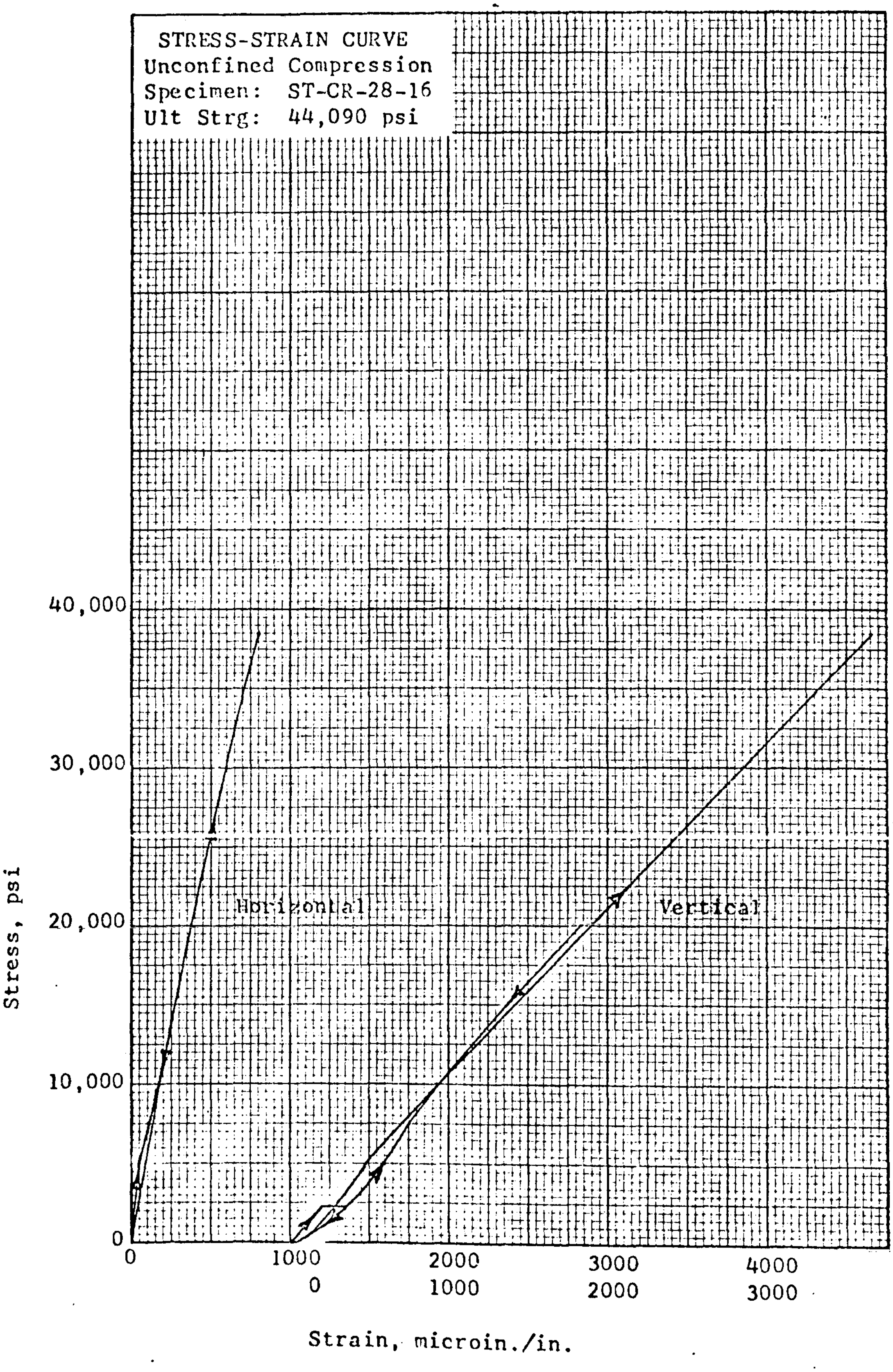

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: ST-CR-28-16
Ult Strg: 44,090 psi
40,000
30,000
20,000
10,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 2

DISTRIBUTION LIST FOR MP C-70-6

Address	No. of Copies
Commander, Space and Missile Systems Organization ATTN: CPT R. G. Tart, Jr. (SMQHF-2) Norton AFB, Calif. 92409	20
Aerospace Corporation ATTN: N. P. Langley San Bernardino Operations, P. O. Box 7308 San Bernardino, Calif. 92402	1
Air Force Weapons Laboratory	
ATTN: Library	1
(WLDC) CPT K. Spalvines	1
Kirtland AFB, N. Mex. 87117	
TRW, Inc.	
ATTN: Mr. F. Pieper	2
Mr. J. Steltenpohl	1
Norton AFB, Calif. 92409	
Ken O'Brien and Associates 3745 Long Beach Blvd ATTN: Mr. Pat Gallo Long Beach, Calif. 90807	1
Bechtel Corporation 2254 E. 49th Street ATTN: Mr. Robert Farwell Vernon, Calif. 90058	5
Physics International Company 2700 Merced Street ATTN: Dr. Fred Finlayson San Leandro, Calif. 94577	1

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Miss.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
TESTS OF ROCK CORES, SCOTT STUDY AREA, MISSOURI

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (First name, middle initial, last name)
Robert W. Crisp
Charles R. Hallford

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1970	124	7

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Miscellaneous Paper C-70-6

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Each transmittal of this document outside the Department of Defense must have prior approval of the Space and Missile Systems Organization (SMQHF-2).

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Space and Missile Systems Organization
U. S. Air Force Systems Command
Norton AFB, California

13. ABSTRACT
Laboratory tests were conducted on rock core samples received from nine core holes in the Scott Area of Iron, Madison, Saint Francois, and Wayne Counties, Missouri. The results were used to determine the quality and uniformity of the rock to depths of 200 feet below ground surface. The cores were identified as predominantly rhyolite and dacite porphyry with some granodiorite and small amounts of dolomite, acid metavolcanics, and dark gray volcanic breccia. Specific gravity, Schmidt hardness, compressional and shear velocity, and uniaxial compressive strength tests indicated that the highly to critically fractured material, representing approximately 10 percent of the core tested, was of questionable competence. The remainder of the core from this area was found to be relatively competent material. An assessment of the area on a hole-to-hole basis indicates that all but two of the Scott formations that were sampled and tested offer good possibilities as competent hard rock media.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rock cores						
Rock properties						
Scott Study Area, Missouri						

Unclassified

Security Classification