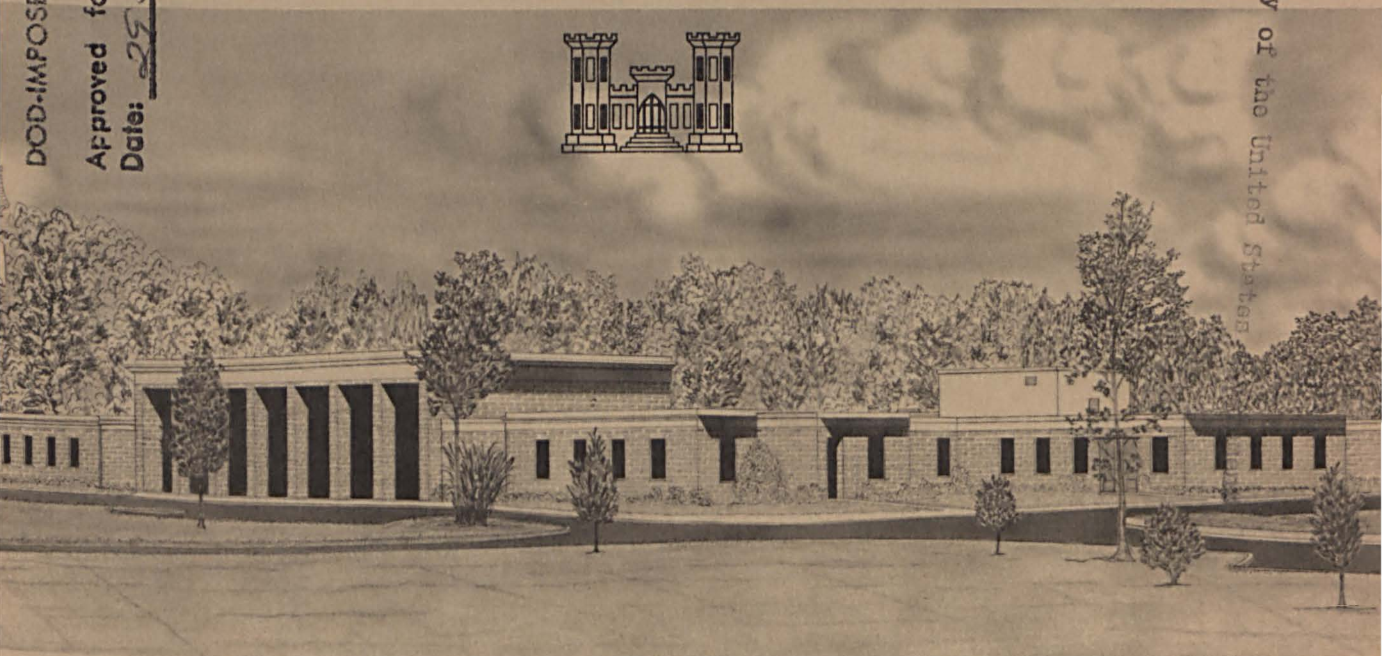
MISCELLANEOUS PAPER C-70-4

TESTS OF ROCK CORES BERGSTROM STUDY AREA, TEXAS

by

K. L. Saucier, A. D. Buck



February 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

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ASSOCIATED REPORTS

Report No.	Title	Date
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

TELEPHONE OR VERBAL CONVERSATION RECORD For use of this form, see AR 340-15; the proponent agency is The Adjutant General's Office.		DATE 29 February 1972
[SUBJ]ECT OF CONVERSATION Distribution Statement on Reports		
INCOMING CALL		
[PERS]ON CALLING	ADDRESS	PHONE NUMBER AND EXTENSION
[PERS]ON CALLED	OFFICE	PHONE NUMBER AND EXTENSION
OUTGOING CALL		
[PERS]ON CALLING Mr. James M. Polatty	OFFICE Concrete Division	PHONE NUMBER AND EXTENSION
[PERS]ON CALLED Captain B. W. Bullard	ADDRESS Space & Missile Systems Organization	PHONE NUMBER AND EXTENSION

[SUMM]ARY 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 [illegible] said following MP's/were to be changed to Statement A : covering rock tests for SAMSO

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

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

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ARMY-MRC VICKSBURG, MISS.

ABSTRACT

Laboratory tests were conducted on rock core samples from nine core holes in the Bergstrom area of Mason, Llano, Gillespie, and Burnet Counties, Texas. The results were used to determine the quality and uniformity of the rock to depths of 200 feet below the ground surface.

Petrographic examination indicated that the samples represented a very complex geologic area. Five general types of material were identified: red granite, light gneiss, dark gneiss, schist, and contact zone rock. The predominant material was red granite.

Based on physical characteristics (specific gravity, Schmidt hardness, wave velocity, and compressive strength), four groups of material were present: poor, marginal, good, and excellent quality rock. Although the better quality rock is predominant, the poorer quality rock is scattered throughout the upper elevation, and one may expect to remove up to 50 feet of material in some areas before competent rock is reached.

The wide area represented by the drill holes and the complex nature of the material preclude assessment of the area on a hole-to-hole basis. In general, however, the Bergstrom area appears to be one of complex geologic nature, but one yielding physical test results that indicate that the area merits further study as a competent hard rock medium.

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 May to 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. Mr. A. D. Buck was responsible for the petrography work. Mr. Saucier performed the majority of the program analysis and prepared this report, with the assistance of Mr. Buck.

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	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
square miles	2.58999	square kilometers

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 required on the specific materials for an analysis of the quality and uniformity of the rock. Results of tests on cores from the Bergstrom area of Mason, Llano, Gillespie, and Burnet Counties in Texas are reported herein.

1.2 OBJECTIVE

The objective of this investigation was to conduct laboratory tests on samples from areas containing hard, near-surface rock 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 on samples received from the field as indicated on the following page. Table 1.1 gives pertinent information on the various tests.

Tests conducted to determine the general quality, uniformity, and integrity of the rock in the area sampled were: (1) relative hardness (Schmidt number), (2) specific gravity, (3) porosity, (4) unconfined compression, (5) dynamic elastic properties, and (6) petrographic examination.

Special tests conducted respectively (1) to determine the degree of anisotropy of the sampled rock and (2) to facilitate comparison of results of direct and indirect tensile tests were: (1) dynamic elastic properties along three mutually perpendicular axes and (2) tensile strength.

1.4 SAMPLES

Samples were received from nine holes in the Bergstrom area designated as BG-CR-6, -8, -10, -19, -25, -28, -32, -34, and -39. All samples were NX size cores (2-1/8-inch[1] diameter). Test specimens of the required dimensions, as given in Table 1.1, were prepared for the individual tests. Quality and uniformity tests were conducted on selected specimens from all holes. Special tests were conducted on specimens selected from the various core holes to represent differences in rock type, weathering, etc.

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[1] A table of factors for converting British units of measurement to metric units is presented on page 7.

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.

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	↓	440,000-pound test machine	X-Y recorder	Compressive strength	Young's, shear, and bulk moduli and Poisson's ratio
Elastic properties	↓	Pulse generator, amplifiers	Oscilloscope	Compressional and shear velocities	Young's, shear, and bulk moduli and Poisson's ratio
Petrographic examination	Variable	Microscopes, X-ray diffraction	--	Appearance, texture, and mineralogy	--

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. The test was conducted as suggested in Reference 1 (a Swiss made hammer was used) except that 8 to 12 readings per specimen were made. The average of these readings is the Schmidt number or relative hardness. The hardness is often taken as an approximation of rock quality, and may be correlated with other physical characteristics such as strength, density, and modulus.

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 (Reference 2). A pycnometer is utilized 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.

2.3 INDIRECT TENSION

The tensile strength was determined by the indirect method, commonly referred to as 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 (Reference 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 of the specimen by more than 0.25 degree. Cylindrical metal caps were cemented to the ends of the specimen and provided the means for applying the direct tensile 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 ASTM and Corps of Engineers standard method of test for triaxial strength of undrained rock core specimens, CRD-C 147 (Reference 2). Essentially, the specimens were cut with a diamond blade saw, and the cut surfaces were ground to a tolerance of 0.001 inch across any diameter with a surface grinder prior to testing. 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. Stress was applied with a 440,000-pound-capacity universal testing machine.

2.6 DYNAMIC PROPERTIES

Compressional and shear wave velocities, bulk, shear, and Young's moduli, and Poisson's ratio were determined by the ASTM proposed "Standard Method of Test for Laboratory Determination of Ultrasonic Pulse Velocities and Elastic Constants of Rock." The method consisted essentially 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 the 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 elastic properties.

In the case of the special tests used to determine the degree of anisotropy of the samples, compression and shear velocities were measured along two mutually perpendicular, diametrical (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 compressive and shear waves perpendicular to these ground surfaces.

2.7 PETROGRAPHIC EXAMINATION

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

CHAPTER 3

QUALITY AND UNIFORMITY TEST RESULTS

3.1 TESTS UTILIZED

Based on past experience with tests on samples received from other areas (Warren, Mountain Home, Fairchild, Castle) the following tests were selected for use in determining the quality and uniformity of the Bergstrom area rock: compressional wave velocity, unconfined compressive strength, Schmidt number, and specific gravity.

Core samples from the nine holes in the Bergstrom area were petrographically identified as predominately medium- to coarse-grained porphyritic granite. Substantial portions of the core from two holes were identified as fine-grained amphibolites and from one hole as gneissic gabbro. Scattered specimens from many of the holes contained: (1) contact zones between the granites and the other type materials and (2) macrofractures; some open, some closed.

Due to the many variables which influenced the testing, it was considered expedient to group the test results according to compressive strength as given below:

Group	Rock Quality	Compressive Strength
		psi
1	Poor	<8,000
2	Marginal	8,000 to 12,000
3	Good	12,000 to 18,000
4	Excellent	>18,000

3.2 POOR QUALITY ROCK

The incompetency of the poor quality rock (compressive strength less than 8,000 psi) was due to several factors, i.e., weathering, fracturing, banding, etc., as given below:

Hole No.	Specimen No.	Description (Field Log)	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
					psi	fps
BG-CR-6	11	Black schist	2.897	38.0	4,280	11,600
BG-CR-8	1	Weathered granite	2.618	26.9	2,640	4,860
BG-CR-8	2	Fractured granite	2.649	46.8	3,400	16,095
BG-CR-10	1	Fractured granite	2.683	41.0	6,670	15,070
BG-CR-10	2	Fractured granite	2.676	36.0	6,450	11,775
BG-CR-32	18	Banded gneiss	2.879	43.6	7,300	17,910
BG-CR-39	6	Fractured granite	2.630	37.0	4,800	15,090
Average			2.719	38.5	5,080	13,200

Due to the presence of different types of rock, the specific gravity results for this area would not necessarily be a good indicator of rock quality. For example, the gneiss and schist are considerably more dense than the granite in the above tabulation, but the other physical tests indicate them to be no more competent than the fractured and weathered granite.

Poor quality rock comprised only 8 percent of the material tested for this area. It should be noted also that the amount of poor quality rock is probably exaggerated with respect to the number of samples received for testing since preference was given in selecting test samples to specimens which contained defects or disparities.

3.3 MARGINAL MATERIAL

A second small group of test specimens yielded compressive results which may be termed marginal (compressive strength 8,000 to 12,000 psi).

Hole No.	Specimen No.	Description (Field Log)	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
					psi	fps
BG-CR-10	6	Massive granite	2.670	46.0	10,640	18,550
	14	Massive granite	2.685	53.0	11,720	19,610
	17	Aplite dike	2.595	50.0	10,500	13,925
BG-CR-19	2	Uniform gneiss	2.827	42.0	9,970	20,700
BG-CR-28	3	Medium-grained biotite granite	2.627	47.3	9,630	18,845
BG-CR-32	19	Banded gneiss	2.785	51.6	10,000	18,060
BG-CR-34	11	Banded gneiss	2.698	48.3	10,970	18,980
	14	Banded gneiss	2.683	52.1	10,410	16,550
Average			2.696	48.8	10,480	18,150

Although the strength results indicate the rock quality to be marginal, the Schmidt number and the compressional wave velocity indicate a competent material. However, it should be noted that the nature of fractures detrimentally affecting the strength, primarily banding, would not necessarily affect the relative hardness or velocity if the bands were very tight, as apparently they were.

3.4 GOOD QUALITY ROCK

Most of the rock described as gneiss or gneissic-granite combinations by the field description would be classified as good quality rock (compressive strength 12,000 to 18,000 psi). Results are given below.

Hole No.	Specimen No.	Description (Field Log)	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
					psi	fps
BG-CR-6	7	Banded gneiss	2.821	--	12,290	18,020
BG-CR-8	7	Coarse-grained granite	2.678	58.9	17,390	16,595
	15	Aplite	2.627	43.7	15,180	19,080
	16	Fractured granite	2.652	--	13,530	17,425
	17	Aplite	2.621	44.1	17,210	16,460
	19	Coarse-grained granite	2.664	54.2	17,960	19,055
	20	Fractured granite	2.637	--	12,000	16,765
BG-CR-10	5	Aplite	2.626	55.0	15,820	18,660
	9	Massive granite	2.687	47.0	13,640	17,010
	21	Aplite	2.613	53.0	16,520	21,640
BG-CR-19	5	Gneiss with vein	2.812	--	12,640	20,015
	6	Uniform gneiss	2.805	44.0	13,450	19,955
	9	Uniform gneiss	2.809	45.0	13,210	18,240
	14	Uniform gneiss	2.826	47.0	12,020	19,205
	16	Gneiss with vein	2.763	--	15,790	20,050
	17	Uniform gneiss	2.862	45.0	17,790	20,065
	22	Gneiss with vein	2.791	--	13,850	19,975

(Continued)

Hole No.	Specimen No.	Description (Field Log)	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
					psi	fps
BG-CR-25	15	Coarse- to medium-grained biotite granite porphyry	2.638	--	17,530	19,720
	19	Coarse- to medium-grained biotite granite porphyry	2.649	--	17,210	20,830
BG-CR-28	1	Medium-grained biotite granite	2.610	44.6	13,740	17,740
BG-CR-32	3	Granite-gneiss contact	2.897	--	17,400	17,080
BG-CR-34	1	Gray gneiss	2.637	50.2	14,660	18,440
	3	Gray to pink gneiss	2.643	46.8	14,370	17,420
	4	Pink gneiss	2.630	--	12,430	16,600
	9	Gray gneiss	2.663	43.1	13,400	15,790
	13	Gray to pink gneiss	2.652	--	13,600	16,070
	17	Dark gray gneiss	2.798	37.4	13,140	17,975
	19	Pink gneiss	2.539	--	14,430	18,045
	21	Pink gneiss	2.590	54.3	14,430	18,660
	23	Gray gneiss	2.645	43.6	13,140	18,360
BG-CR-39	10	Hornblende biotite granite porphyry	2.651	--	14,200	19,060
	15	Hornblende biotite granite porphyry	2.640	--	12,110	13,080
	17	Hornblende biotite granite porphyry	2.645	38.0	13,970	17,320
	21	Hornblende biotite granite porphyry	2.646	--	16,600	19,850
Average			2.690	47.1	14,610	18,245

The compressional wave velocities are indicative of very tight fractures and contacts between the bands. Observation of the failure modes of the compressive test specimens indicated only slight influence of the banding on the ultimate strength of the material. Otherwise, the material in the marginal and good quality groups appears to be of comparable quality.

3.5 EXCELLENT QUALITY ROCK

The group of rock described herein as excellent quality rock (compressive strength greater than 18,000 psi) was predominately from four holes, BG-CR-32, -6, -25, and -28, which appeared to be quite uniform throughout. Results are given below.

Hole No.	Specimen No.	Description (Field Log)	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
					psi	fps
BG-CR-6	2	Banded gneiss	2.681	49.0	36,140	19,200
	4	Banded gneiss	2.673	56.0	32,710	20,890
	9	Banded gneiss	2.756	57.0	22,900	19,390
	14	Banded gneiss	2.663	60.0	27,800	17,460
	16	Banded gneiss	2.721	62.0	27,600	17,720
	18	Banded gneiss	2.997	--	21,800	20,260
	20	Banded gneiss	2.674	59.0	34,980	15,140
	22	Banded gneiss	2.697	--	23,070	16,300
BG-CR-8	4	Coarse-grained granite	2.661	59.6	21,420	17,850
	10	Coarse-grained granite	2.660	61.7	20,440	17,660
	11	Aplite	2.644	52.2	18,480	15,170
	13	Coarse-grained granite	2.656	56.0	19,880	17,120
BG-CR-19	23	Gneiss with vein	2.756	--	21,150	21,120
BG-CR-25	1	Weathered granite	2.642	--	23,800	18,335
	2	Unfractured granite	2.653	56.0	23,970	19,255
	6	Unfractured granite	2.653	51.0	23,310	19,640
	10	Unfractured granite	2.655	57.0	25,460	20,185
	12	Unfractured granite	2.643	55.0	20,220	19,755
	13	Unfractured granite	2.646	60.0	26,340	20,650
	16	Unfractured granite	2.657	53.0	24,130	20,190
	19	Fractured granite	2.654	--	18,830	19,175
BG-CR-28	2	Weathered granite	2.615	49.8	18,910	17,535
	7	Medium-grained biotite granite	2.623	51.3	28,260	18,835
	8	Medium-grained biotite granite	2.636	52.2	33,430	18,825
	11	Medium-grained biotite granite	2.636	53.8	33,570	18,565
	15	Medium-grained biotite granite	2.623	54.7	31,280	17,980
	19	Medium-grained biotite granite	2.613	52.2	29,860	18,360
	21	Medium-grained biotite granite	2.603	48.1	19,370	15,840
BG-CR-32	4	Banded gneiss	2.940	--	19,750	16,880
	5	Pink granite	2.654	60.6	34,030	18,230
	6	Granite-gneiss contact	2.792	--	23,420	15,880
	8	Pink granite	2.648	--	32,200	16,840
	11	Pink granite	2.655	60.1	31,140	18,460
	13	Pink granite	2.683	--	18,600	17,860
	20	Pink granite	2.644	61.0	26,000	18,160
BG-CR-39	2	Hornblende biotite granite porphyry	2.648	46.0	18,400	18,250
	24	Hornblende biotite granite porphyry	2.644	60.0	24,690	18,010
Average			2.678	55.5	25,330	18,295

The compressional wave velocity and specific gravity results indicate little difference in the rock grouped previously as lower quality material. However, the Schmidt number and compressive strength results indicate a substantially better material. Significantly, the four most competent cores contained essentially one type material, granite, in three cores and gneiss, apparently tightly banded, in the fourth.

CHAPTER 4

SPECIAL TESTS

4.1 PETROGRAPHIC EXAMINATION

4.1.1 Samples. Nine boxes of NX size rock core from nine holes located in Mason, Llano, Gillespie, and Burnet Counties, Texas, were received for testing. Each box contained about 15 feet of core which represented scattered depths to 200 feet.

The contents of each box were inspected for homogeneity and to select representative material for petrographic examination. The inspection indicated the following:

1. Hole BG-CR-6. The core is composed of two kinds of rock. One type is fine-grained, light-colored gneiss with the foliation dipping about 45 degrees. The other type of rock is black and schistose like the black rock in Core 32.

Pieces 1 through 6, 8, 9, 10, 12, 13, 14, 16, 17, 19, 20, and 21 are light-colored gneissic rock. Pieces 7 and 15 contain both types of rock; Pieces 11 and 18 are all black rock.

At least two sets of opposing joint systems are present which include both open and closed fractures. One set parallels the foliation of the light-colored rock.

2. Hole BG-CR-8. The entire core was medium-grained, reddish granitic igneous rock. There are open-coated joints dipping at

about 45 to 60 degrees along the entire length of core. Piece 1 was visibly more weathered or altered than the other pieces.

Pieces 8, 9, 11, 14, 15, 17, and 20 contained volumes of pale red pegmatite. Such areas tend to consist of massive single crystals of microcline feldspar.

3. Hole BG-CR-10. The entire core is coarse-grained pink granitic igneous rock. There are no visible joint systems. Pieces 5, 10, 17, 18, 19, and 21 contain volumes of pegmatite.

4. Hole BG-CR-19. Most of this core is dark-colored, medium-grained igneous or metamorphic rock. Piece 16 includes some pink pegmatite; Piece 17 is black schistose rock like that in Cores 32 and 6. Piece 24 is like the light-colored gneiss rock in Core 6. A few low-angle open fractures are present.

5. Hole BG-CR-25. The entire core is medium- to coarse-grained pale red granitic igneous rock. A few pieces of core show open, coated fracture surfaces; they dip less steeply than the fractures in Core 8. These surfaces are coated with white clay. The clay is also found in some small scattered cavities in the rock. No pegmatite was seen.

6. Hole BG-CR-28. The entire core is pale red medium-grained igneous rock. Pieces 1 through 4 show open, coated fractures which dip at about 45 degrees; Pieces 20 and 21 contain healed high-angle fractures.

7. Hole BG-CR-32. The core is composed of two kinds of rock. Some of the core is pale red, in part, with detectable parallel orientation of dark minerals and bands of varying composition and grain size. The banding shows varying dips and may represent flow folding. Some of the core is pale red medium-grained granitic rock which does not show foliation in the core; the remainder is fine-grained black schistose rock showing horizontal foliation.

Pieces 1, 2, 8 through 17, and 20 are the pale red rock; Pieces 1 and 2 contain both open and closed steeply dipping fracture surfaces. Most of the remaining pieces are combinations of the pale red and the black rock; the black rock is present in zones up to 6 inches in thickness, but they are usually thinner. Pieces 3 and 18 are principally black rock.

8. Hole BG-CR-34. The core was taken from an area that represents the contact zone between the pale red igneous rocks and the surrounding country rock. While all of the core is generally similar, each piece exhibits contorted volumes of pale red igneous rock, a black schistose rock, and possibly a later dark intrusive. There are fragments of red igneous rock and black rock in a dark matrix in much of the core. Veins of calcite traverse a few pieces of core.
Piece 17 is black schistose rock like that found in Cores 6, 19, and 32.

9. Hole BG-CR-39. The entire core is red medium-grained granitic igneous rock. Open and closed coated fractures, dipping about 45 degrees, are present along entire core. Approximately 2 inches of Piece 18 is pegmatite.

The 11 pieces of core selected for petrographic examination are identified below:

CD Serial No.	Core Hole No.	Piece No.	Approximate Depth	Description
			feet	
SAMSO-6 DC-2	BG-CR-6	4	46	Typical light-colored gneiss rock
SAMSO-6 DC-2	BG-CR-6	18	156	Typical black schistose rock
SAMSO-6 DC-7	BG-CR-8	8	102	Typical pale red igneous rock on one end and pegmatite on other end. Pegmatite was not examined.
SAMSO-6 DC-3	BG-CR-10	8	73	Typical pink igneous rock; this piece shows antirapakivi texture
SAMSO-6 DC-5	BG-CR-19	14	49.5	Typical dark medium-grained rock
SAMSO-6 DC-6	BG-CR-25	15	148.5	Typical pale red igneous rock
SAMSO-6 DC-8	BG-CR-28	5	43	Typical pale red igneous rock

(Continued)

CD Serial No.	Core Hole No.	Piece No.	Approximate Depth	Description
			feet	
SAMSO-6 DC-1	BG-CR-32	7	74	Shows pale red gneissic granite rock and black schistose rock and a contact between them
SAMSO-6 DC-9	BG-CR-34	2	38.5	Typical piece showing contorted contact between red igneous rock and black schistose rock
SAMSO-6 DC-9	BG-CR-34	7	67	Typical piece showing xenoliths or fragments, calcite vein, black schistose rock, and matrix of fault breccia (?)
SAMSO-6 DC-4	BG-CR-39	14	123.5	Typical pale red igneous rock

The recent geologic literature on the Llano uplift was reviewed because the geology revealed by the cores appeared to be complex and to involve some peculiar contact relations.

This review, with the names used on the field logs, permitted deducing what rock units should be present in the cores. The rock units are discussed under Results.

4.1.2 Test Procedure. Each of the 11 pieces of core was sawed axially; one sawed surface of each piece was polished and photographed at normal size. In addition, typical areas of Pieces 15 of

Core 25, 5 of Core 8, and 14 of Core 19 were photographed at × 20 to illustrate whether microcracks (cracks not detected visually) were present in representative rocks from this area.

Composite samples were obtained from the whole length or from selected portions from the other halves of the pieces. The samples were ground until all of each sample passed a No. 325 sieve (44μ). X-ray diffraction (XRD) patterns were made of each sample as a back-loaded powder to minimize orientation effects. The patterns were examined and compared to make mineralogical identifications and comparisons. The following list shows the samples X-rayed:

Core Hole No.	Piece No.	Description
BG-CR-6	4	Entire length was sampled
BG-CR-6	18	Entire length was sampled
BG-CR-8	8	Typical light red igneous rock was sampled; the pegmatite was not
BG-CR-10	8	Entire length was sampled
BG-CR-19	14	Entire length was sampled
BG-CR-25	15	Entire length was sampled
BG-CR-28	5	Entire length was sampled
BG-CR-32	7	The pale red gneiss rock and the black schistose rock were sampled separately

(Continued)

Core Hole No.	Piece No.	Description
BG-CR-34	7	The black schistose rock and the dark-colored flow were sampled separately; xenoliths were avoided
BG-CR-39	14	Entire length was sampled

When samples contained detectable 14-A material by XRD, some of the sized powder of the sample was slurried with water on a glass slide and X-rayed in the air-dry condition, after saturation with glycerol, and after heat treatment as needed for identification of the 14-A material.

Thin sections were prepared from all of the pieces except Piece 18 of Core 6. Some of the black schistose rock like Piece 18 was included in the section made from Piece 7 of Core 32. The sections were examined with a polarizing microscope.

Polished surfaces and broken surfaces of each piece were examined with a stereomicroscope.

Small portions of the sized powders were tested in dilute hydrochloric (HCl) acid and by a magnetized needle to determine, respectively, whether carbonate minerals were present and whether magnetic minerals were present.

Immersion mounts of powders were prepared from Pieces 8, 8, 15, and 5 of Cores 8, 10, 25, and 28, respectively, and examined with a polarizing microscope to determine the approximate composition of the plagioclase feldspar in each.

All X-ray patterns were made with an XRD-5 diffractometer using nickel-filtered copper radiation.

4.1.3 Results. Inspection of the cores, of the rock compositions, and of the rock textures indicates that the rock should be considered in five groups. Study of recent literature (References 3, 4, and 5) and of the core logs suggests which geologic units in the Llano Uplift are probably represented. These are discussed below. It should be recognized that the assignment of rocks from these cores, other than the granites, to geologic units described in the literature is tentative. The literature reviewed suggests that amphibolite is less likely to come from the Valley Spring gneiss than from the Packsaddle formation. It is also clear that contacts between the granites and the Valley Spring gneiss and between the granites and the Packsaddle are altered and contorted. The fairly brief study of a relatively few pieces of selected core sections does not permit definite formation assignments of the amphibolites and the rock described in this report as Valley Spring gneiss. Some of the rock in Core 34 could not be assigned to any of the described units; some is tentatively interpreted as showing small-scale localized fault breccias.

The five rock groups identified are:

1. Reddish granitic rocks. Cores 8, 10, 25, 28, and 39 were identified on field logs as reddish granitic rocks (Figures 4.1 through 4.5), and apparently represent material mapped as granites. Cores 8 and 10 are from the Lone Grove pluton; Core 39 is from the Enchanted Rock batholith; Cores 25 and 28 are from an igneous body northwest of the other two. The pale red gneissic part of Core 32 is included in this group of cores even though it is foliated in part (Figure 4.4) and somewhat finer grained that the others. Core 32 was taken north of the Enchanted Rock batholith and may be mapped as part of the Valley Spring gneiss. The variables within this group of six cores that may be expected to influence test results are texture, jointing, and degree of alteration.

2. Light gneiss. Most of Core 6 is fine-grained, light gneiss (Figure 4.6, Piece 4), which is possibly part of the Valley Spring gneiss. Except for Piece 24, Core 19, this rock is unlike that in any of the other eight cores in appearance.

3. Dark gneiss. All of Core 19, except for Piece 24, is medium-grained dark rock (Figures 4.6 and 4.7, Piece 14), which is probably mapped as Big Branch quartz diorite gneiss. Except for Piece 24, the rock in this core is unlike that in the other eight cores. This rock unit is described in the literature examined as

perceptibly foliated, but foliation is only dubiously recognizable in the NX core.

4. Schist. Parts of Cores 32 and 6 (Figures 4.4 and 4.6) are fine-grained black schistose rock. One piece of this material was also recognized in Core 19 and one in Core 34. It is probably part of the Packsaddle schist. This rock differs in appearance from the rocks in the other cores.

5. Rock from contact zones. All of the rock from Core 34 appears to represent contact material between granite and country rock, or country rock and either a graywacke-like sediment derived from it or a brecciated zone. Figure 4.8 shows Piece 2 and Piece 7 from Core 34. Piece 2 probably represents the partial assimilation of country rock by granite, but thin sections reveal zones containing what appears to be fault breccia in a gouge matrix on a microscopic scale. Piece 7 to the right of the arrow represents a less assimilated dark schist. To the left of the arrow is a fault breccia on a larger scale than was found in Piece 2. These interpretations are tentative, and the phenomena could be more clearly interpreted if a larger continous core or an outcrop could be examined and sampled.

Figures 4.3, 4.5, and 4.7 show typical areas on polished surfaces from Pieces 5, 15, and 14 of Cores 28, 25, and 19, respectively, at a magnification of $\times$ 20. Pieces 5 and 15 represent the group of red granitic rocks while Piece 14 is from the core of dark-colored

Big Branch gneiss. The location of existing microcracks is indicated by arrows. It can be seen that the dark gneiss is practically free of microcracks, while they are abundant in the red granitic rocks. Piece 15 contains fewer but longer cracks than Piece 5; those in Piece 5 are shorter and tend to be grouped in clusters.

The compositions of the five red granites, the reddish gneissic granite, and the light gneiss as indicated by the X-ray results are shown in Table 4.1. The relative proportions of minerals in each of six rocks are compared to those in the nonpegmatitic portion of Piece 8, Core 8.

The five red granites are generally similar in composition (Table 4.1); they vary mainly in texture and in degree of alteration. There should be a direct relation between amount of clay minerals and degree of alteration; increased alteration should be reflected in lower compressive strength, elastic modulus, and pulse velocity. The reddish gneissic granite of Core 32 is similar in composition to the five red granites; the only evident difference justifying the classification as gneiss is the foliation. On the other hand, the light gneiss of Core 6 is much finer grained than any of the other rocks listed in Table 4.1; it contains much less microcline and less clay than the granites. These differences suggest that it may be assigned to the Valley Spring gneiss.

The rocks, other than contact zone rock, are described below as they appear in thin section:

1. Red granitic rocks (Cores 8, 10, 25, 28, 39, and part of 32) contain red microcline phenocrysts up to 1 inch in maximum dimension, usually subhedral, in a medium- to coarse-grained, fairly equigranular matrix of quartz, plagioclase, and biotite. Except for the biotite, the grains in the matrix do not show crystal outlines. All these rocks are porphyritic in texture. The feldspars show perthitic or antiperthitic intergrowths, and most show alteration. The plagioclase is more altered than the microcline in all except Core 28, in which the microcline is more altered. The composition of the plagioclase was determined in Cores 8, 10, 25, and 28 and was found to be albite.

Piece 8 of Core 8 is medium-grained albite granite by the system described in Reference 6 because of the amount and composition of the plagioclase (albite). Several parts of the core are pegmatite composed of red microcline crystals about 1 inch in maximum dimension. A few scattered grains of chlorite, calcite, and opaque minerals are present in the rock.

Piece 8 of Core 10 is coarse-grained pinkish albite granite (Reference 6). Some of the core shows development of mantles of reddish microcline around cores of plagioclase and other minerals (antirapakivi texture, Figure 4.1). It differs from Core 8 in texture, containing some hornblende and lacking montmorillonitic clay.

Piece 15 of Core 25 is medium- to coarse-grained reddish granite (Reference 6) which is lower in biotite and higher in kaolinite than others of this group. There are coatings of white clay in cracks and cavities in the rock; this suggests more alteration, and this is supported by the increased clay content. Some of the limited amount of mica that is present is muscovite. There is a little calcite.

Piece 5 of Core 28 is medium-grained reddish albite granite (Reference 6). This rock differs from others in this group by being low in biotite mica and relatively high in muscovite mica. The total mica is only slightly lower than in the other granites. Another difference is that the microcline is more altered than the plagioclase, reversing the situation in the others.

Piece 14 of Core 39 is medium-grained granite (Reference 6) which is generally similar to the others in this group.

The reddish gneissic granite from Core 32 is like the five just described in color and composition, but it is foliated and banded.

2. The light gneiss (Core 6) is fine-grained rock containing anhedral grains of quartz, plagioclase, microcline, and biotite. Table 4.1 shows that it differs from the reddish granites in proportions of minerals. The rock shows enough foliation to indicate it is gneiss; thin sections show it may have had an igneous origin. If so,

its low microcline content would suggest it was probably a tonalite (quartz diorite). There are some healed fractures normal to the foliation which dips about 45 degrees. This is fresher rock than the reddish granites because the feldspars show less alteration and there are less clays. This rock is probably part of the older metamorphic rocks (the Valley Spring?) rather than the later igneous intrusives.

3. The dark gneiss (Core 19) shows inconspicuous preferred orientation of feldspar and quartz rather than foliation in this sample, but it seems clear that it is part of that rock unit. It is composed largely of subhedral biotite and anhedral plagioclase with moderate amounts of subhedral hornblende and smaller amounts of anhedral quartz, muscovite, magnetite, and microcline grains. There is no detectable clay. It is low in quartz and microcline and high in biotite and hornblende by comparison with the rocks in Table 4.1. The plagioclase shows some alteration. The rock in this core is too dark to be diorite and too deficient in quartz to be called quartz diorite; it is more like gabbro in composition. While it does not agree with the reported composition of the Big Branch rock, it does look like the description. This difference in composition may represent the kind of variation to be expected in a large rock unit.

4. The fine-grained, equigranular black schistose rock (Cores 32 and 6) is principally hornblende and plagioclase. XRD indicates that

in Core 32 it also contains small amounts of quartz and montmorillonitic clay, but no biotite.

In Core 6, there is some biotite but no definitely detectable quartz or clay. In general, these rocks are high in hornblende and low in quartz, microcline, and biotite by comparison with the rocks in Table 4.1. As mentioned earlier, there is also one piece of this type of rock in Cores 19 and 34.

The fine-grained black schistose rock in Cores 19 and 34 is metamorphic amphibolite. In Core 32, the foliation of the amphibolite is flat lying, and it can be determined that the reddish granite gneiss is intrusive into it. In Core 6, the foliation of the black amphibolite dips about 30 degrees. This dip could influence strength test data. Aside from this possible difference, the two amphibolites should yield similar test results.

The black schist and the dark green matrix enclosing fragments of granite and schist (Figure 4.8) were examined separately by XRD. The black rock contains much less hornblende than the black amphibolites; it is more similar in composition to the reddish granites of Table 4.1, containing abundant biotite; it also contains a small amount of chlorite and montmorillonitic clay, and a sulfide mineral. Figure 4.9 is a selected portion of the XRD pattern of this dark schist, and Figure 4.10 is a composite of several patterns of the same rock which illustrate the basis of the clay identifications.

The dark schist is traversed by at least two sets of fractures, one subparallel to the core axis and the other across the core. The dark green matrix is regarded tentatively as a small-scale fault breccia; it encloses angular silt-, sand-, and gravel-sized fragments of minerals and rocks and contains some distorted biotite and chlorite, and more montmorillonitic clay than any of the rest of the cores. Both the black schist and the green fault breccia are expected to be weak, the schist because of extensive fracturing.

4.1.4 Summary. Portions of nine NX cores from the Llano Uplift in Central Texas were subjected to petrographic examination. They were divided into the following five groupings:

1. Red granites. All of five cores (BG-CR-8, -10, -25, -28, -39) and portions of another (BG-CR-32) belonged in this group. They are medium- to coarse-grained porphyritic granites composed largely of quartz, plagioclase and microcline feldspars, and biotite. The reddish portion of Core 32 was foliated enough to be classified as gneissic granite.

2. Light gneiss. A portion of Core 6 is fine-grained gneiss. Aside from one piece of rock like it in Core 19, this rock is different from that in the other eight cores in appearance.

3. Dark gneiss. Almost all of Core 19 was medium-grained dark rock, which is classified as gneissic gabbro; it is believed to be part of the Big Branch gneiss. It is completely unlike the rock in

any of the other cores in appearance.

4. Schist. One piece of Cores 19 and 34 and substantial portions of Cores 32 and 6 were fine-grained, black, hornblende amphibolites unlike the rock in the other cores in appearance.

5. Contact zones. All of the rock in Core 34 came from a contact zone between the reddish granites and a black biotite schist or biotite gneiss (not like the amphibolites). Some pieces contained microscopic and small-scale fault breccias. These sections were extensively fractured and were unique among these nine.

4.2 ELASTIC MODULI

Samples representative of the different materials in each hole were selected for deformation moduli tests for the data reports. After dynamic tests were completed, a portion of each sample was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given in Table 4.2.

The poor and marginal quality rock yielded very erratic moduli determinations. This is not unexpected in an anisotropic rock since the strain gages would not necessarily average the strains over a fractured or composite material. The moduli of the more competent core were indicative of relatively brittle, rigid rock. Significantly, comparatively high moduli were obtained on the several types of rock tested (gneiss, aplite, granite) and variations thereof.

Examination of the stress-strain curves in the data reports reveals that they are predominately linear-elastic to approximately 90 percent of the ultimate strength. Little hysteresis or residual strain is evident. Some erratic behavior occurred on several specimens in which the strain gages had apparently been placed over fractures or contact zones. The fact that slippage occurred prior to ultimate failure is evidence that many of the fractures and contacts were very tight.

4.3 TENSILE STRENGTH RESULTS

Nine NX-diameter rock specimens were selected to represent the variation of rock type and weathering present in the core. 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 are given in Table 4.3. The three specimens which yielded the highest direct tensile strength failed on the first attempt in bond. Obviously, the direct tensile strength is lower than the tensile splitting strength; the effect is especially pronounced in the weathered material. As in the Castle area granite, the vertical direction appears to be affected more by the alteration. Expectedly, the direct tensile strength of the gneiss, determined perpendicular to the foliations, is significantly less than the tensile splitting strength. The competent material, pink granite, like the Castle area granite, yielded direct tensile strength results which were approximately 75 percent of those obtained by the tensile splitting method.

4.4 ANISOTROPY TESTS

Nine rock specimens from the Bergstrom area were selected and prepared for determination of compression (dilatational) and shear velocities according to the ASTM proposed method of test for laboratory determination of ultrasonic pulse velocities and elastic constants of rock. The NX-diameter specimens were cut to lengths of 2 to 4 inches and ground on the ends to a tolerance of 0.001 inch. Four 1/2-inch-wide strips were also ground down the sides of the cylindrical surface at 90-degree angles. The velocities, densities, and dimensions were measured as specified in the proposed test method.

Results of the velocity determination are given in Table 4.4. Generally, the compressive and shear velocities of the pink granite are higher than those of the weathered granite and the gneiss. Also, the deviation from the average for the compressive velocity is consistently lower for the intact pink granite.

A compilation of the elastic properties computed from the compressive and shear velocities and the specific gravity is given in Table 4.5. However, discretion must be used in utilizing the moduli results since experimental errors introduced with the differences in velocities are significant. The proposed ASTM test method states that the equations for computation of elastic moduli should not be used if "any of the three compressional wave velocities varies by more than two percent from their average value. The error in E and G due to both anisotropy and experimental error then does not exceed 6 percent." Naturally, the effect of the error is compounded by greater differences in the three-directional velocity measurements.

TABLE 4.1 COMPARISON OF ROCK COMPOSITIONS IN SEVEN CORES

All XRD charts were compared to that for BG-CR-8, Piece 8, and rated relative to it. nd - not detected; ? - not definitely identified.

Constituent	Red Porphyritic Granites					Foliated Granite,	Fine-Grained Gneiss,
	BG-CR-8 Piece 8[a]	BG-CR-10 Piece 8	BG-CR-25 Piece 15	BG-CR-28 Piece 5	BG-CR-39 Piece 14	BG-CR-32 Piece 7	BG-CR-6 Piece 4
Quartz	Abundant	Abundant	More	More	Abundant	More	More
Plagioclase	Abundant	Abundant	Abundant	More	More	Abundant	More
Microcline	Abundant	Abundant	More	Abundant	More	More	Much less
Biotite	Common	Common	Less	Slightly less	Common	Less	Slightly less
Hornblende	nd	Minor	nd	nd	nd	nd	nd
Montmorillonitic clay	Minor	nd	Minor	nd	Less	Less	nd
Kaolin	Minor	Minor	More	Minor	Minor	?	Much less
Chlorite	nd	nd	nd	nd	nd	Minor	nd
Background intensity at 18 2-θ[b]	1.7	1.5	1.2	0.9	1.1	1.2	1.3

[a] Excluding pegmatite.
[b] A rough measure of relative iron content or relative clay content.

TABLE 4.2 ELASTIC MODULI RESULTS

Hole No.	Specimen No.	Description	Dynamic Modulus			Static Modulus		
			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
Poor and Marginal Quality Rock:								
BG-CR-6	11	Schist	5.2	2.0	2.4	2.0	1.3	0.8
BG-CR-8	2	Fractured granite	7.1	5.6	2.8	6.2	3.7	2.5
BG-CR-10	2	Fractured granite	4.0	2.9	1.6	3.0	--	--
BG-CR-10	17	Aplite	5.4	3.9	2.5	8.8	3.9	3.9
BG-CR-32	18	Banded gneiss	9.8	6.0	3.8	10.6	5.9	4.4
BG-CR-34	11	Gray gneiss	9.9	8.0	3.9	9.7	6.5	3.9
BG-CR-39	6	Fractured granite	6.6	4.6	2.6	3.5	2.3	1.4
		Average	6.8	4.7	2.8	6.3	3.9	2.8
Good and Excellent Quality Rock:								
BG-CR-6	18	Banded gneiss	15.0	8.2	6.3	9.2	10.2	3.4
BG-CR-6	22	Banded gneiss	8.5	5.0	3.5	10.1	5.4	4.2
BG-CR-8	10	Coarse-grained granite	9.0	6.5	3.5	9.2	5.7	4.7
BG-CR-8	17	Aplite	6.8	6.1	2.6	10.0	5.6	4.2
BG-CR-10	9	Massive granite	9.0	5.6	3.6	10.0	5.1	4.3
BG-CR-19	9	Uniform gneiss	11.4	6.2	4.8	9.2	5.7	3.7
BG-CR-19	17	Uniform gneiss	12.3	9.1	4.9	11.7	7.0	4.8
BG-CR-25	6	Unfractured granite	10.9	8.0	4.3	10.0	7.9	3.9
BG-CR-25	13	Unfractured granite	11.5	9.3	4.5	10.7	8.9	4.1
BG-CR-28	2	Weathered granite	8.5	6.4	3.3	7.7	3.8	3.3
BG-CR-28	8	Medium-grained granite	9.4	7.7	3.6	10.2	5.7	4.2
BG-CR-32	3	Granite-gneiss contact	9.6	6.2	3.9	8.8	4.6	3.7
BG-CR-32	20	Pink granite	10.4	7.3	4.3	10.8	6.2	4.5
BG-CR-34	3	Gray to pink gneiss	8.1	6.7	3.1	7.5	4.3	3.1
BG-CR-34	21	Pink gneiss	8.9	7.6	3.4	7.8	6.2	3.0
BG-CR-39	15	Fractured granite	5.3	3.2	2.2	6.5	2.7	3.0
BG-CR-39	24	Fractured granite	10.4	5.7	4.4	11.0	9.2	4.2
		Average	9.7	6.8	3.9	9.4	6.1	3.9

TABLE 4.3 TENSILE STRENGTH DETERMINATIONS

Hole No.	Specimen No.	Depth	Tensile Strength			Rock Type
			Splitting	Direct	Direct/ Splitting	
		feet	psi	psi	pct	
6	5	58	1,635	520	32	Gray gneiss
8	5	75	825	200	24	Weathered granite
10	22	194	1,105	720	65	Pink granite
19	4	39	985	810[a]	82	Gray gneiss
25	17	170	1,260	1,150[a]	91	Pink granite
28	14	119	1,370	1,160[a]	85	Pink granite
32	17	171	1,130	780	69	Pink granite
34	8	77	935	570	61	Gray gneiss
39	5	61	550	250	45	Weathered granite
Average gneiss			1,185	635	54	
Average granite			1,220	950	78	
Average weathered granite			690	225	33	

[a] Result of second test attempt; in first attempt, epoxy bonding agent failed.

TABLE 4.4 VELOCITY DETERMINATIONS

		Velocity[a]	
		Compression	Shear
		fps	fps
Hole BG-CR-6, Specimen 5:			
Gray gneiss		14,210	9,445
Depth: 58 feet		16,310	9,940
Specific gravity: 2.71		14,595	9,565
Compressive deviation:[b] 8.4 pct			
	Average	15,040	9,650
Hole BG-CR-8, Specimen 5:			
Weathered granite		16,790	9,685
Depth: 75 feet		18,790	9,235
Specific gravity: 2.65		17,395	9,615
Compressive deviation: 6.4 pct			
	Average	17,660	9,510
Hole BG-CR-10, Specimen 22:			
Pink granite		18,235	10,300
Depth: 195 feet		19,235	11,730
Specific gravity: 2.64		19,490	13,150
Compressive deviation: 4.0 pct			
	Average	18,985	11,725

[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 compressional wave velocity.

(1 of 3 sheets)

TABLE 4.4 (CONTINUED)

		Velocity	
		Compression	Shear
		fps	fps
Hole BG-CR-19, Specimen 4:			
Gray gneiss		20,285	11,180
Depth: 39 feet		20,350	11,085
Specific gravity: 2.81		21,105	11,065
Compressive deviation: 2.6 pct			
	Average	20,580	11,110
Hole BG-CR-25, Specimen 17:			
Pink granite		20,625	10,305
Depth: 170 feet		21,645	12,145
Specific gravity: 2.71		21,420	12,195
Compressive deviation: 2.8 pct			
	Average	21,230	11,550
Hole BG-CR-28, Specimen 14:			
Pink granite		19,120	10,645
Depth: 119 feet		18,960	10,955
Specific gravity: 2.62		18,840	11,900
Compressive deviation: 0.8 pct			
	Average	18,975	11,165

(2 of 3 sheets)

TABLE 4.4 (CONCLUDED)

		Velocity	
		Compression	Shear
		fps	fps
Hole BG-CR-32, Specimen 17:			
Pink granite		21,085	11,680
Depth: 171 feet		21,465	11,545
Specific gravity: 2.69		21,625	11,475
Compressive deviation: 1.4 pct			
	Average	21,390	11,565
Hole BG-CR-34, Specimen 8:			
Gray gneiss		18,425	10,400
Depth: 77 feet		16,540	10,190
Specific gravity: 2.65		18,190	10,640
Compressive deviation: 6.7 pct			
	Average	17,720	10,410
Hole BG-CR-39, Specimen 5:			
Weathered granite		16,445	8,030
Depth: 61 feet		18,175	9,335
Specific gravity: 2.62		17,630	10,120
Compressive deviation: 5.9 pct			
	Average	17,485	9,160

(3 of 3 sheets)

TABLE 4.5 ELASTIC PROPERTIES

Hole No.	Specimen No.		Moduli			Poisson's Ratio
			Young's	Shear	Bulk	
			10^6 psi	10^6 psi	10^6 psi	
BG-CR-6	5		7.20	3.26	3.03	0.10
			8.70	3.61	4.91	0.20
			7.51	3.34	3.33	0.12
		Average	7.80	3.40	3.76	0.15
BG-CR-8	5		8.38	3.35	5.60	0.25
			8.17	3.05	8.55	0.34
			8.46	3.30	6.40	0.28
		Average	8.34	3.23	6.85	0.29
BG-CR-10	22		9.54	3.77	6.80	0.27
			11.70	4.89	6.62	0.20
			13.30	6.14	8.31	0.18
		Average	11.51	4.93	7.24	0.22
BG-CR-19	4		12.10	4.74	9.27	0.28
			12.00	4.65	9.47	0.29
			12.10	4.64	10.60	0.31
		Average	12.07	4.68	9.78	0.29
BG-CR-25	17		10.30	3.88	10.30	0.33
			13.70	5.39	9.94	0.27
			13.70	5.44	9.53	0.26
		Average	12.43	4.90	9.92	0.29
BG-CR-28	14		10.20	4.00	7.57	0.28
			10.50	4.24	7.04	0.25
			12.10	5.00	7.23	0.22
		Average	10.93	4.41	7.28	0.25
BG-CR-32	17		12.70	4.95	9.54	0.28
			12.50	4.84	10.20	0.29
			12.40	4.78	10.60	0.30
		Average	12.53	4.86	10.11	0.29
BG-CR-34	8		9.78	3.86	6.97	0.27
			8.85	3.71	4.83	0.19
			10.00	4.04	6.42	0.24
		Average	9.54	3.87	6.07	0.23
BG-CR-39	5		6.13	2.28	6.52	0.34
			8.14	3.08	7.57	0.32
			9.08	3.62	6.16	0.25
		Average	7.78	2.99	6.75	0.30

Figure 4.1 Core BG-CR-8, Piece 8, and Core BG-CR-10, Piece 8. Magnification, × 1. Portion on left side of Piece 8, Core 8, is typical reddish granitic rock; that on right side is reddish pegmatite. Piece 8, Core 10, is typical pinkish granitic rock. The large phenocryst below the label shows a mantle of pink microcline around a core of plagioclase feldspar, biotite, and quartz (antirapakivi texture).

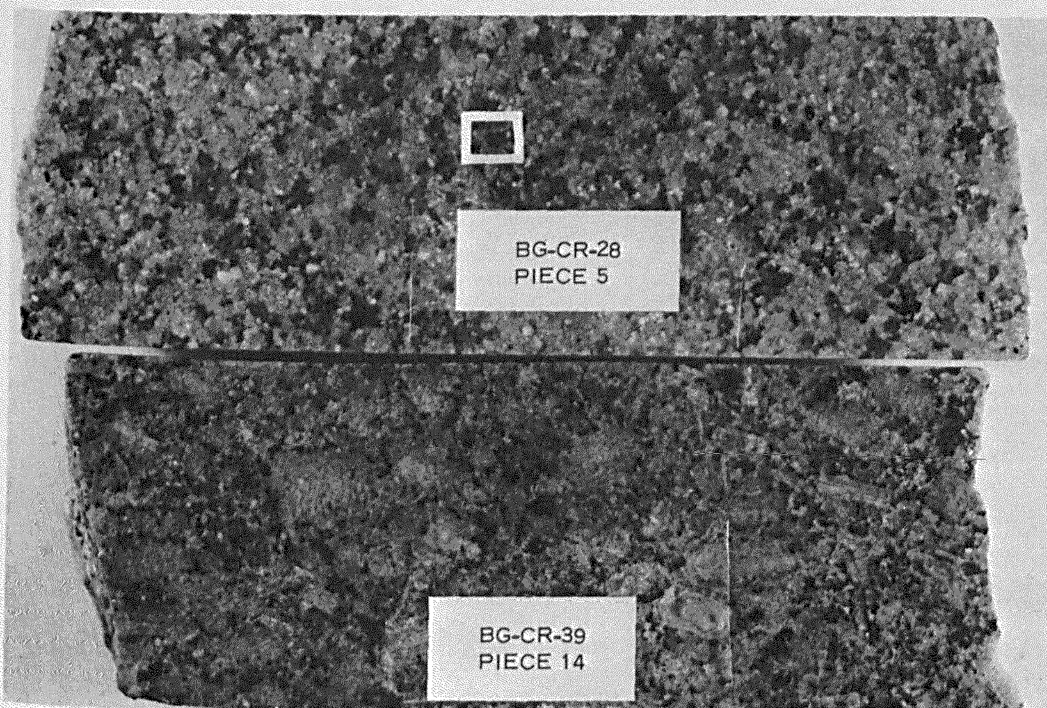


Figure 4.2 Core BG-CR-28, Piece 5, and Core BG-CR-39, Piece 14. Magnification, × 1. Both pieces show typical reddish granite rock from Cores 28 and 39. The area indicated on Piece 5 is shown at × 20 in the next photograph.

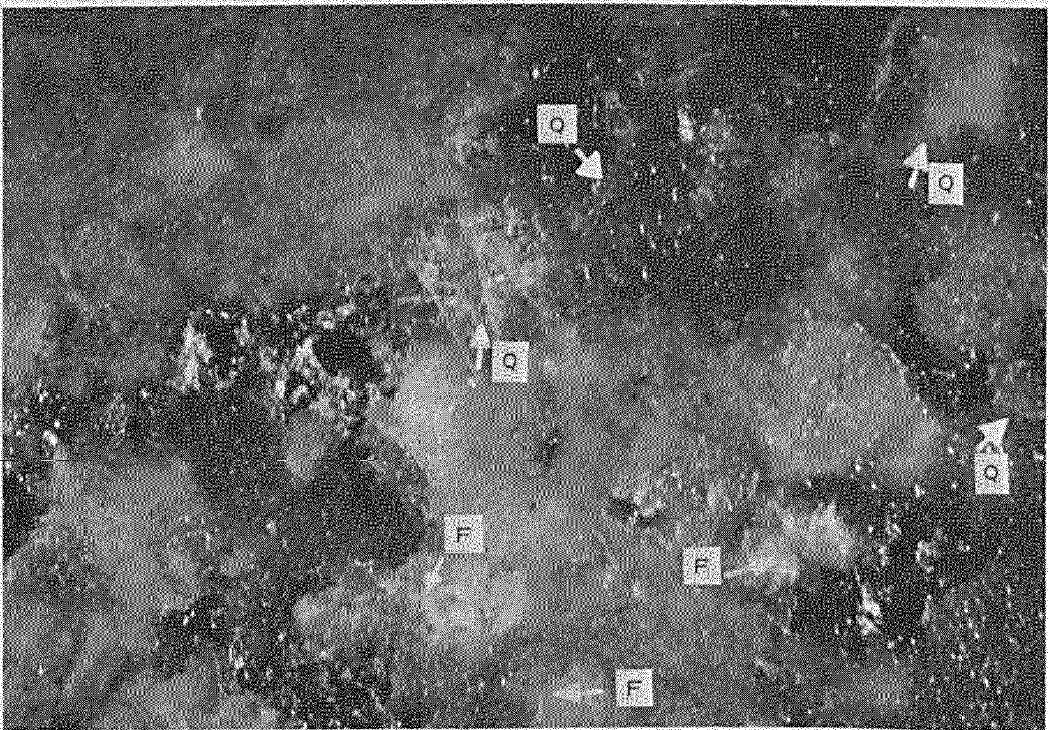


Figure 4.3 Typical portion of Core 28, Piece 5, at × 20 magnification. Several areas of cracks in quartz (Q) and feldspars (F) are indicated by arrows.

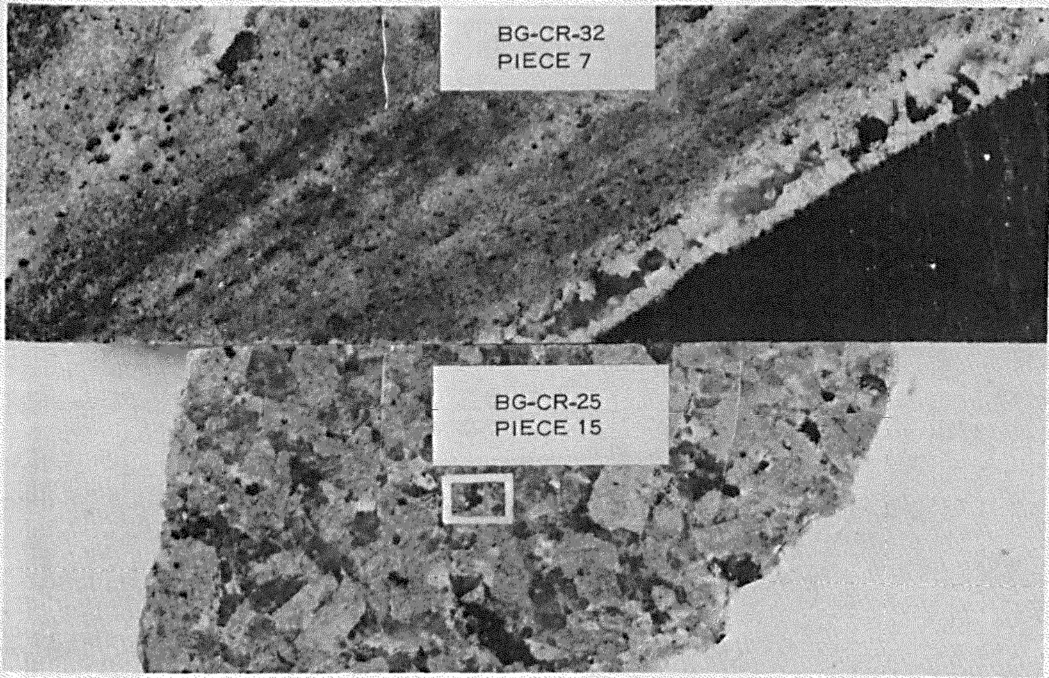


Figure 4.4 Core BG-CR-32, Piece 7, and Core BG-CR-25, Piece 15. Magnification, × 1. Piece 7, Core 32, shows typical reddish gneissic rock and typical black schistose rock. Piece 15, Core 25, shows typical reddish granitic rock. The area indicated on Piece 15 is shown at × 20 in the next photograph.

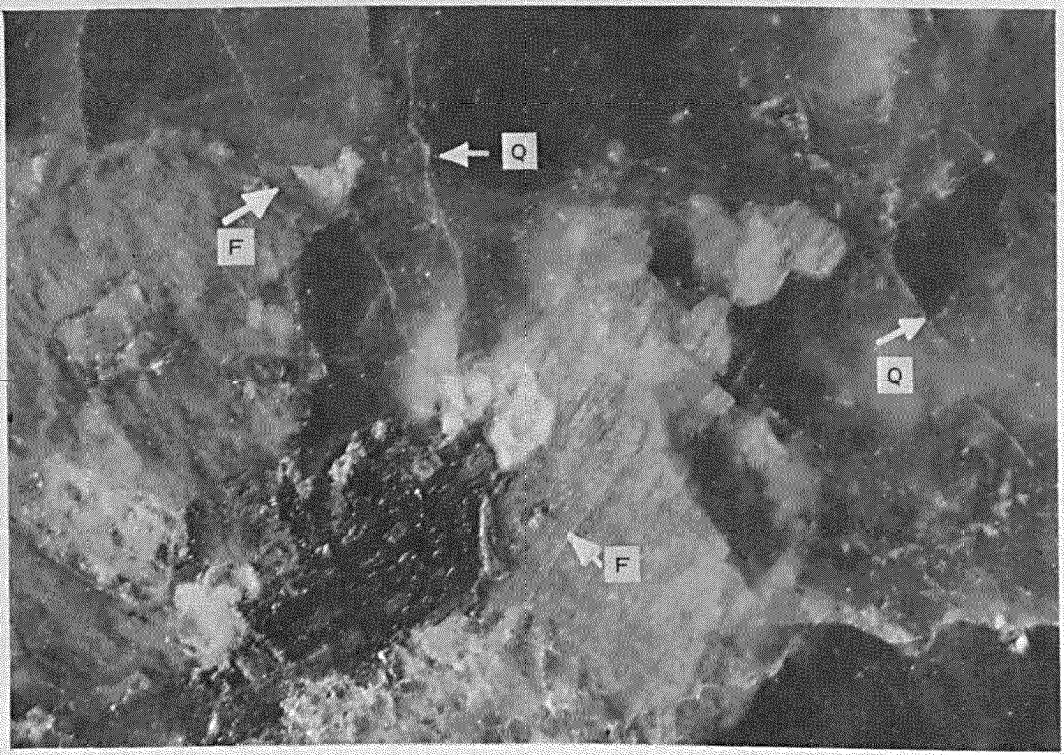


Figure 4.5 Typical portion of Core 25, Piece 15, at × 20 magnification. Several cracks are visible in quartz (Q) and in microcline feldspar (F).

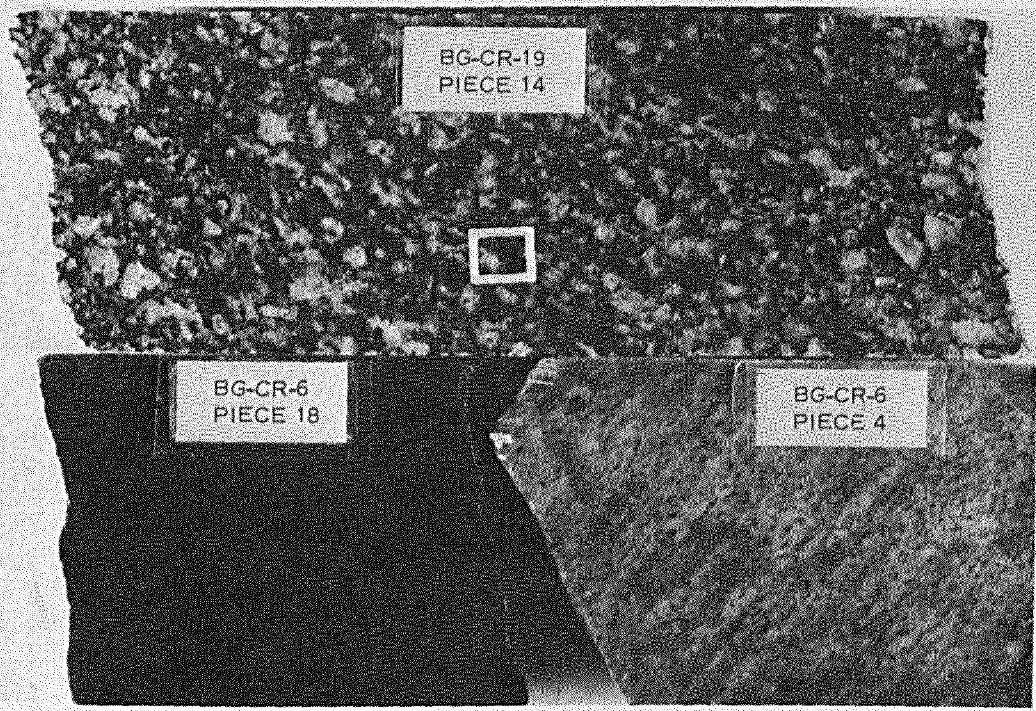


Figure 4.6 Core BG-CR-19, Piece 14, and Core BG-CR-6, Pieces 18 and 4. Magnification, × 1. Each of the three pieces shows typical rock from Cores 19 and 6. Piece 14 is dark-colored, medium-grained rock; the area outlined is shown at × 20 in the next photograph. Piece 4 is light-colored, fine-grained, gneissic rock. Piece 18 is black schistose rock.

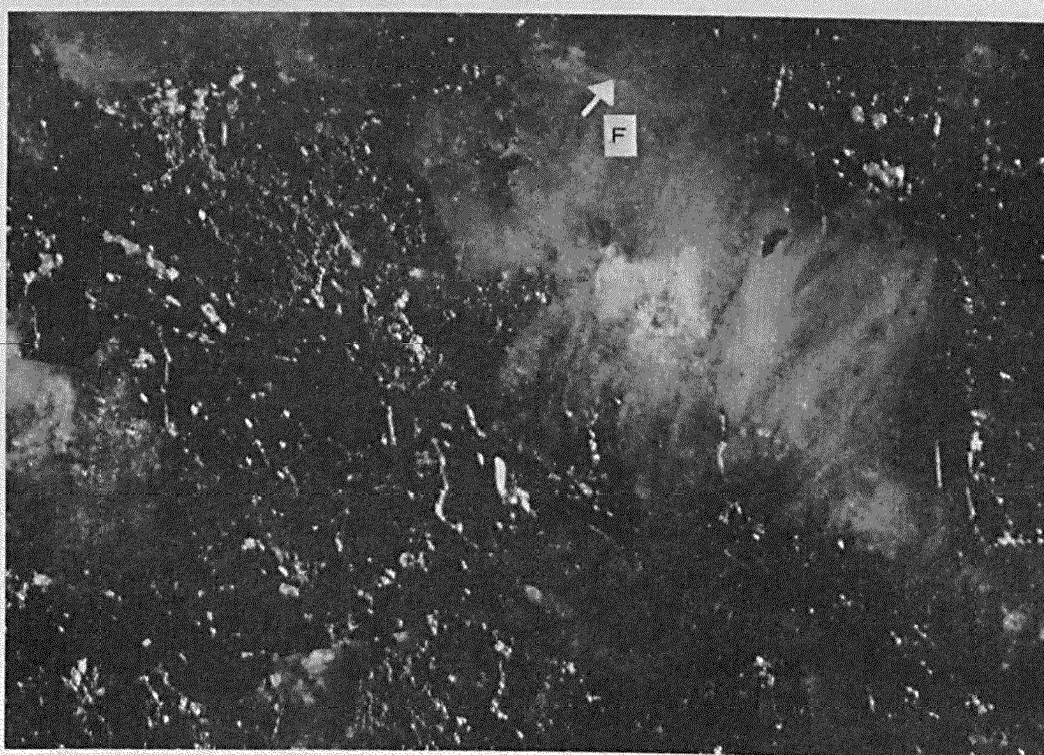


Figure 4.7 Typical portion of Core 19, Piece 14, at × 20 magnification. There is only one perceptible crack; it is in plagioclase feldspar and is indicated by an arrow.

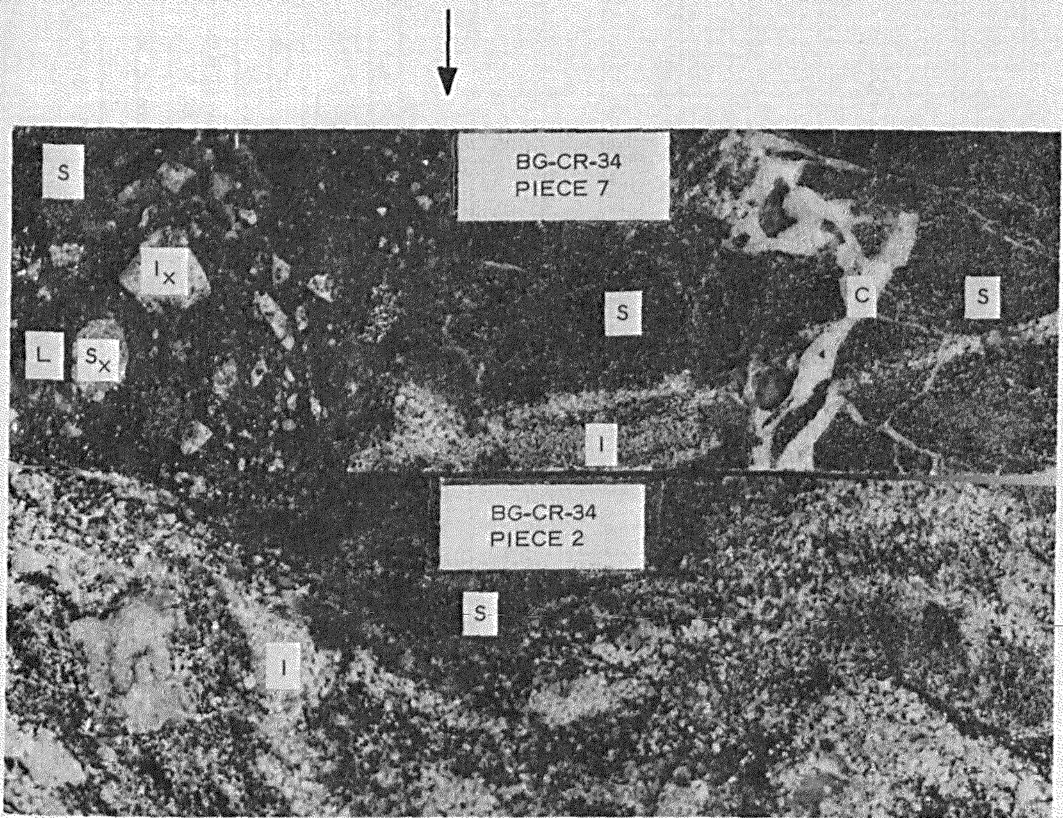


Figure 4.8. Core BG-CR-34, Pieces 7 and 2. Magnification, × 1. Pieces 7 and 2 are representative of Core 34. Piece 7, to the right of the arrow in the upper margin, is a dark schist (S), probably in part assimilated by the pale red granitic rock (I), subsequently fractured and the fractures filled by calcite (C). To the left of the arrow, the core is a conglomerate of rock fragments with angular quartz and feldspar, and mica, in a chlorite-clay-carbonate matrix. Fragments of dark schist (S_X) and granite (I_X) are marked. This part of the core may be a fault breccia. Piece 2 illustrates partial assimilation of the dark schist by the igneous rock, but microscopic brecciation like that in piece 7 was detected, and the core is extensively fractured.

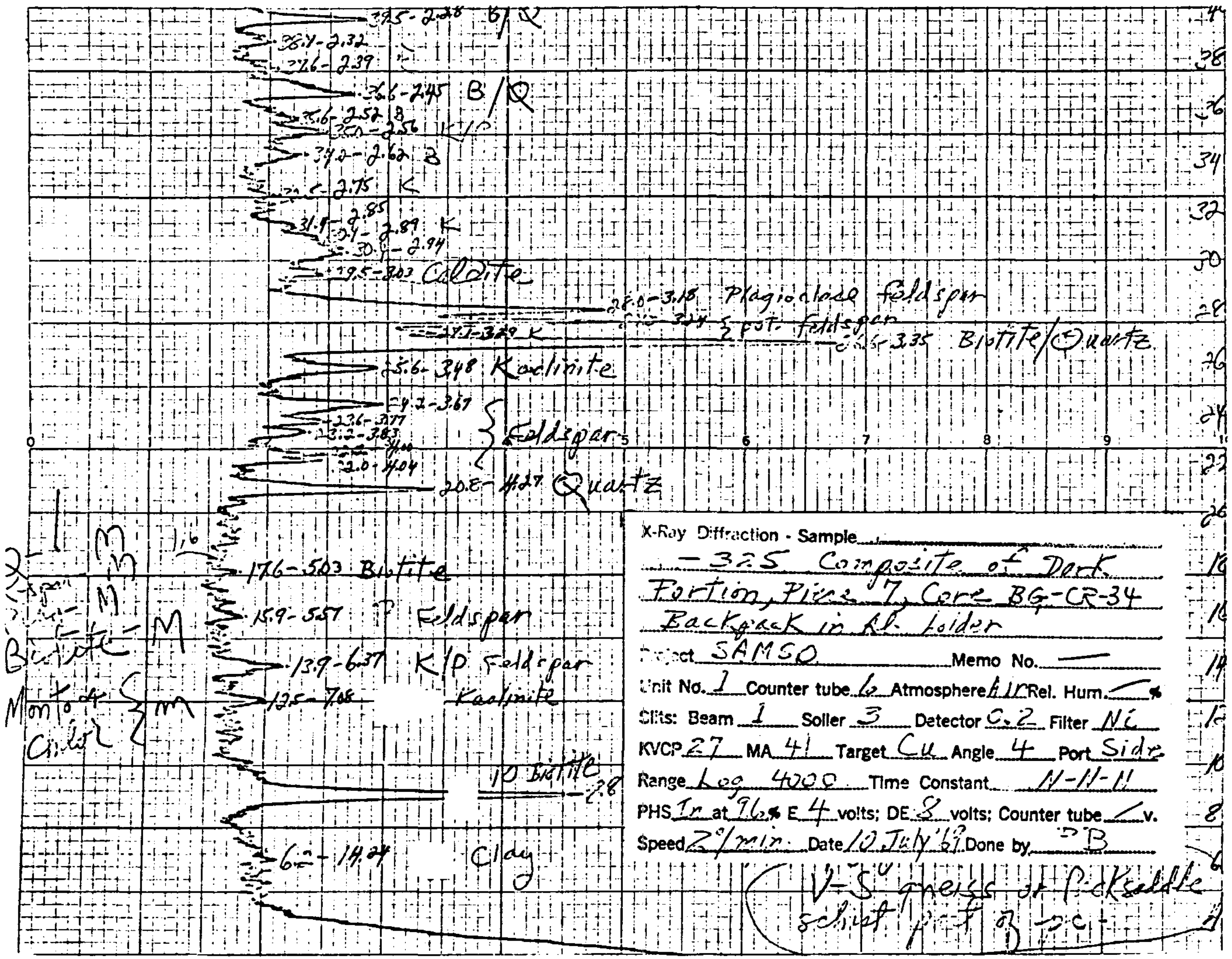


Figure 4.9 Partial trace of XRD chart, dark portion of Piece 7 of Core BG-CR-34.

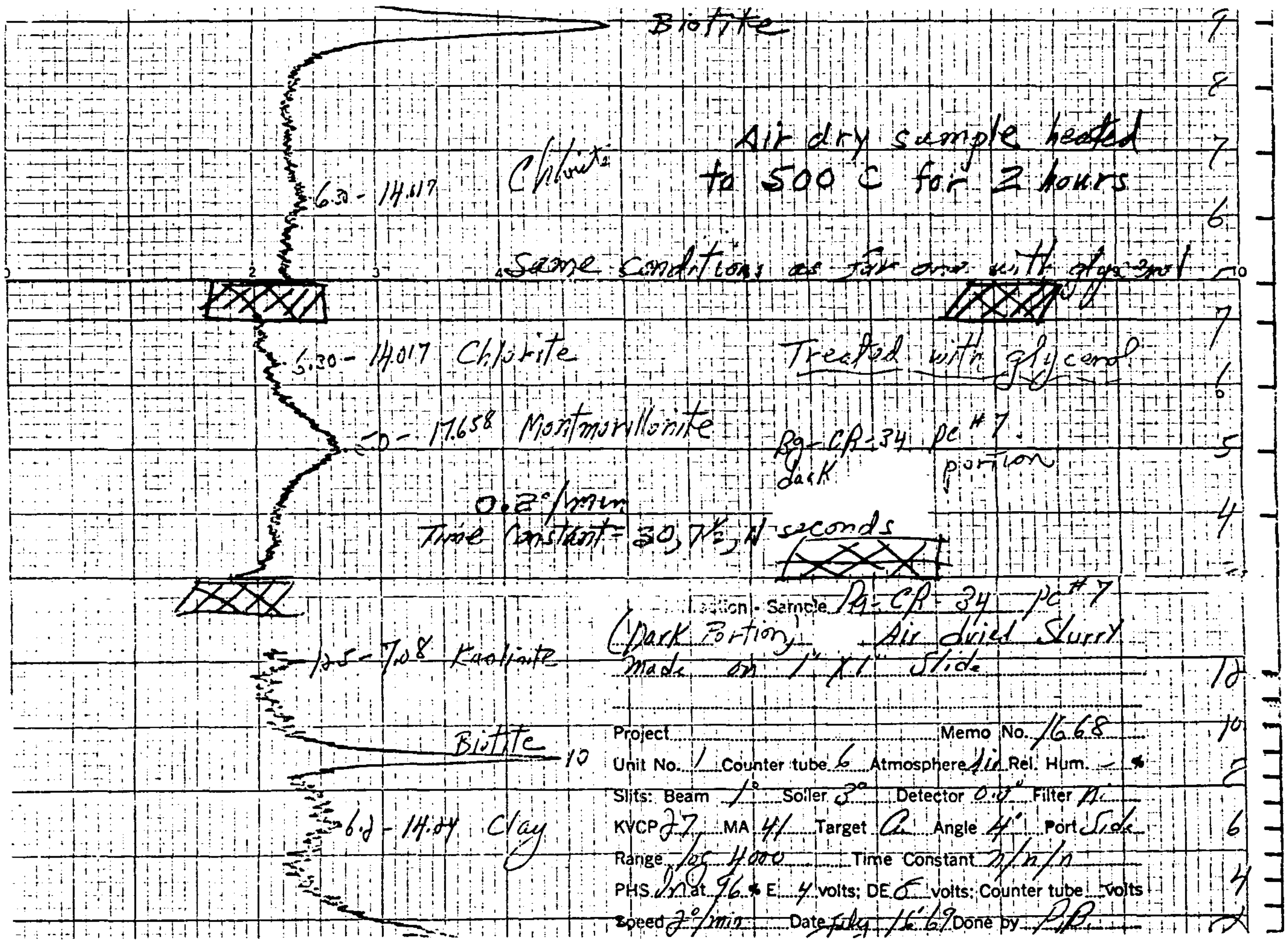


Figure 4.10 Partial traces of XRD charts, same rock as Figure 4.9.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

The wide area covered by the drill holes from which core was taken (delineated in Figure 5.1) and the complex nature of the rock preclude assessment of the area on a geographical basis. The area is approximately 2,000 mi^2. The core from six holes, BG-CR-8, -10, -25, -28, -39, and -19, is predominately pale red granitic igneous rock; however, variations in grain size, mineral constituents, and degree of fracturing and weathering prevent classification as a uniform material. The remaining three cores are very complicated both in type of rock and structural makeup. A rock quality chart based on compressive strength divided into three categories (poor, marginal, and good to excellent) was prepared (Figure 5.2). The poor and marginal material was scattered throughout the several holes and depths. The poor quality rock occurs predominately near the top of the holes, i.e., down to depths of 50 to 60 feet in Holes 8, 10, and 39. Also, fractured rock, although missed in the testing, was present in Hole 32 to a depth of 41 feet (see petrographic report). Thus, possibly 50 feet or more of poor quality rock could be encountered in the area before competent material is reached.

As mentioned previously, the physical properties are quite variable, not unexpectedly in such a complex rock mass. The schist was the heaviest material, but the least competent as indicated by the other tests. The strength results and compressional wave velocities, although quite variable, were satisfactory for the large majority of rock tested including specimens which contained contacts of the several rock types. Only 8 percent of the compressive specimens were classified as poor quality material and an additional 9 percent as marginal by the criteria utilized herein. Only 5 of 87 specimens had compressive wave velocities of less than 15,000 fps. Therefore, overall appearance of the area is one of a complex rock mass with quite variable physical properties, but within the complexity a relatively competent medium.

5.2 CONCLUSIONS

Based on the test results of rock core samples reported herein, the following conclusions appear to be justified:

1. Petrographically, the samples give the appearance of representing a very complex geologic area. Five general types of material were identified: light gneiss, dark gneiss, schist, red granite, and contact zone rock. The predominant material was the red granite. Even within the types, differences in texture, jointing, and degree of alteration were observed.

2. Based on physical characteristics, four groups of material

were present: poor, marginal, good, and excellent quality rock.

3. If 12,000-psi compressive strength is taken as the acceptable minimum of competence, 17 percent of all material tested would be classified as incompetent (approximately one-half as much as in the Castle area). Only 6 percent of the specimens tested had compressive wave velocities below 15,000 fps.

4. The wide area represented by the nine drill holes and the complex nature of the material preclude assessment of the area on a hole-to-hole basis. The poorer quality rock is predominately in the upper elevation. One may expect to remove up to 50 feet of material in some areas before competent rock is reached.

5. Three-dimensional compressional wave velocity tests on representative samples indicate that anisotropy exists within the area; however, this anisotropy was within the range of only 1 to 8 percent with respect to the vertical direction.

6. In summary, the Bergstrom area appears to be one of complex geologic nature, but one yielding physical test results that indicate that the area merits further study as a competent hard rock medium.

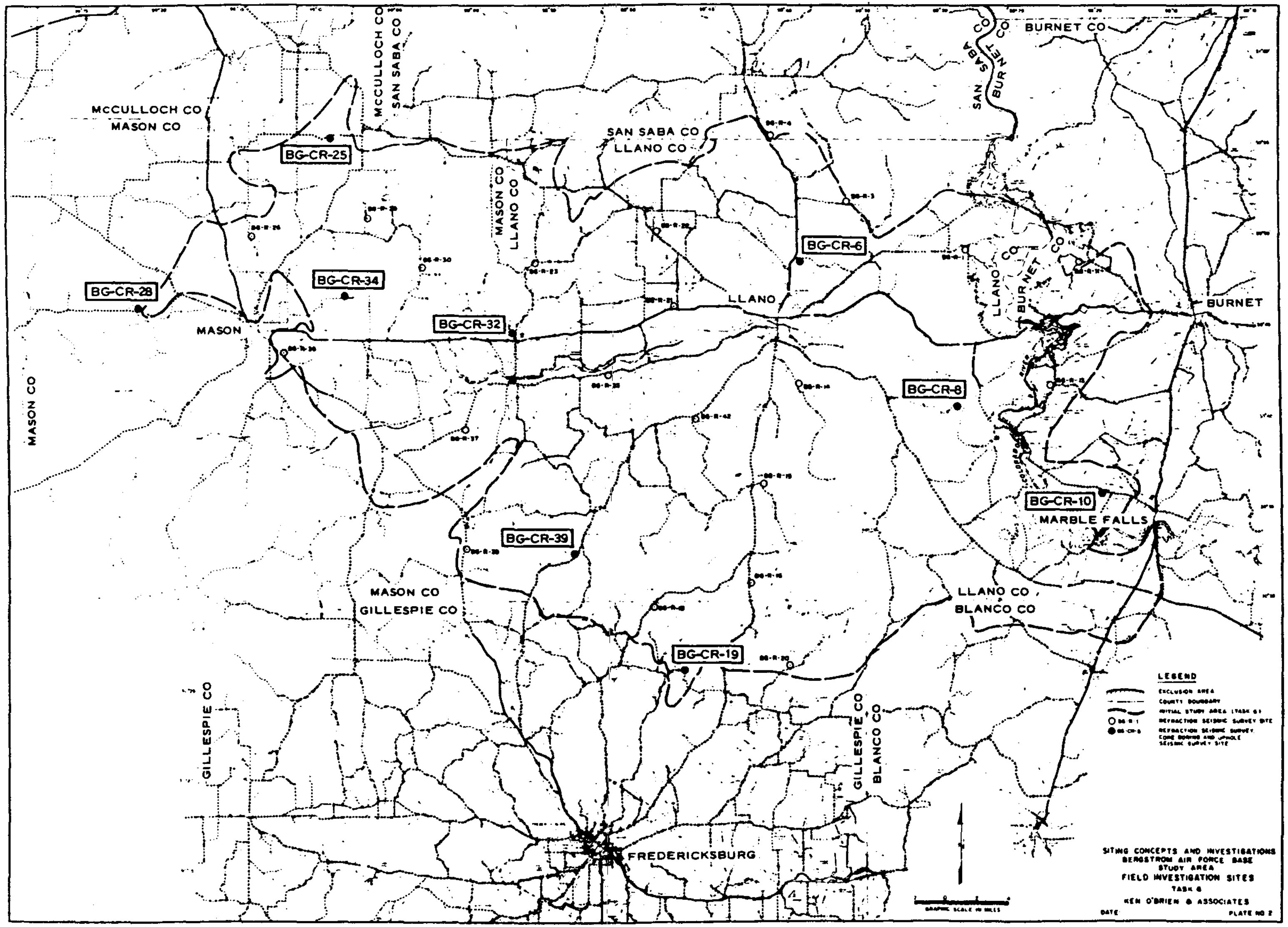


Figure 5.1 Field investigation sites.

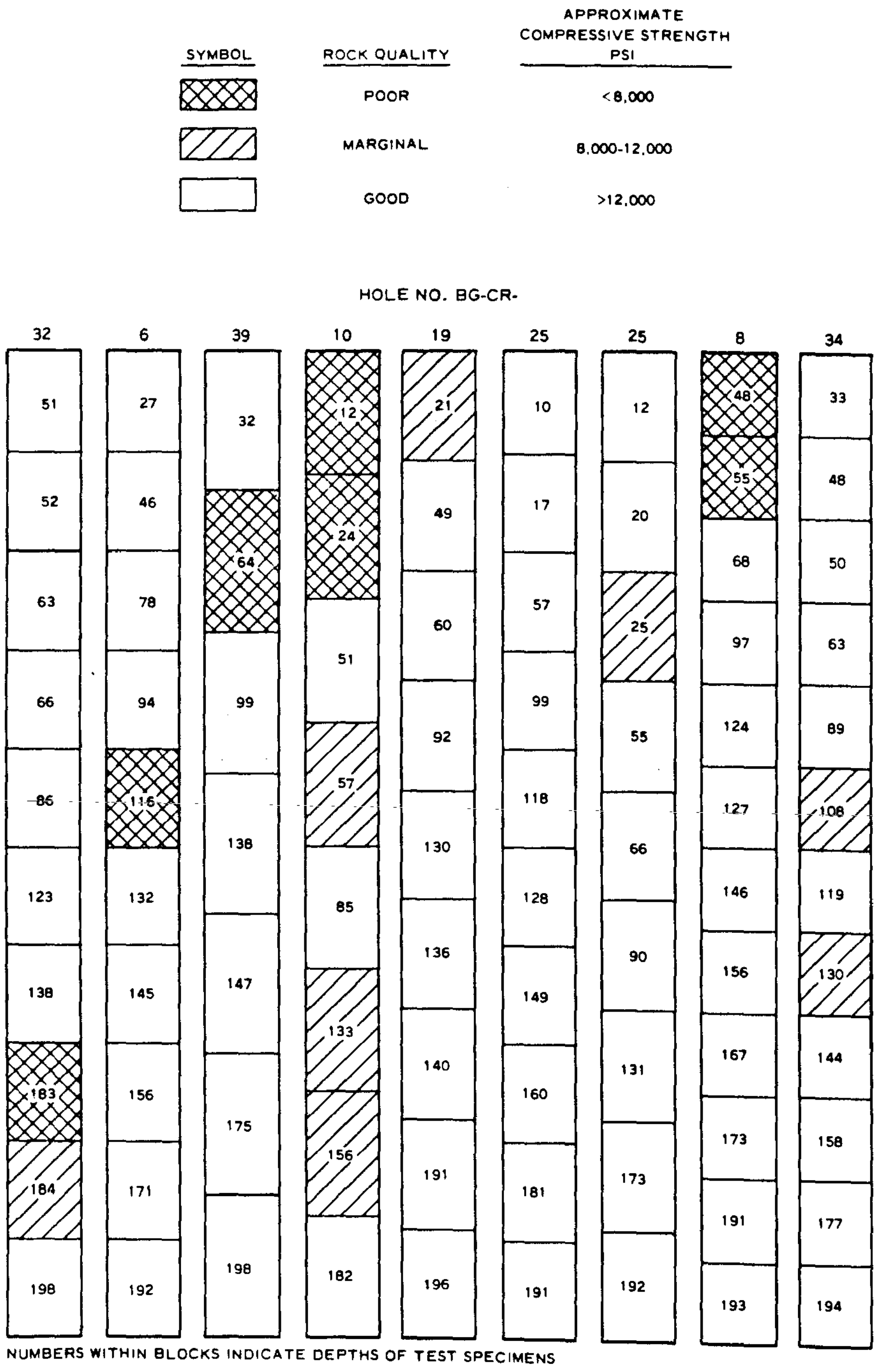


Figure 5.2 Depth versus quality as indicated by compressive strength for individual holes.

APPENDIX A

DATA REPORT

Hole BG-CR-6

28 May 1969

Hole Location: Llano County, Texas

Longitude: 98° 39' 08" West

Latitude: 30° 48' 45" North

Core

1. The following core were received on 26 May 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	16
2	27
3	38
4	46
5	58
6	71
7	78
8	84
9	94
10	103
11	116
12	120
13	129
14	133
15	142
16	145
17	151
18	156
19	162
20	172
21	182
22	192

Description

2. The samples received were predominantly light-gray colored banded rock identified as gneiss on the field log supplied with the core. Specimens 7, 11, and 18 were black colored. Specimens 7 and 18 were identified as gneiss and 11 as schist by the field logs. The remainder of the specimens were banded at angles up to 45 deg.

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	Gray Gneiss with Pink Banding	27.0	2.681	49	36,140	19,200
4	Gray Gneiss with Pink Banding	45.0	2.673	56	32,710	20,890
7	Gneiss, Dark Black with Banding	78.0	2.821	--	12,290	18,020
9	Gray Gneiss with Gray Banding	94.0	2.756	57	22,900	19,390
11	Schist, Dark Black	116.0	2.897	38	4,280	11,600
14	Gray Gneiss with Gray Banding	132.0	2.663	50	27,800	17,450
16	Gray Gneiss with Gray Banding	145.0	2.721	62	27,600	17,720
18	Gneiss, Dark Black with Banding	155.0	2.997	--	21,800	20,260
20	Gray Gneiss with Gray Banding	171.0	2.674	59	34,980	15,140
22	Gray Gneiss with Gray Banding	192.0	2.697	--	23,070	16,300
Avg Gray Gneiss (7)			2.695	57	29,310	18,010
Avg Black Gneiss (2)			2.909	--	17,045	19,140
Avg Black Schist (1)			2.897	38	4,280	11,600

All specimens failed in high-angle cones through the banding except specimen 7 which failed on a band and specimen 11 which split vertically.

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. Stress-strain curves are given in plates 1, 2, 3, and 4. Results are given below:

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
9	*	*	*	*	*
11	5.2	2.0	2.4	7,925	*
18	15.0	8.2	6.3	12,475	0.19
22	8.5	5.0	3.5	9,800	0.22
		Static Tests			
9	12.6	7.5	5.2	--	0.22
11	2.0	1.3	0.8	--	0.25
18	9.2	10.2	3.4	--	0.35
22	10.1	5.4	4.2	--	0.19

* Extraneous results.

Some difficulty was experienced with the dynamic measurements, possibly due to the banded nature of the specimens.

Conclusions

5. The core received for testing from hole BG-CR-32 was predominantly dense, banded, black and gray gneiss according to the core log. In contrast to the rock from hole BG-CR-6, the compressive mode of failure of the gneiss was influenced by the banding in only one out of nine tests. One sample of dark rock, identified on the log as schist, was relatively incompetent material. Typical properties are given below:

Property	Gneiss	Schist
Specific Gravity	2.742	2.897
Schmidt No.	57	38
Compressive Strength, psi	26,590	4,280
Compressional Wave Velocity, fps	18,260	11,600
Young's Modulus, psi x 10^6	10.6	2.0

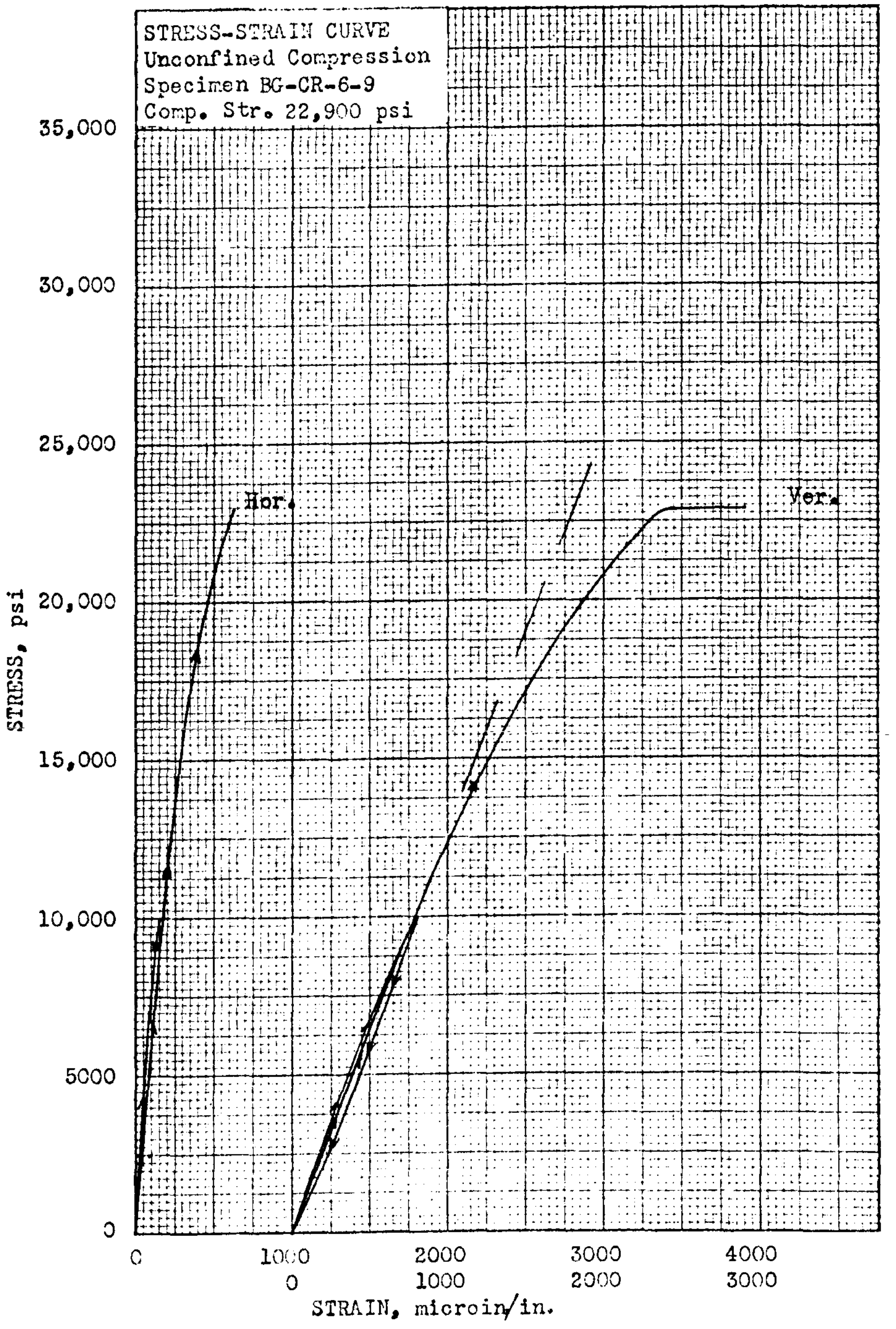
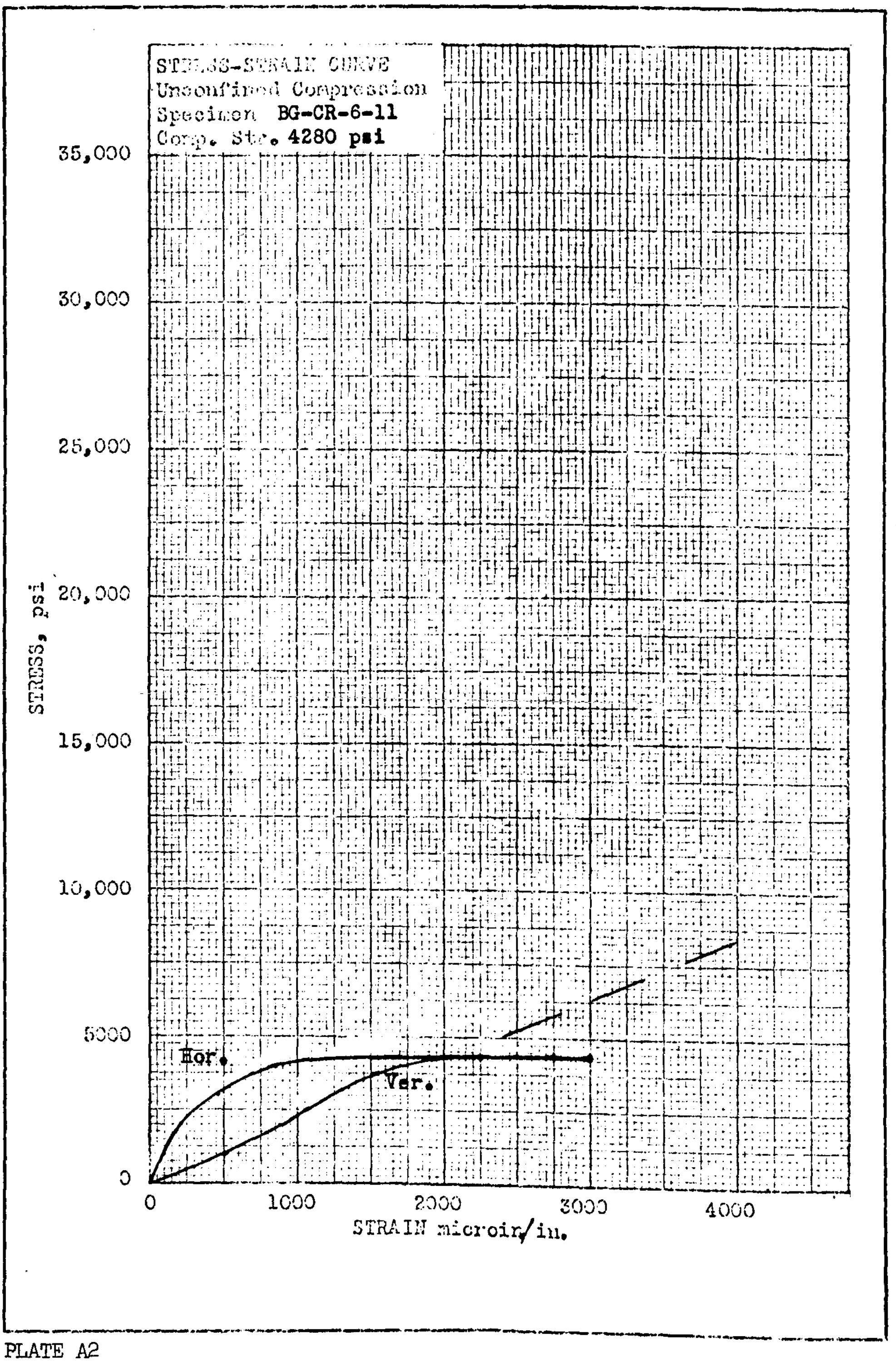
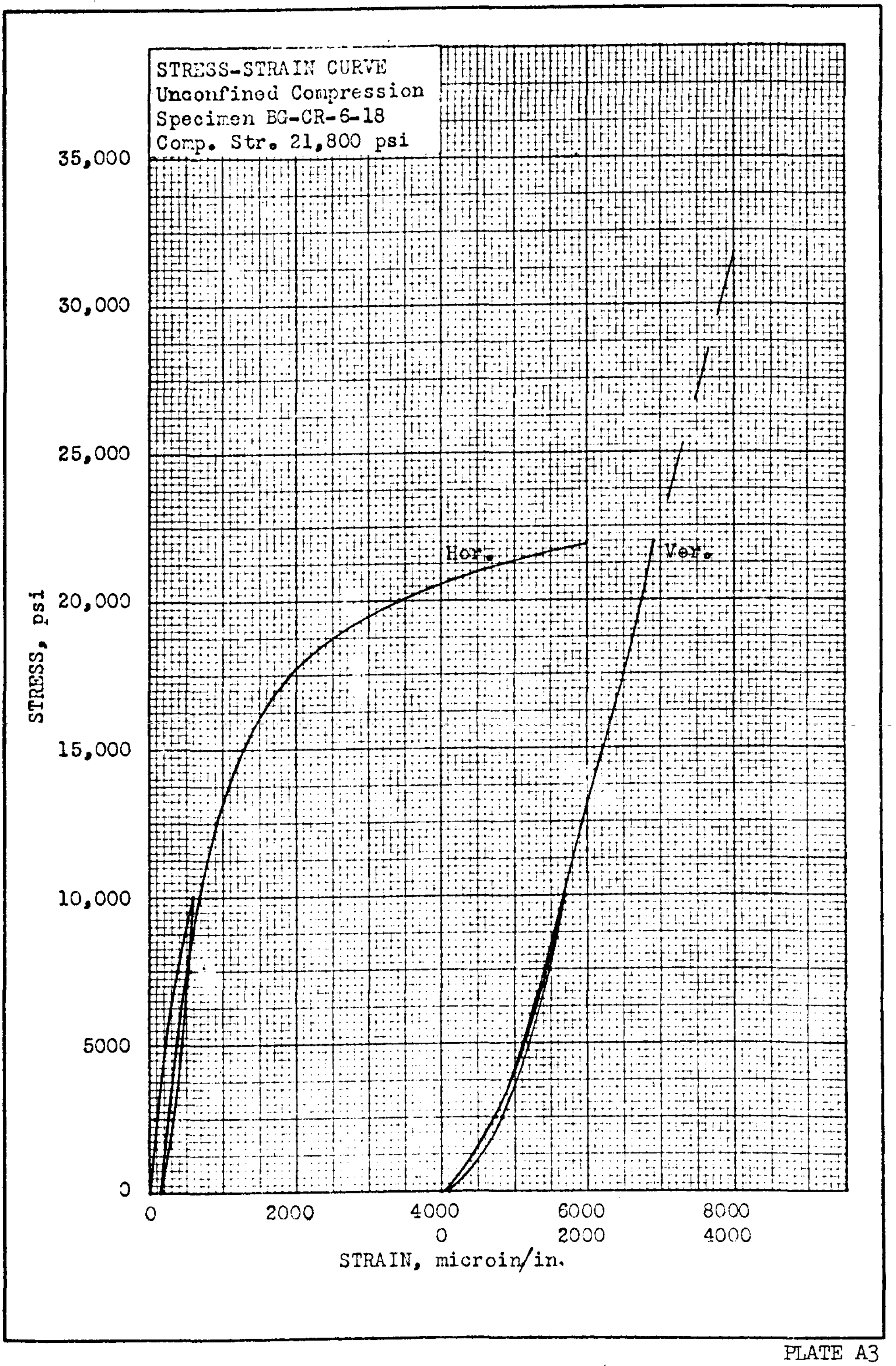

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-6-9
Comp. Str. 22,900 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in.

PLATE A1



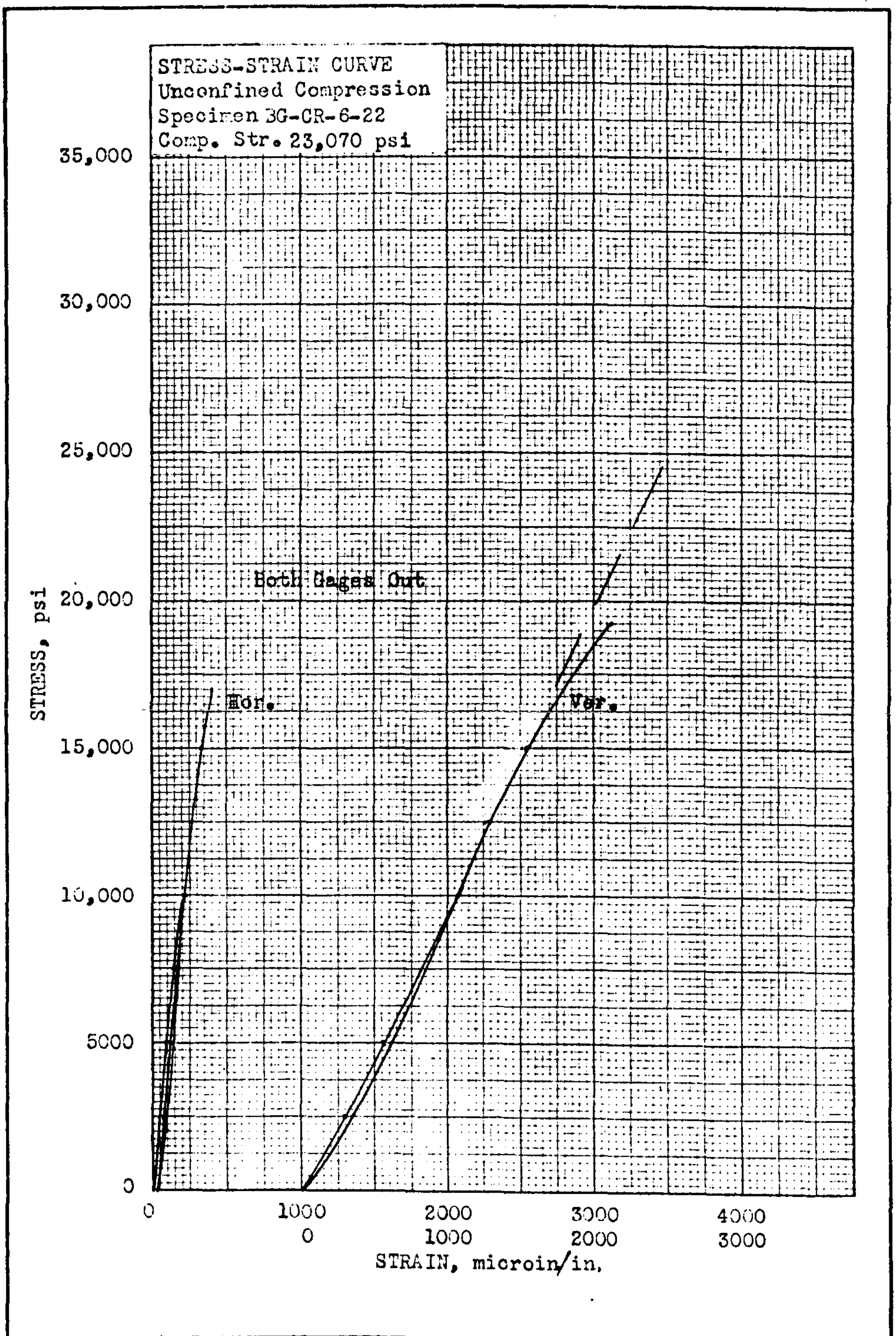
STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-6-11
Comp. Str. 4280 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in.

PLATE A2



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-6-18
Comp. Str. 21,800 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
2000
4000
6000
8000
0
2000
4000
STRAIN, microin/in.

PLATE A3



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-6-22
Comp. Str. 23,070 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Both Gages Out
Hor.
Ver.
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in.

PLATE A4

APPENDIX B

DATA REPORT

Hole BG-CR-8

10 June 1969

Hole Location: Llano County, Texas

Longitude: 98° 29' 17" West

Latitude: 30° 40' 53" North

Core

1. The following core was received on 3 June 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	48
2	55
3	64
4	68
5	75
6	85
7	97
8	102
9	114
~~10~~	~~124~~
11	127
12	135
13	146
14	155
15	156
16	167
17	173
18	179
19	191
20	193
21	200

Description

2. The samples received were pink- to gray-colored rock identified as coarse-grained granite by the field log received with the core. Piece No. 1 appeared somewhat weathered. Piece Nos. 2, 3, 8, 14, 16, and 20 contained seams and/or fractures. Portions of piece Nos. 8, 9, 11, 15, 17, and 20 appeared to be aplite.

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	Weathered	48	2.618	26.9	2,640	4,860
2	Fractured	55	2.649	46.8	3,400	16,095
4	Intact Rock	68	2.661	59.6	21,420	17,850
7	Intact Rock	97	2.678	58.9	17,390	16,595
10	Intact Rock	124	2.660	61.7	20,440	17,660
11	Aplite	127	2.644	52.2	18,480	15,170
13	Intact Rock	146	2.656	56.0	19,880	17,120
15	Aplite	156	2.627	43.7	15,180	19,080
16	Fractured	167	2.652	--	13,530	17,425
17	Aplite	173	2.621	44.1	17,210	16,450
19	Intact Rock	191	2.664	54.2	17,960	19,055
20	Fractured	193	2.637	--	12,000	16,765
Avg weathered and fractured (4)			2.639	36.9	7,890	11,030
Avg aplite (3)			2.631	46.7	16,960	16,900
Avg intact rock (5)			2.664	58.1	19,420	17,660

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

The weathered and fractured rock, especially at the depths near the surface, is relatively poor material. The remainder of the rock, including the aplite, is competent although some pre-existing fracturing is present.

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. 2, 10, and 17. Stress-strain curves are given in plates 1, 2, and 3. Specimens 10 and 17 were cycled at 10,000 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	7.1	5.6	2.8	8810	0.29
10	9.0	6.5	3.5	9920	0.27
17	6.8	6.1	2.6	8580	0.31
		Static Tests			
2	6.2	3.7	2.5	--	0.22
10	9.2	5.7	4.7	--	0.23
17	10.0	5.6	4.2	--	0.20

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

Conclusions

5. The core received for testing from hole BG-CR-8 was identified as coarse-grained granite by the field log received with the core. All of the core was light pink to gray colored; some weathering and fracturing were present. Several pieces were apparently aplite. Low physical test results were obtained on the weathered and/or fractured specimens as given below:

Property	Weathered and Fractured	Aplite	Intact Rock
Specific Gravity	2.639	2.631	2.664
Schmidt No.	37	47	58
Compressive Strength, psi	7,890	16,960	19,420
Compressional Wave Velocity, fps	11,030	16,900	17,660
Young's Modulus, psi x 10^6	6.0	8.0	9.0

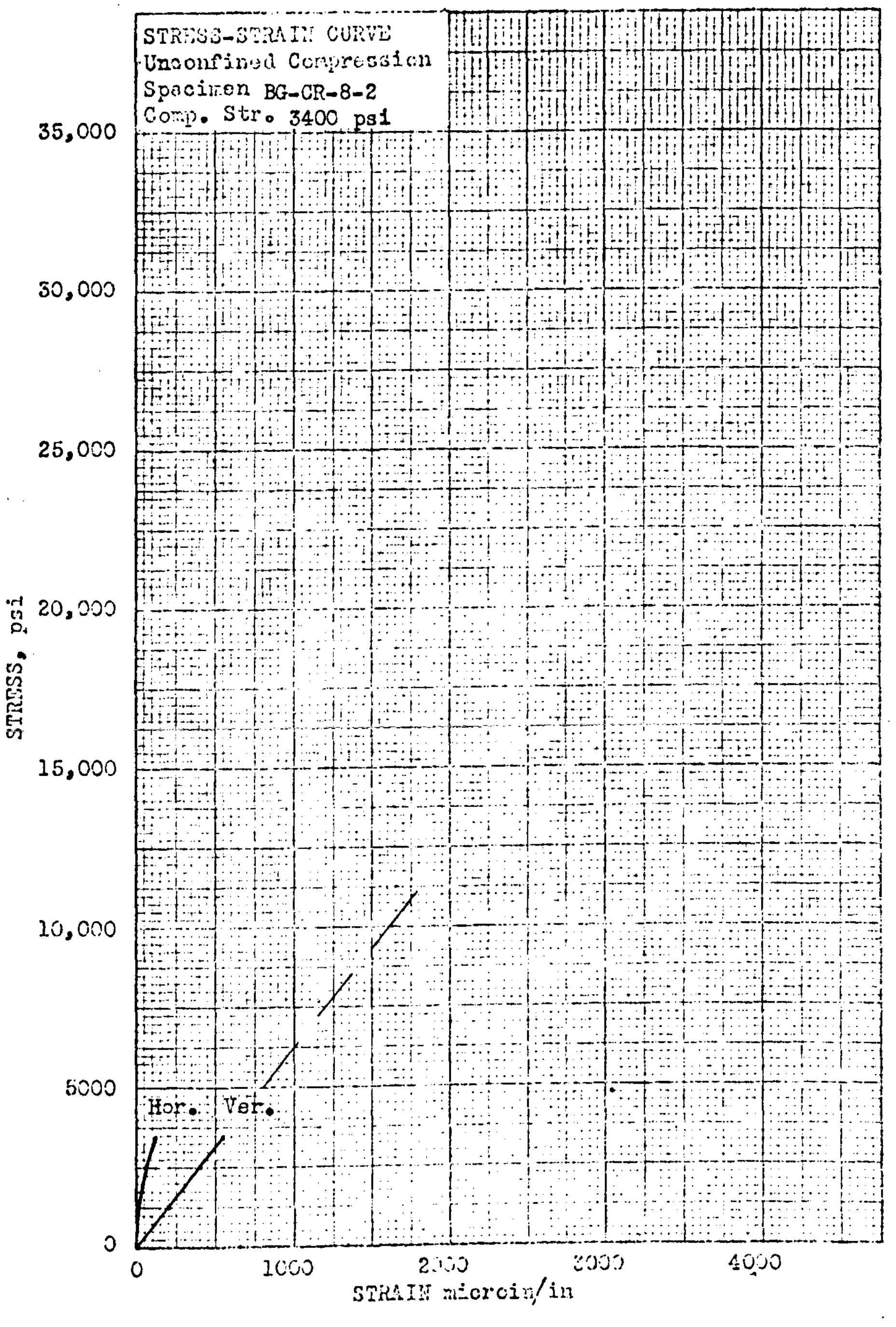
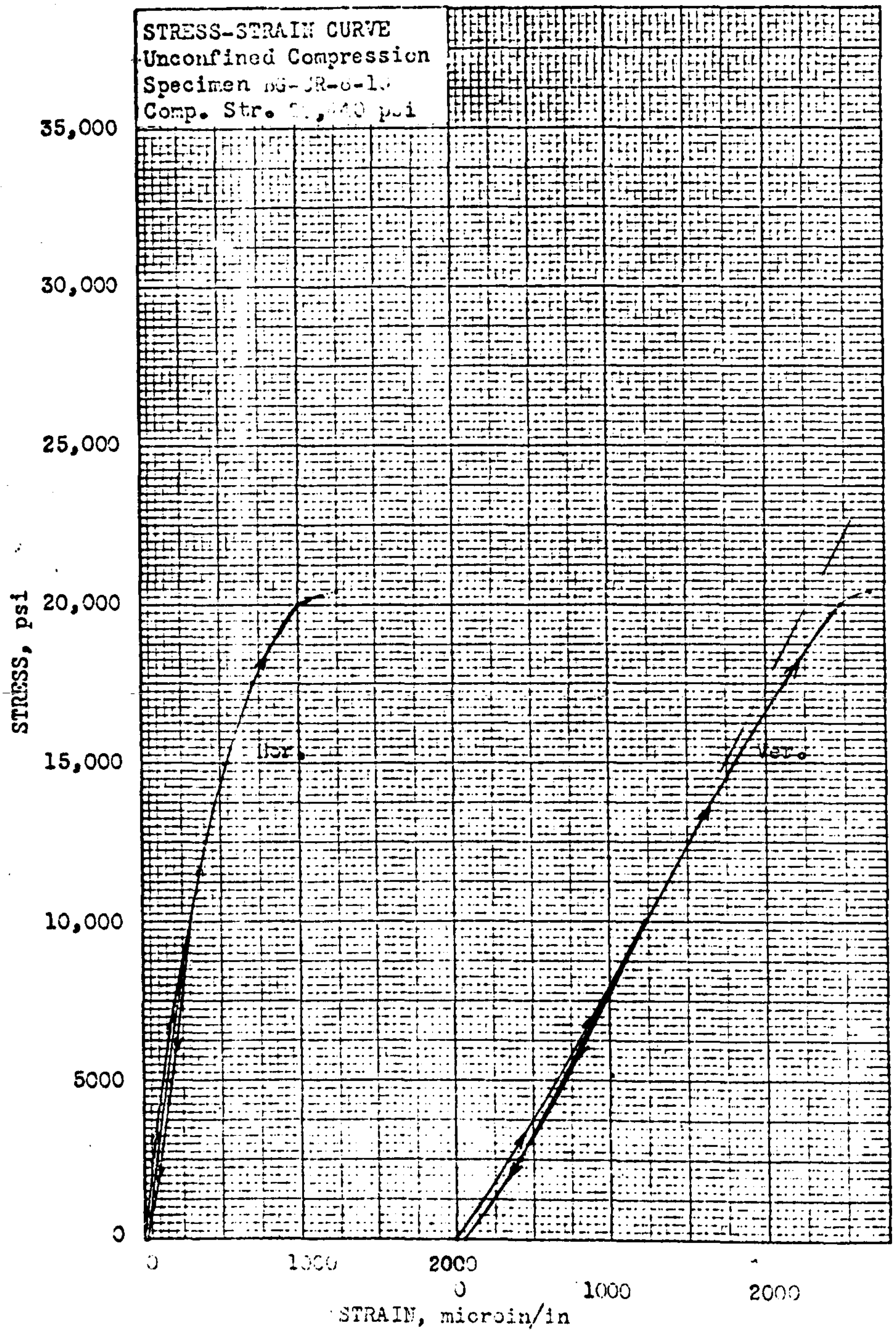

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-8-2
Comp. Str. 3400 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE B1



STRESS-STRAIN CURVE
Unconfined Compression
Specimen
Comp. Str.
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
2000
0
1000
2000
STRAIN, microin/in

PLATE B2

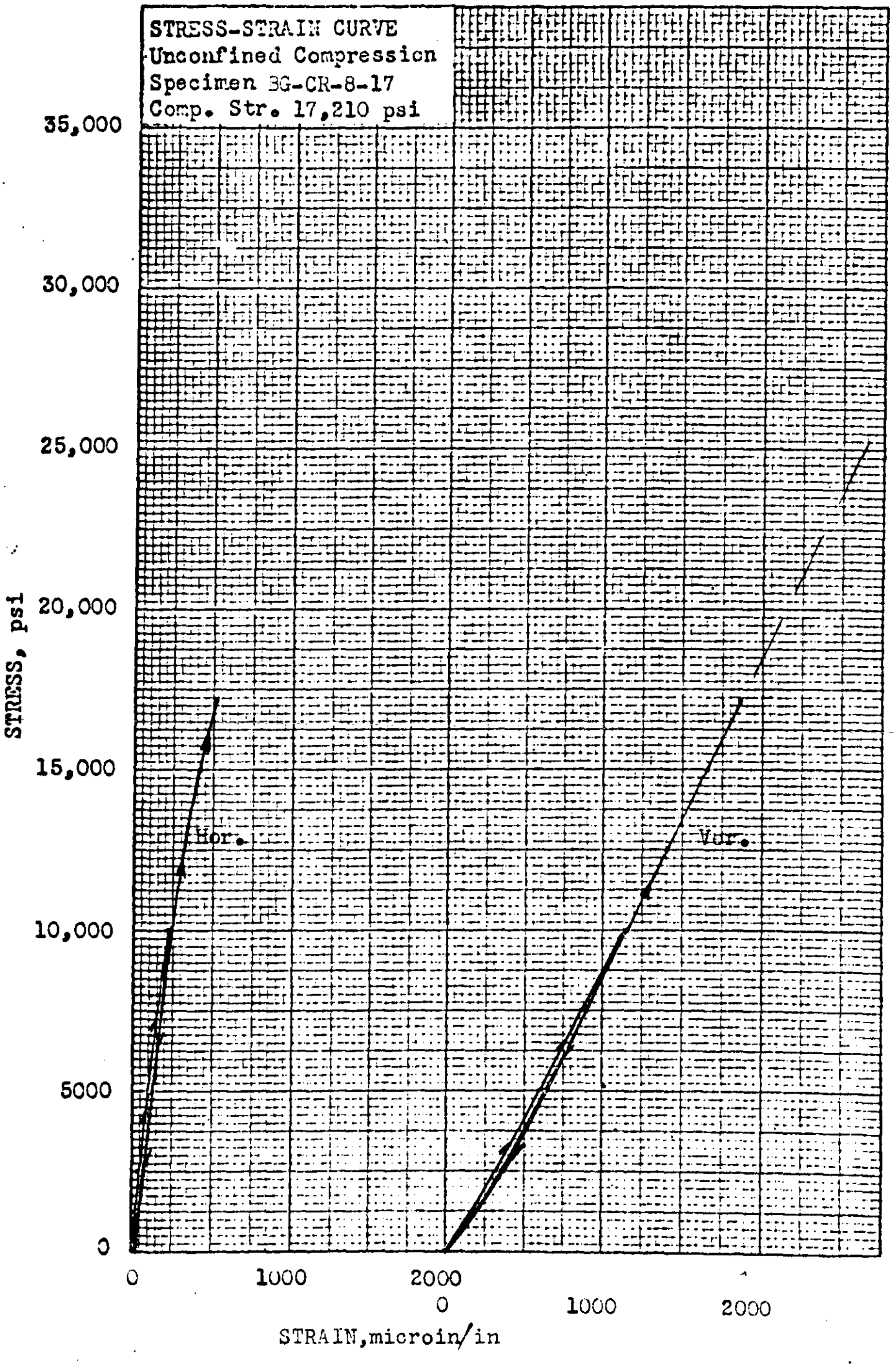

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-8-17
Comp. Str. 17,210 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
0
1000
2000
STRAIN, microin/in

PLATE B3

APPENDIX C

DATA REPORT

Hole BG-CR-10

3 June 1969

Hole Location: Burnet County, Texas

Longitude: 98° 20' 02" West

Latitude: 30° 36' 00" North

Core

1. The following core was received on 26 May 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	12
2	24
3	38
4	48
5	51
6	57
7	63
8	73
9	85
10	95
11	104
12	114
13	123
14	133
15	140
16	150
17	156
18	157
19	164
20	173
21	182
22	194
23	198

Description

2. The samples received were predominantly pink-colored rock identified as massive, dense granite by the field log received with the core. Piece Nos. 5, 7, 17, 18, and 21 were identified on the log as aplite. The granite rock had a salt and pepper appearance while the aplite was of solid pink color. Piece Nos. 1 and 2 appeared somewhat weathered and fractured.

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	Fractured granite	12	2.683	41	6,670	15,070
2	Fractured granite	24	2.676	36	6,450	11,775
5	Aplite	51	2.626	55	15,820	18,650
6	Massive granite	57	2.670	46	10,640	18,550
9	Massive granite	85	2.687	47	13,640	17,010
14	Massive granite	133	2.685	53	11,720	19,610
17	Aplite	156	2.595	50	10,500	13.925
21	Aplite	182	2.613	53	16,520	21,640
Avg fractured granite (2)			2.680	38	6,560	13,420
Avg massive granite (3)			2.681	49	12,000	18,390
Avg aplite (3)			2.611	53	14,280	18,010

Obviously the fractured granite is somewhat poorer rock than the other material. As expected, failure occurred in the compressive tests of the fractured specimens along the preexisting fractures. In the remainder of the specimens the failure mode was a combination splitting and conical fracture, possibly explaining the relatively low strengths obtained (approximately 12,000 and 14,000 psi) for such competent appearing material. Since the rock appears very similar to the material from hole BG-CR-39, it may contain an undetected vertical fracture pattern which tended to induce the splitting type failure.

4. Due to the relatively low compressive strengths obtained on the above-mentioned tests, especially the granite, concern was expressed that possibly the liquid substance used in the velocity determinations was adversely affecting the strength results. The liquid, utilized as a coupling agent between the specimen and the transducer, appeared to saturate the ends of the specimen to a depth of 1/8 to 1/4 in. Despite thorough cleaning, some of the agent remained. Consequently, three additional relatively uniform samples, Nos. 11, 12, and 16, were selected and two adjacent compressive test specimens prepared from each. One specimen of each sample was coated with the coupling liquid and then cleaned and one each was left dry. Results are given below:

Coated and Cleaned		Dry	
Specimen	Compressive Strength, psi	Specimen	Compressive Strength, psi
11A	18,760	11B	20,330
12A	22,550	12B	21,590
16A	22,000	16B	19,700
Avg	21,100	Avg	20,540

5. The coupling agent apparently did not affect the strength results. However, the strengths are significantly higher than those obtained on the original specimens (para 3). Coning type failure was also more evident in specimens 11, 12, and 16. Apparently the massive granite specimens selected originally contained undetected flaws, possibly microfractures, which resulted in relatively low indicated compressive strengths.

Moduli of deformation

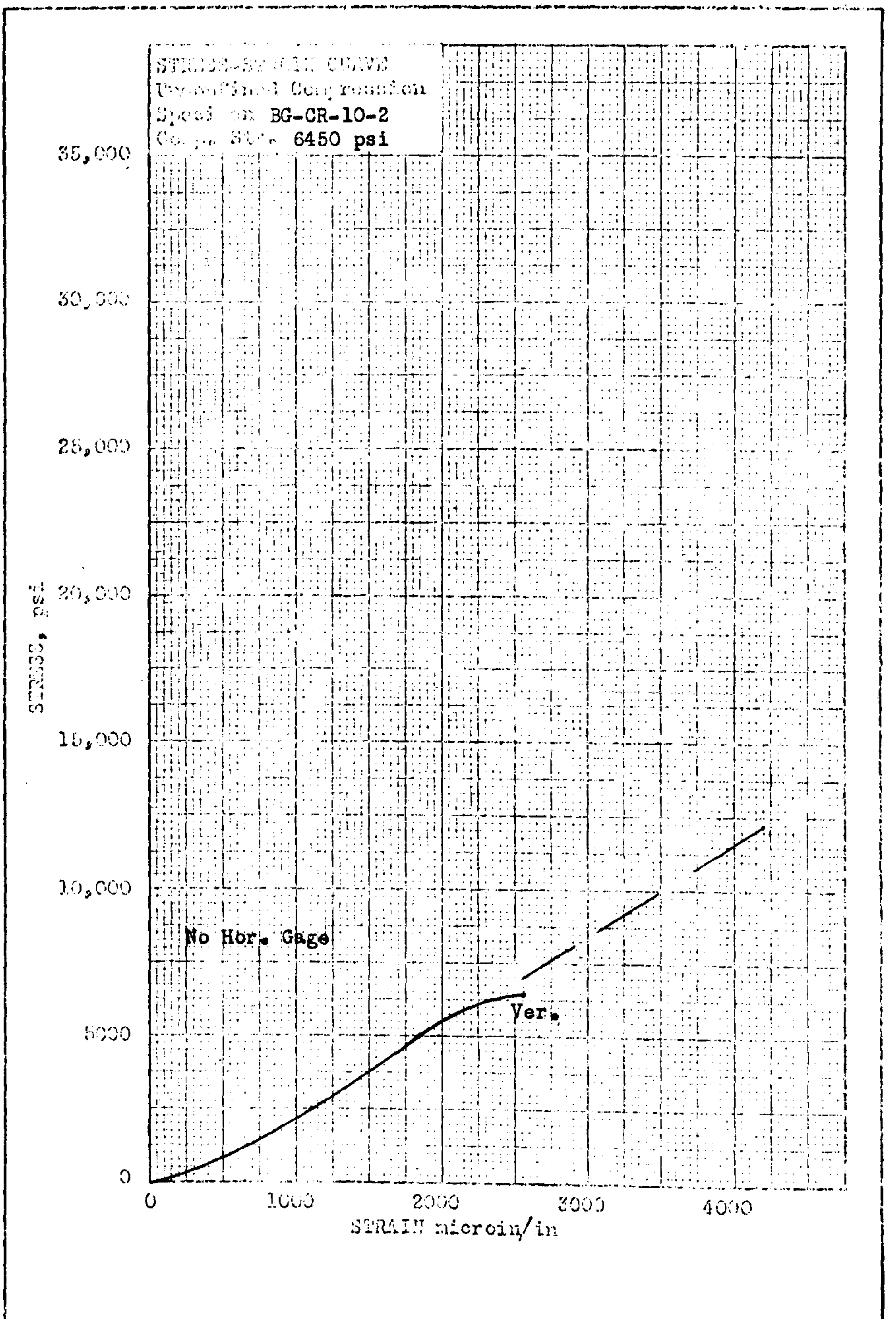
6. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens. Stress-strain curves are given in plates 1, 2, and 3. Specimens 9 and 17 were cycled at 10,000 psi. The horizontal gages on specimen 2 failed early in the test due to the fractured nature of the specimen. The unusual behavior of specimens 2 and 17 during the unloading portion of the stress-strain test is probably due to slippage on small cracks or fractures. Results are given below:

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
			Dynamic Tests		
2	4.0	2.9	1.6	6,625	0.27
9	9.0	5.6	3.6	10,050	0.23
17	5.4	3.9	2.5	7,820	0.27
			Static Tests		
2	3.0	--	--	--	--
9	10.0	5.1	4.3	--	0.17
17	8.8	3.9	3.9	--	0.12

Conclusions

7. The cores received for testing from hole BG-CR-10 were predominantly pink-colored rock identified as massive, dense granite by the field log received with the cores. Some weathered, fractured material was evident in the upper elevations. Several specimens were identified as aplite on the core log. Except for the weathered samples, the rock appeared to be competent material. However, the massive granite yielded compressive strengths which ranged between 10,000 to 22,000 psi depending apparently upon the extent of microfracturing present in the samples. Typical properties are given below.

Property	Fractured Granite	Massive Granite	Aplite
Specific Gravity	2.680	2.681	2.611
Schmidt No.	38	49	53
Compressive Strength, psi	6,560	10,000 to 22,000	14,280
Compressional Wave Velocity, fps	13,420	18,930	18,010
Young's Modulus, psi	3.0	10.0	8.8



BG-CR-10-2
6450 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
No Hor. Gage
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE C1

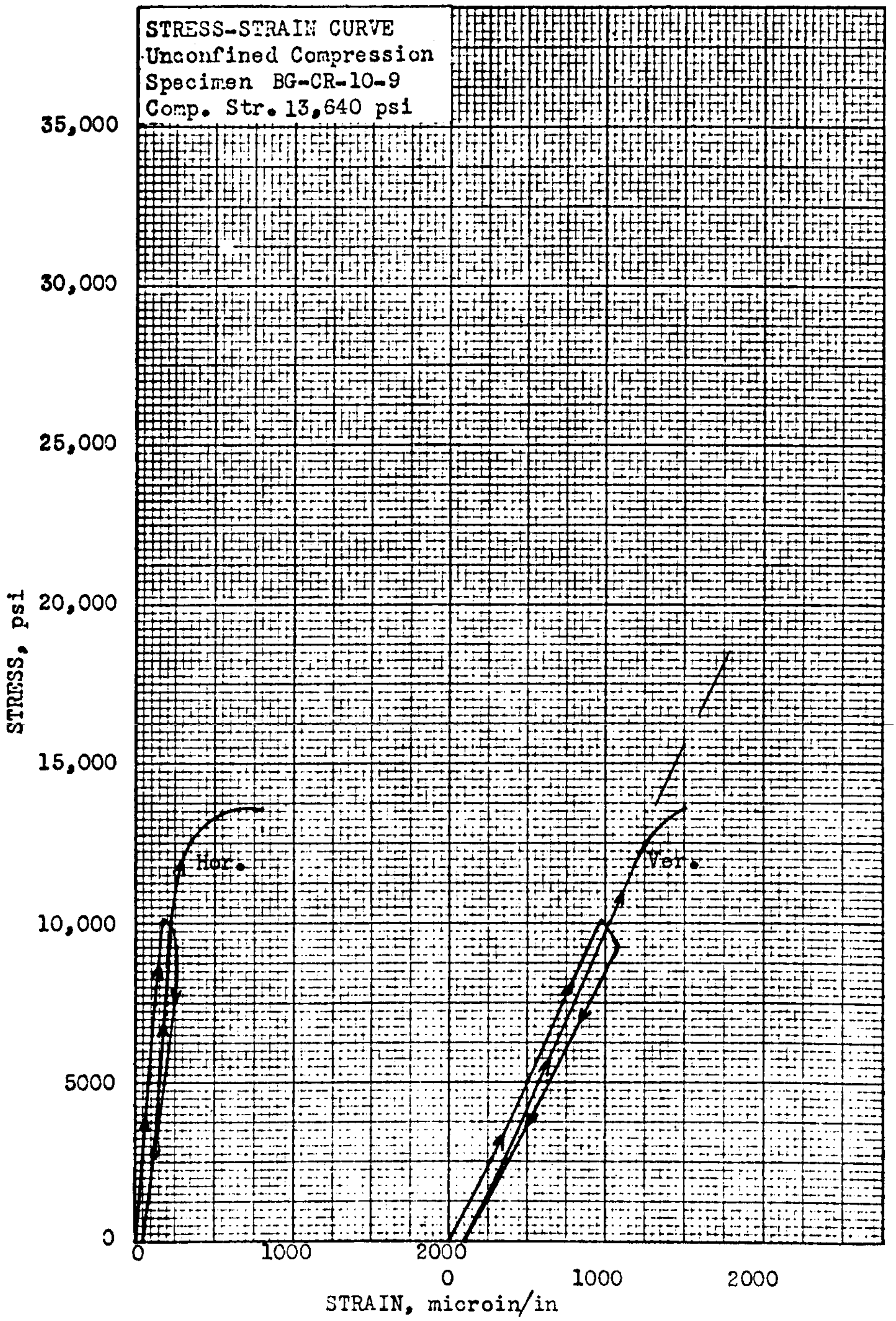

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-10-9
Comp. Str. 13,640 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
0
1000
2000
STRAIN, microin/in

PLATE C2

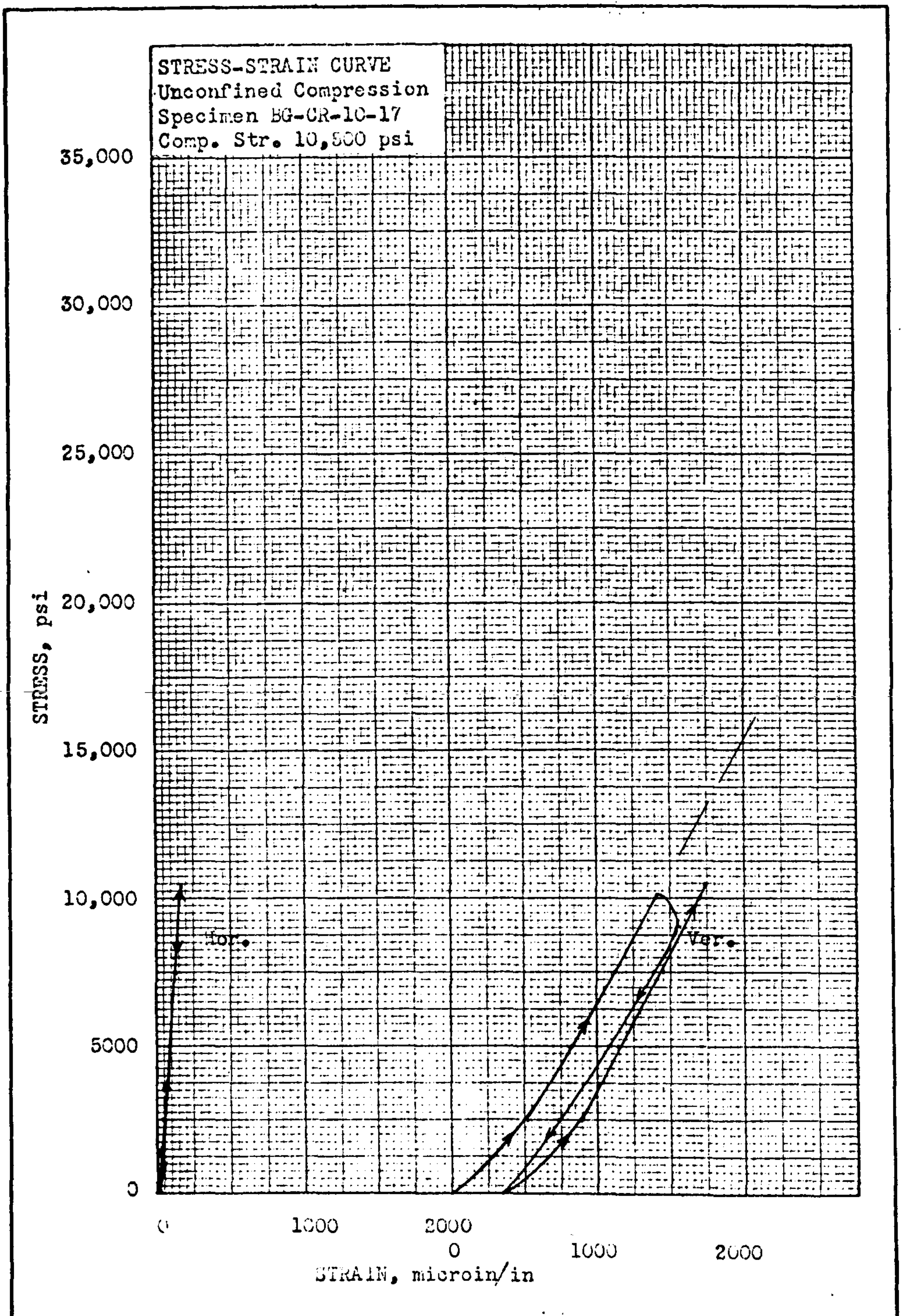

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-10-17
Comp. Str. 10,500 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
0
1000
2000
STRAIN, microin/in

PLATE C3

APPENDIX D

DATA REPORT

Hole BG-CR-19

4 June 1969

Hole Location: Gillespie County, Texas

Longitude: 98° 45' 40" West

Latitude: 30° 25' 12" North

Core

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

Core Piece No.	Approximate Depth, ft
1	10
2	21
3	28
4	39
5	49
6	60
7	73
8	84
9	92
10	102
11	110
12	120
13	123
14	130
15	133
16	135
17	140
18	150
19	160
20	172
21	184
22	191
23	195
24	200

Description

2. The samples received were predominantly dark-gray-colored rock identified as coarse- to medium-grained biotite quartz diorite gneiss by the field log received with the core. Piece No. 17 was very dark gray and fine grained and piece 24 was cream colored and fine grained.

Banding was not pronounced, but the individual grains were aligned in high-angle patterns. Veins and streaks were evident in several pieces.

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	Uniform gneiss	21	2.827	42	9,970	20,700
5	Gneiss with vein	40	2.812	--	12,640	20,015
6	Uniform gneiss	60	2.805	44	13,450	19,955
9	Uniform gneiss	92	2.8[illegible]	45	13,210	18,240
14	Uniform gneiss	130	2.826	47	12,020	19,205
15	Gneiss with vein	136	2.763	--	15,790	20,050
17	Uniform gneiss*	140	2.862	45	17,790	20,065
22	Gneiss with vein	191	2.791	--	13,850	19,975
23	Gneiss with vein	196	2.756	--	21,150	21,120
Avg all specimens			2.806	45	14,430	19,925

Standard deviation of compressive strength: 3350 psi.

* Fine grained, dark gray.

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

Since there were no apparent differences in the results obtained on the uniform or veined specimens, all results were averaged. The compressive strength appears rather low and the standard deviation rather high for an otherwise competent rock. Significantly, the failure mode, inclined splitting along the aligned bands, indicates that the banding, although not pronounced, influenced the strength results.

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. 9 and 17. Stress-strain curves are given in plates 1 and 2. Both specimens were cycled at 10,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
9	11.4	6.2	4.8	11,280	0.19
17	12.3	9.1	4.9	11,210	0.27
		Static Tests			
9	9.2	5.7	3.7	--	0.23
17	11.7	7.0	4.8	--	0.22

The relatively high moduli and little hysteresis in the stress-strain relationships indicate that the gneiss is a rather rigid material.

Conclusions

5. The core received for testing from hole BG-CR-19 was identified as biotite quartz diorite gneiss on the core log. All but two of the samples were coarse- to medium-grained, gray-colored, slightly banded rock. Although the banding was not pronounced, it apparently resulted in lower unconfined compressive strengths than would be expected with an otherwise competent material. Typical properties are given below:

Property	Results
Specific Gravity	2.806
Schmidt No.	45
Compressive Strength, psi	14,430
Compressional Wave Velocity, fps	19,925
Young's Modulus, psi x 10^6	10.0

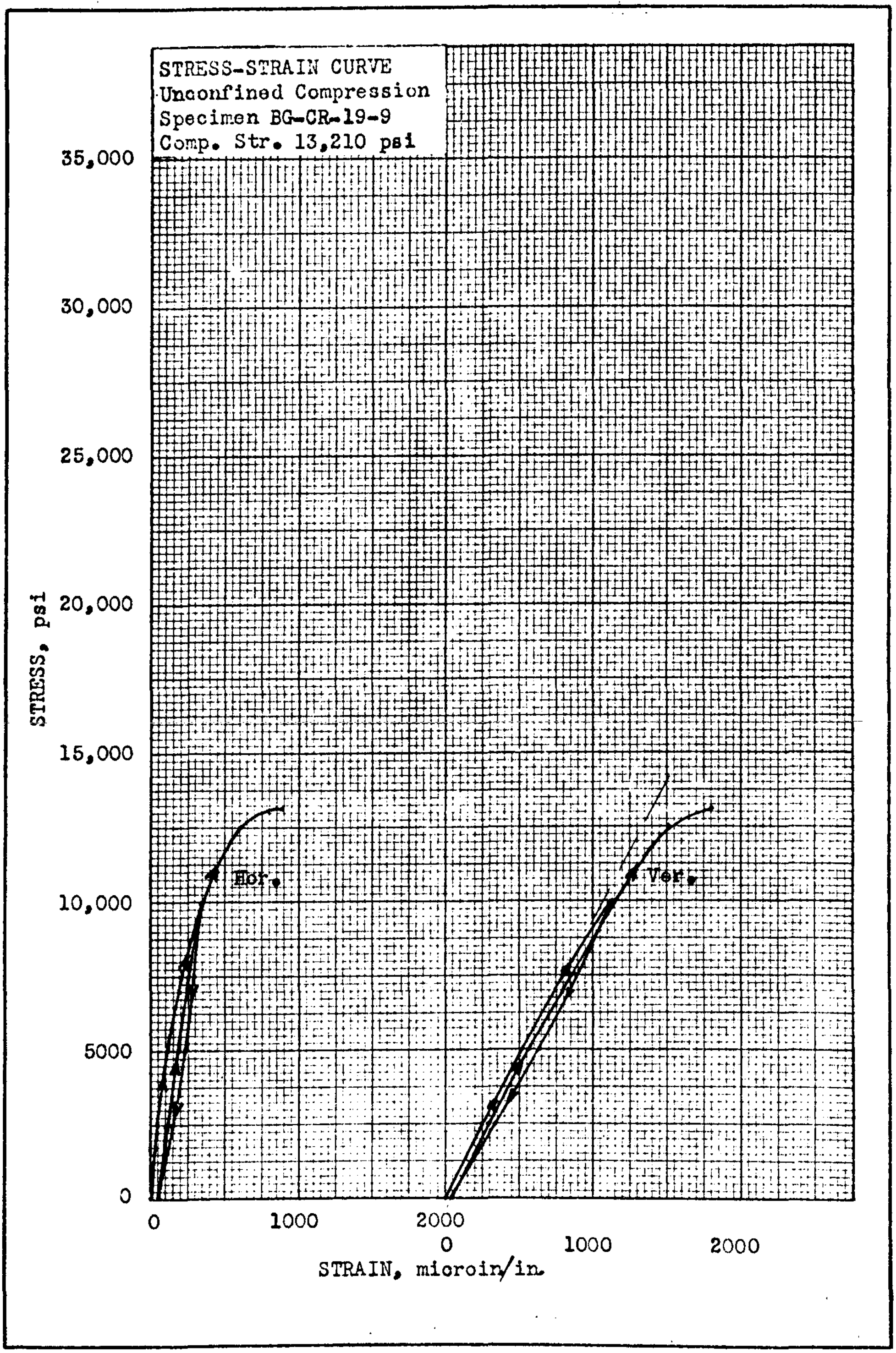
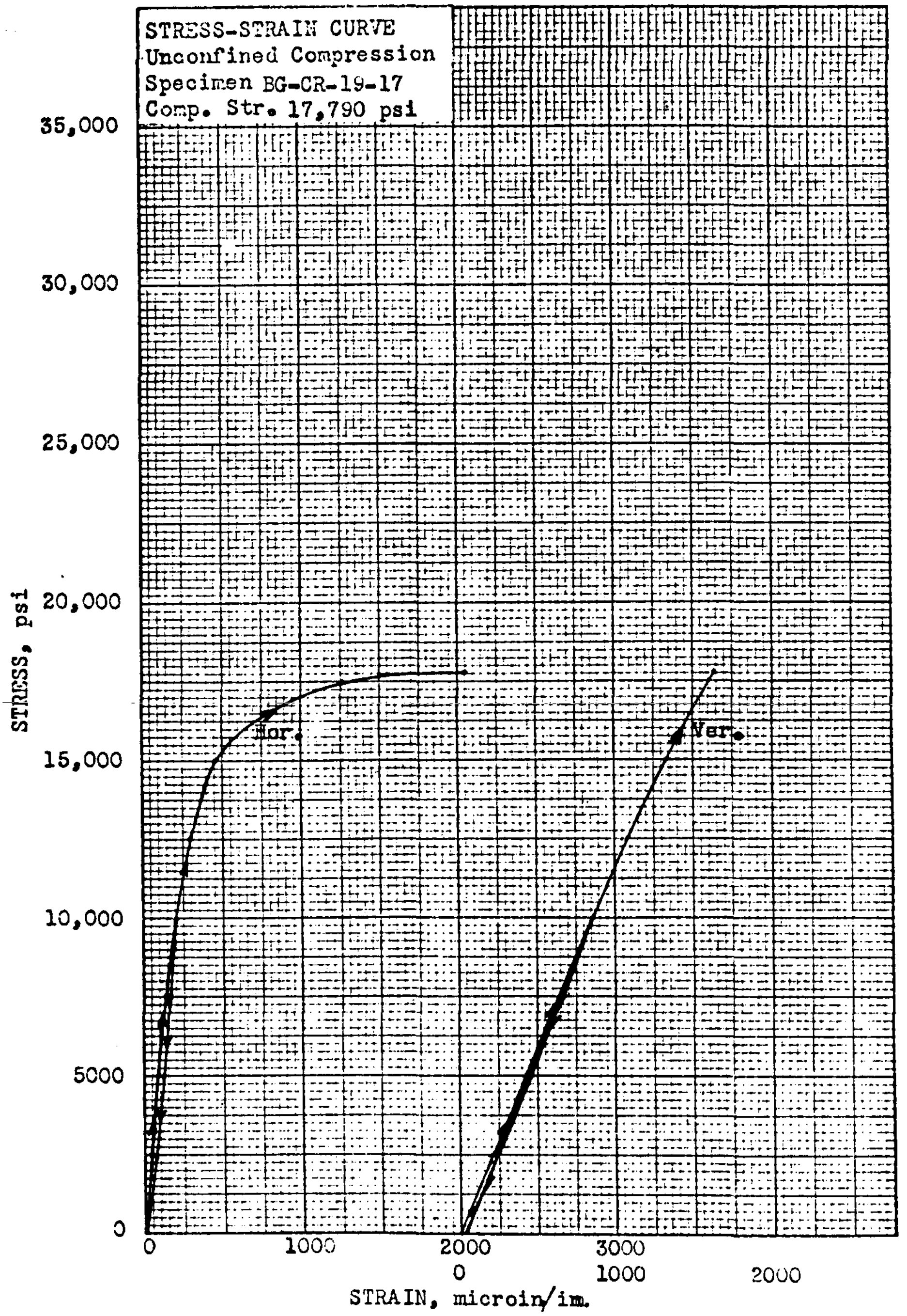

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-19-9
Comp. Str. 13,210 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
0
1000
2000
STRAIN, microin/in.

PLATE D1



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-19-17
Comp. Str. 17,790 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
0
1000
2000
STRAIN, microin/im.

PLATE D2

APPENDIX E

DATA REPORT

Hole BG-CR-25

5 June 1969

Hole Location: Mason County, Texas

Longitude: 99° 09' 01" West

Latitude: 30° 55' 20" North

Core

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

Core Piece No.	Approximate Depth, ft
1	10
2	17
3	29
4	37
5	47
6	57
7	64
8	76
9	87
10	99
11	108
12	118
13	128
14	138
15	149
16	160
17	170
18	181
19	191
20	199

Description

2. The samples received were buff-pink-colored rock identified as coarse- to medium-grained biotite granite porphry by the field log received with the core. Piece No. 1 appeared weathered and piece Nos. 15, 18, and 19 contained high-angle, 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	Weathered	10	2.642	--	23,800	18,335
2	Unfractured	17	2.653	56	23,970	19,255
6	Unfractured	57	2.653	51	23,310	19,640
10	Unfractured	99	2.655	57	25,460	20,185
12	Unfractured	118	2.643	55	20,220	19,755
13	Unfractured	128	2.646	60	26,340	20,650
15	Closed Fractures	149	2.638	--	17,530	19,720
16	Unfractured	160	2.657	53	24,130	20,190
18	Closed Fractures	181	2.654	--	18,830	19,175
19	Closed Fractures	191	2.649	--	17,210	20,830
Avg fractured specimens			2.647	--	17,860	19,910
Avg unfractured specimens			2.650	55	23,390	19,950

Standard deviation of compressive strength unfractured specimens: 1930 psi.

---

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

Specimen No. 1 apparently was not significantly weathered; therefore, the results except for the wave velocity were averaged with the unfractured specimens. The three specimens which contained high-angle, closed fractures yielded lower compressive strengths than the unfractured specimens, but the average strength, 17,860 psi, and the compressional wave velocities were high for fractured rock. The fractures are apparently well healed and/or closed.

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. 6 and 13. Stress-strain curves are given in plates 1 and 2. Both specimens were cycled at 10,000 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	10.9	8.0	4.3	11,100	0.27
13	11.5	9.3	4.5	11,320	0.29
		Static Tests			
6	10.0	7.9	3.9	--	0.29
13	10.7	8.9	4.1	--	0.30

Like the gneiss from hole BG-CR-19, the relatively high moduli and little hysteresis in the stress-strain relationships indicate the CR-25 granite porphyry is a rather rigid rock.

Conclusions

5. The core received for testing from hole BG-CR-25 was identified as coarse- to medium-grained biotite granite porphry. Several pieces contained high-angle, closed fractures which yielded only slightly lower physical properties than the intact samples. The high moduli and little hysteresis in the stress-strain relationships are indications of a very rigid material. Typical properties are given below.

Property	Unfractured Rock	Rock With Closed Fractures
Specific Gravity	2.650	2.647
Schmidt No.	55	--
Compressive Strength, psi	23,890	17,860
Compressional Wave Velocity, fps	19,950	19,910
Young's Modulus, psi $\times 10^6$	10.0	--

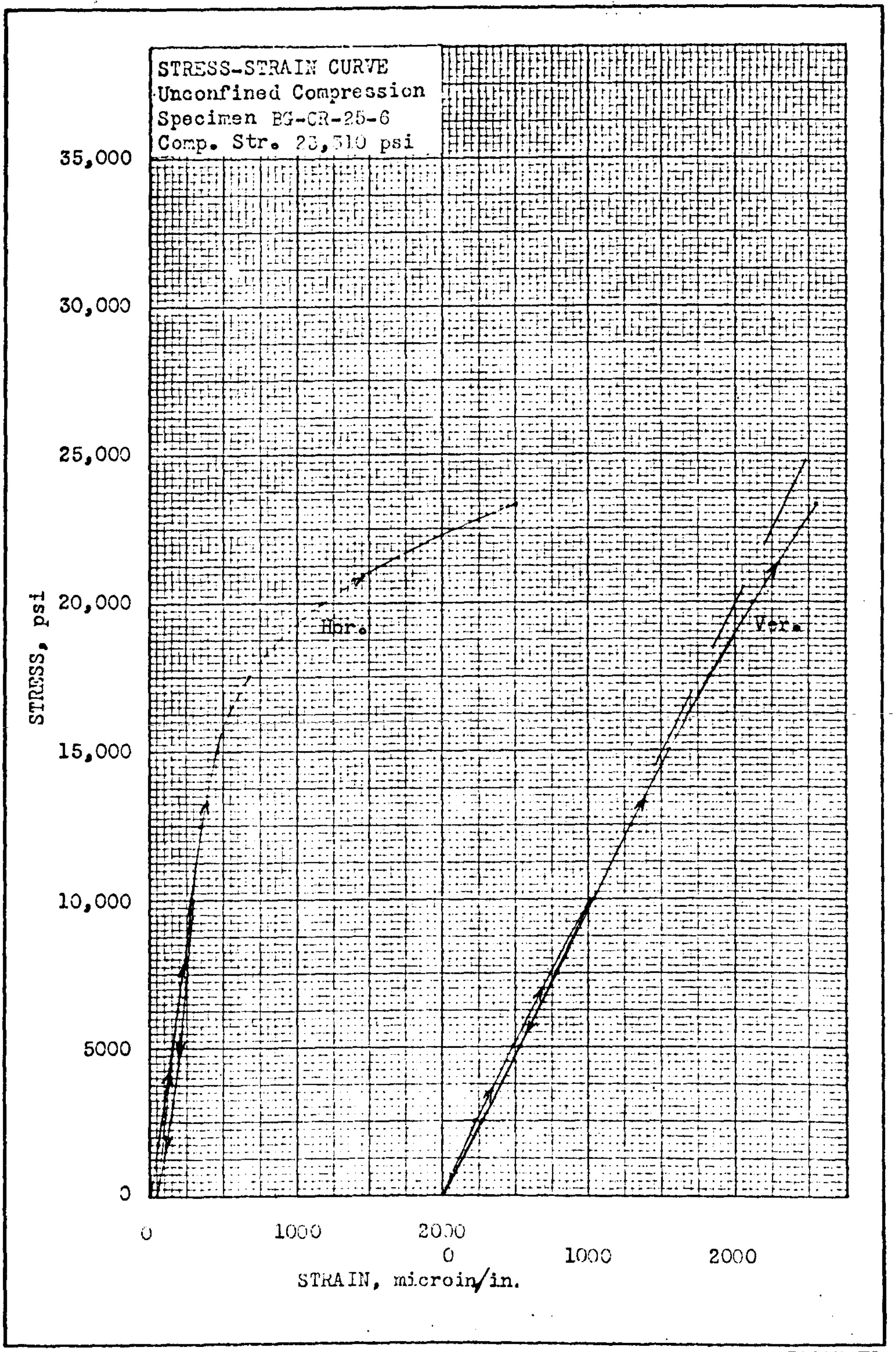
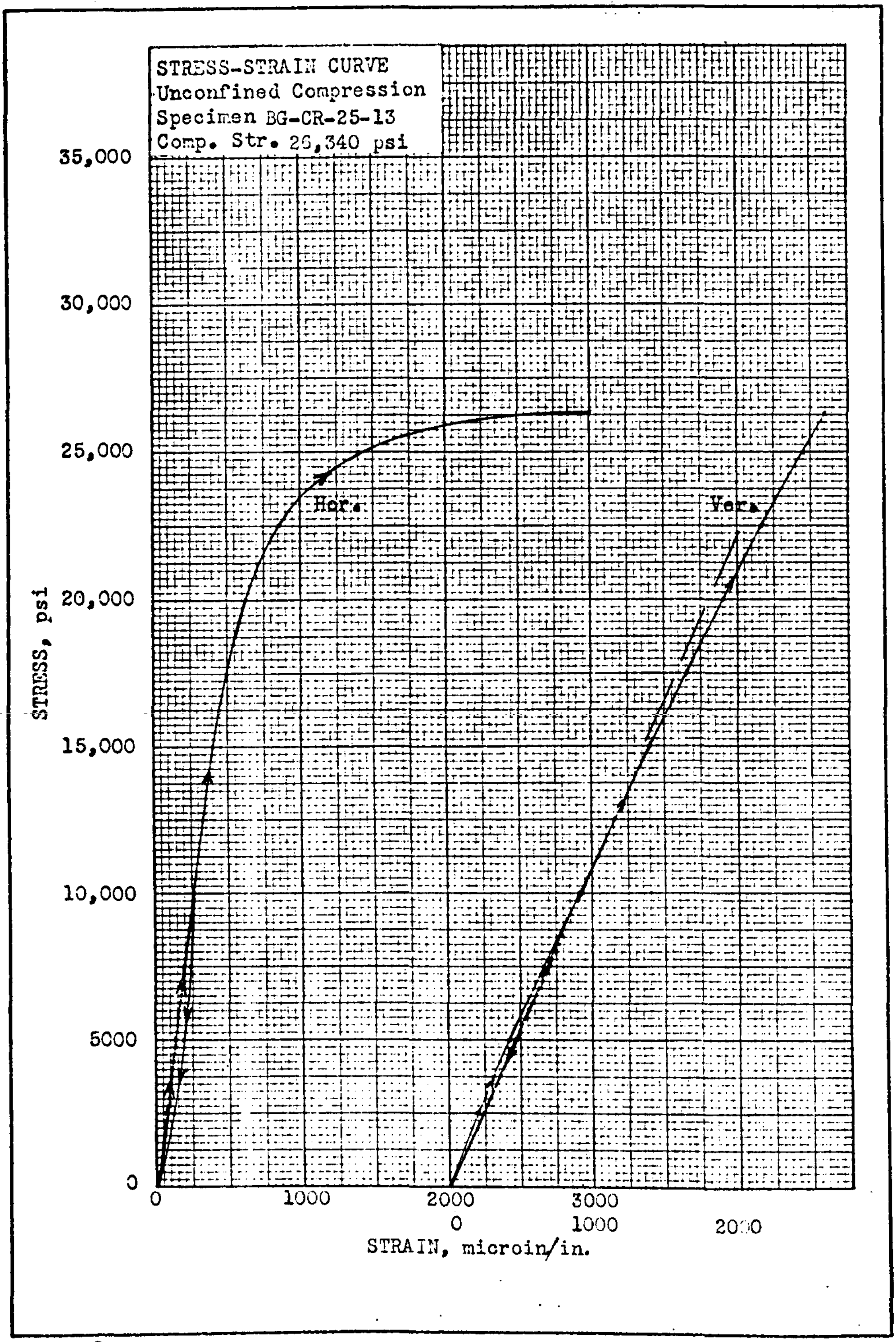

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-25-6
Comp. Str. 23,310 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
0
1000
2000
STRAIN, microin/in.

PLATE E1



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-25-13
Comp. Str. 26,340 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
3000
0
1000
2000
STRAIN, microin/in.

PLATE E2

APPENDIX F

DATA REPORT

Hole BG-CR-28

6 June 1969

Hole Location: Mason County, Texas

Longitude: 99° 21' 25" West

Latitude: 30° 46' 00" North

Core

1. The following core was received on 3 June 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	12
2	20
3	25
4	33
5	43
6	53
7	55
8	66
9	74
10	83
11	90
12	97
13	108
14	119
15	131
16	139
17	150
18	162
19	173
20	186
21	192
22	197

Description

2. The samples received were light-pink-colored rock identified as medium-grained biotite granite by the field log received with the core. Piece No. 2 appeared somewhat weathered and piece Nos. 1, 3, and 21 were lighter colored than the other pieces.

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	Very light colored	12	2.610	44.6	13,740	17,740
2	Weathered	20	2.615	49.8	18,910	17,535
3	Very light colored	25	2.627	47.3	9,630*	18,845
7	Light colored	55	2.623	51.3	28,260	18,835
8	Light colored	66	2.635	52.2	33,430	18,825
11	Light colored	90	2.636	53.8	33,570	18,565
15	Light colored	131	2.623	54.7	31,280	17,980
19	Light colored	173	2.613	52.2	29,860	18,360
21	Very light colored	192	2.603	48.1	19,370	15,840
Avg very light colored and weathered			2.609	47.5	17,340	17,040
Avg light colored			2.626	52.8	31,280	18,510

* Failed on high-angle fracture; deleted from average.

There are slight differences in the physical properties of the two different colored granites; however, both would be classed as relatively competent rock.

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. 2 and 8. Stress-strain curves are given in plates 1 and 2. Both specimens were cycled at 10,000 psi. Results are given below.

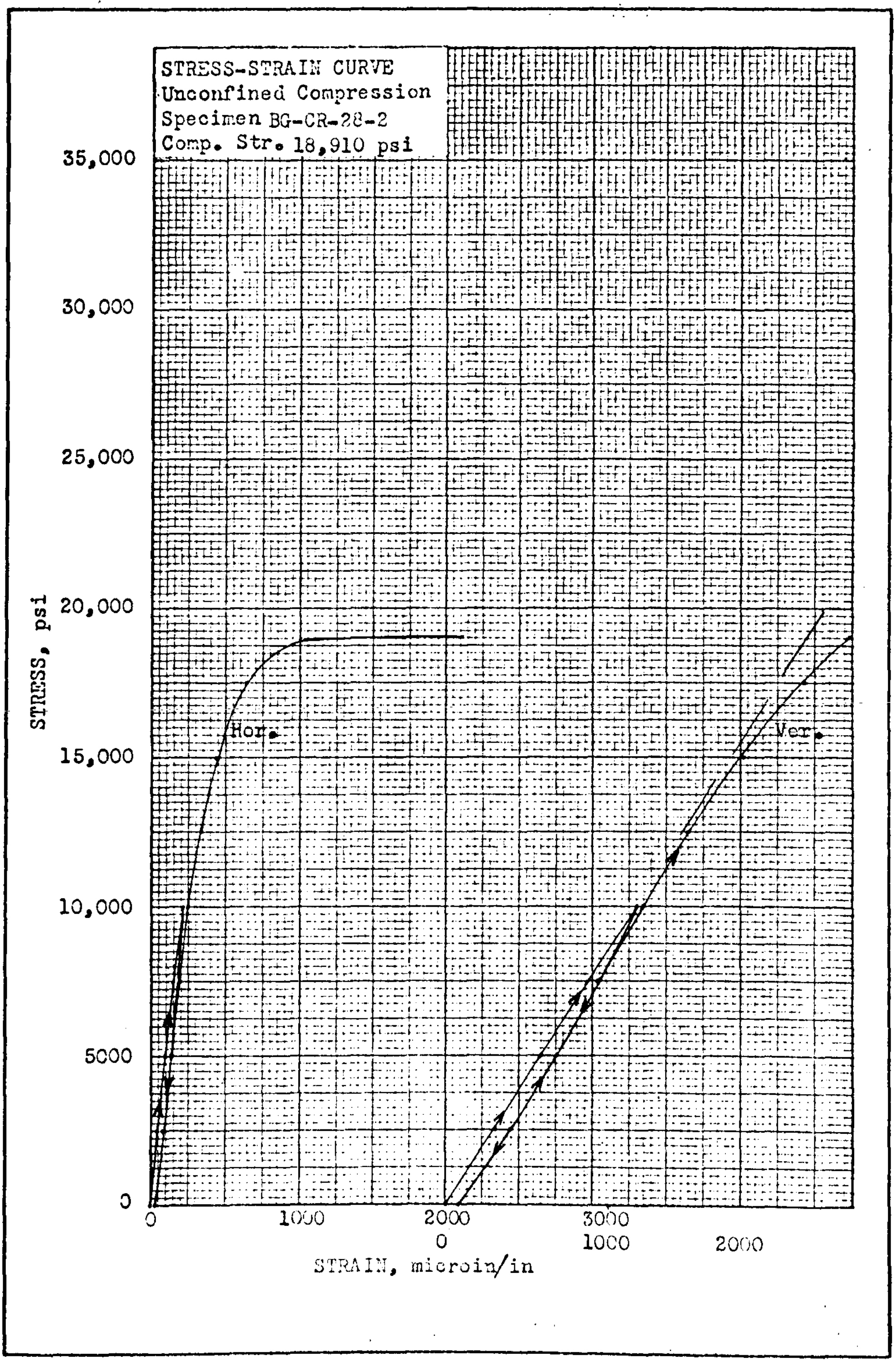
Specimen	Modulus, psi x 10^6			Shear	Poisson's
No.	Young's	Bulk	Shear	Velocity, fps	Ratio
			Dynamic Tests		
2	8.5	6.4	3.3	9,740	0.27
8	9.4	7.7	3.6	10,125	0.29
			Static Tests		
2	7.7	3.8	3.3	--	0.16
8	10.2	5.7	4.2	--	0.20

The moduli and stress-strain relationships are comparable to those of the gneiss and granite porphry from the previous holes in the Bergstrom Area.

Conclusions

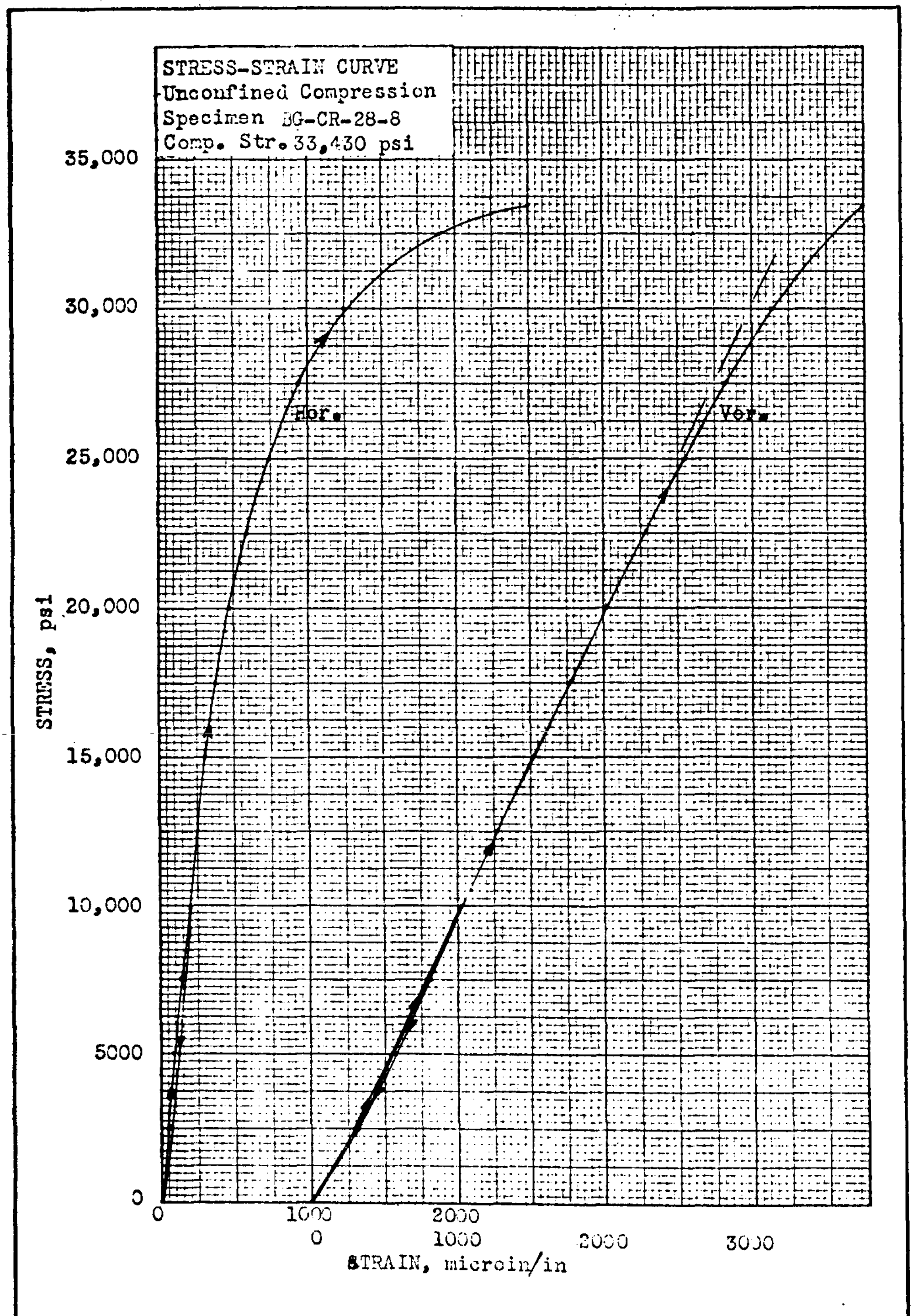
5. The core received for testing from hole BG-CR-28 was identified as medium-grained biotite granite by the field log received with the core. All of the core was light pink colored; several pieces were, however, distinctly lighter than the majority. There were slight differences in the physical properties of the two different colored granites as given below:

Property	Light Colored	Very Light Colored
Specific Gravity	2.626	2.609
Schmidt No.	53	48
Compressive Strength, psi	31,280	17,340
Compressional Wave Velocity, fps	18,510	17,040
Young's Modulus, psi x 10^6	10.0	8.0



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-28-2
Comp. Str. 18,910 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
3000
0
1000
2000
STRAIN, microin/in

PLATE F1



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-28-8
Comp. Str. 33,430 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
0
1000
2000
3000
STRAIN, microin/in

PLATE F2

APPENDIX G

DATA REPORT

Hole BG-CR-32

27 May 1969

Hole Location: Llano County, Texas

Longitude 98° 57' 30" West

Latitude 30° 44' 35" North

Core

1. The following core were received on 19 May 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	25
2	41
3	51
4	52
5	63
6	66
7	74
8	85
9	95
10	111
11	123
12	131
13	138
14	143
15	150
16	158
17	171
18	183
19	184
20	198

Description

2. The samples received were predominantly pink to grey colored rock identified as biotite granite by the field log received with the core. Pieces (samples) Nos. 3, 4, 5, 18, and 19 were significantly darker than the other samples and were identified as banded gneiss on the field log.

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
3	Granite-Gneiss Contact	51.0	2.897	-	17,400	17,080
4	Banded Gneiss	52.0	2.940	-	19,750	16,890
5	Pink Granite	63.0	2.654	60.6	34,030	18,230
6	Granite-Gneiss Contact	66.0	2.792	-	23,420	15,880
8	Pink Granite	86.0	2.648	-	32,200	16,840
11	Pink Granite	123.0	2.655	60.1	31,140	18,460
13	Pink Granite	138.0	2.683	-	18,600	17,860
18	Banded Gneiss	183.0	2.879	43.6	7,300	17,910
19	Banded Gneiss	184.0	2.785	51.6	10,000	18,060
20	Pink Granite	198.0	2.644	61.0	26,000	18,160
Avg Gneiss and Gneiss-Granite Contact			2.859	47.6	15,570	17,160
Avg Pink Granite			2.657	60.6	28,390	17,910

The gneiss and gneiss-granite contact specimens failed predominantly along bands and the granite specimens failed in the familiar shear cones.

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. Stress-strain curves are given in plates 1, 2, and 3. Results are given below:

Specimen No.	Modulus, psi x 10^6			Shear Velocity, fps	Poisson's Ratio
	Young's	Bulk	Shear		
			Dynamic Tests		
3	9.6	6.2	3.9	9,965	0.24
18	9.8	6.0	3.8	9,945	0.28
20	10.4	7.3	4.3	10,965	0.21
			Static Tests		
3	8.8	4.6	3.7	-	0.18
18	10.6	5.9	4.4	-	0.20
20	10.8	6.2	4.5	-	0.21

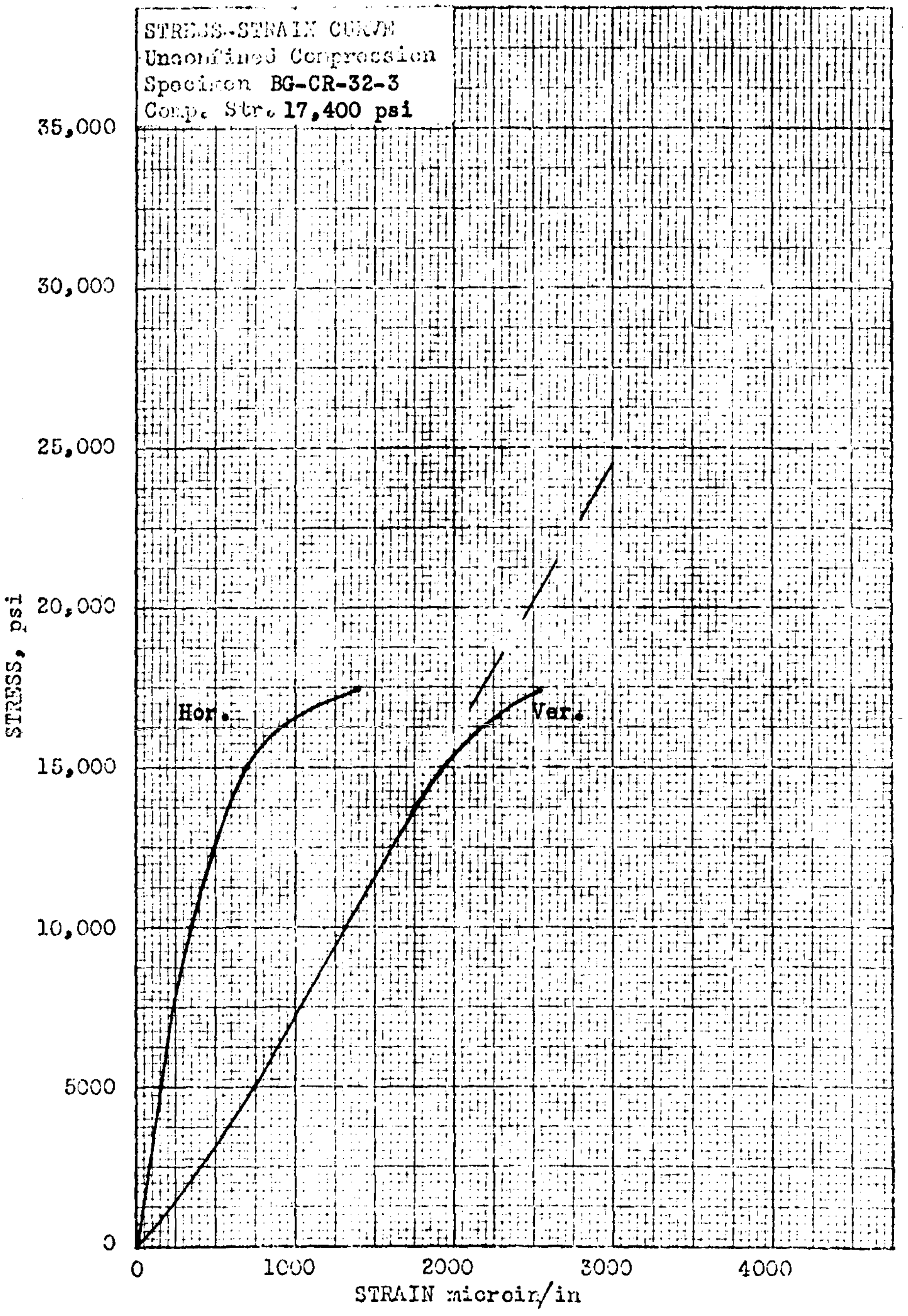
The deformation properties of the three types of specimens tested, a gneiss (18), granite (20), and a gneiss-granite contact specimen (3), are not significantly different.

Conclusions

5. The core received for testing from hole BG-CR-32 was predominantly pink granite with some banded gneiss according to the core log. The pink granite is a rigid, dense, very competent rock. The banded gneiss is also very dense, but the unconfined compressive strength is significantly lower

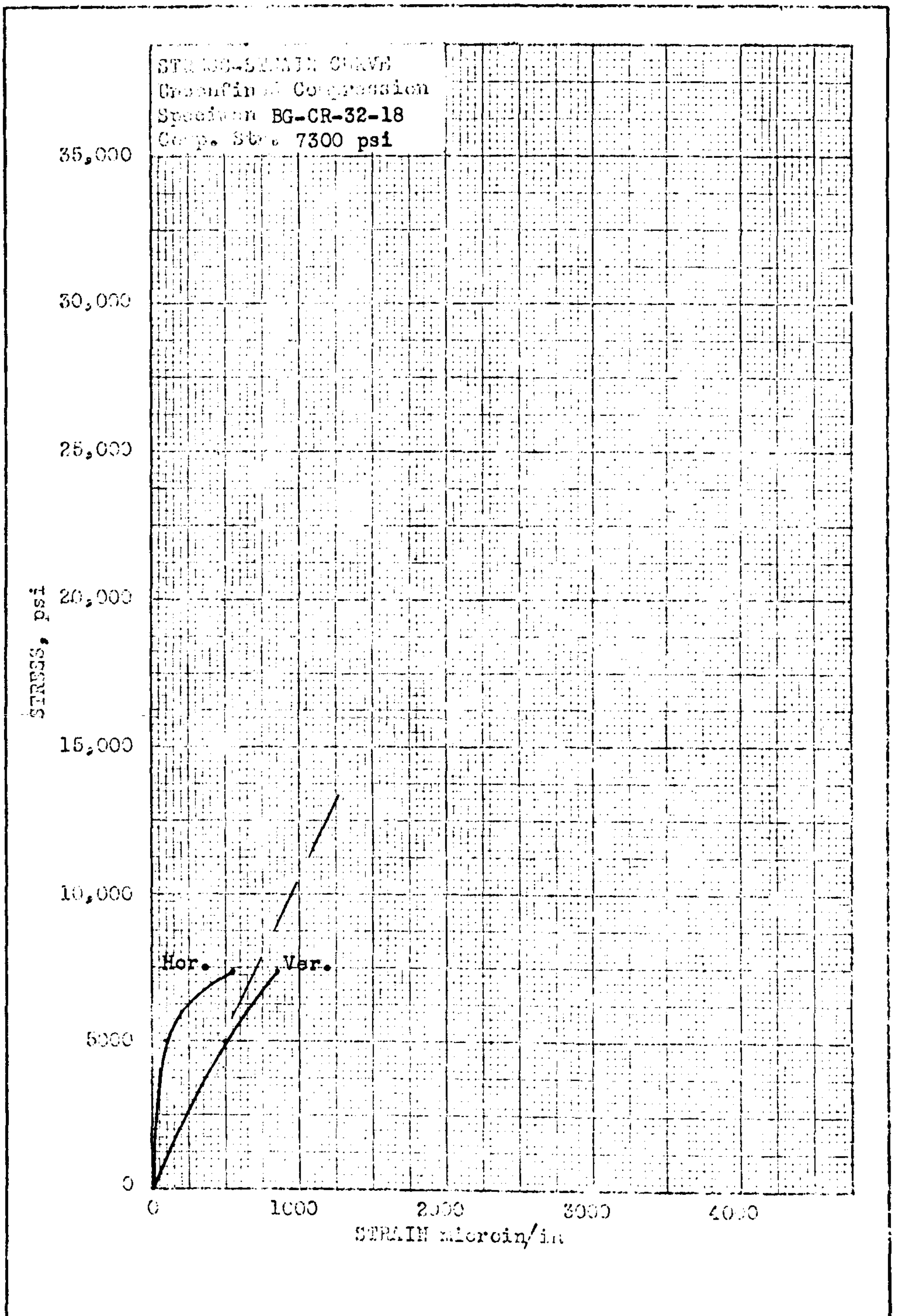
than the granite due to failure along the bands. Typical properties are given below:

Property	Granite	Gneiss
Specific Gravity	2.657	2.859
Schmidt No.	60.6	47.6
Compressive Strength, psi	28,390	15,570
Compressional Wave Velocity, fps	17,910	17,160
Young's Modulus, psi x 10^6	10.8	10.6



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-32-3
Comp. Str. 17,400 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE G1



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-32-18
Comp. Str. 7300 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE G2

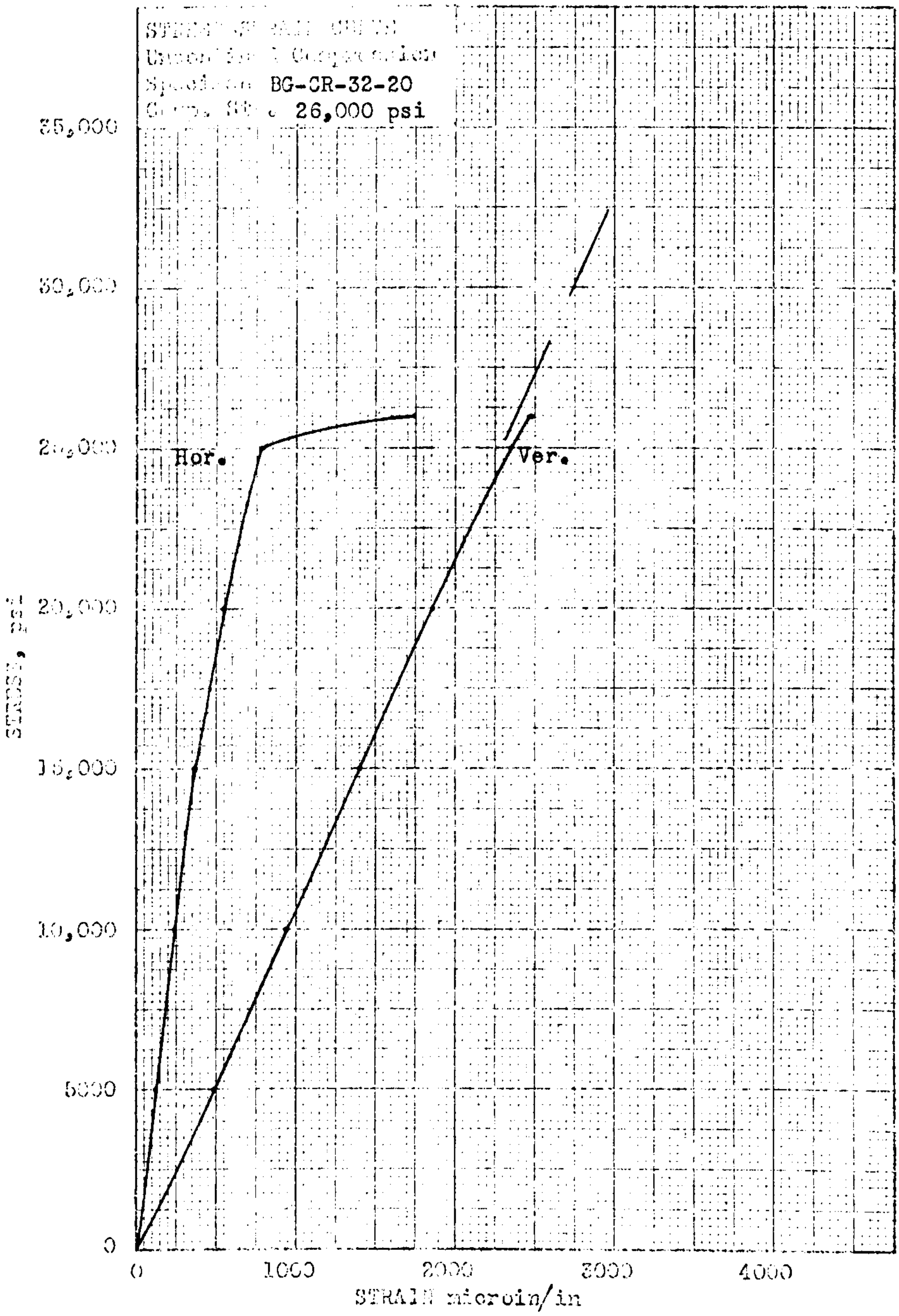

BG-CR-32-20
26,000 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE G3

APPENDIX H

DATA REPORT

Hole BG-CR-34

11 June 1969

Hole Location: Mason County, Texas

Longitude: 99° 08' 22" West

Latitude: 30° 46' 43" North

Core

1. The following core was received on 3 June 1969 for testing:

Core Piece No.	Approximate Depth, ft	Color
1	33	Gray
2	38	Gray to Pink
3	48	Gray to Pink
4	50	Pink
5	58	Gray
6	63	Dark Gray
7	67	Gray
8	77	Gray
9	89	Gray
10	97	Gray
11	108	Gray
12	118	Gray to Pink
13	119	Gray to Pink
14	130	Gray to Pink
15	138	Pink
16	141	Gray
17	144	Dark Gray
18	150	Pink
19	158	Pink
20	167	Pink
21	177	Pink
22	186	Pink
23	194	Gray
24	201	Gray

Description

2. The samples received were predominantly gray- and pink-colored rock identified as gneiss by the field log received with the core. Piece Nos. 6, 7, 16, 17, and 23 were identified as breccia. All of the core was streaked and banded, mostly at high angles. Hairline fracturing and contact surfaces were common.

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	33	2.637	50.2	14,660	18,440
3	Gray to Pink	48	2.643	46.8	14,370	17,420
4	Pink	50	2.630	--	12,430	16,600
6	Dark Gray	63	2.580	30.3	**	**
9	Gray	89	2.663	43.1	13,400	15,790
11	Gray	108	2.698	48.3	10,970	18,980
13	Gray to Pink	119	2.652	--	13,600	16,070
14	Gray to Pink	130	2.683	52.1	10,410	16,550
17	Dark Gray	144	2.798	37.4	13,140	17,975
19	Pink	158	2.539	--	14,430	18,045
21	Pink	177	2.590	54.3	14,430	18,660
23	Gray	194	2.645	43.6	13,140	18,360
Avg all core			2.647	45.1	13,180	17,535

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

4. Due to the relative consistency of the compressive strength tests, all results were averaged. The one exception, sample No. 6, contained a chalky deposit on the surface which broke during the Schmidt hammer test. The unusually large variation in specific

gravities indicates a wide range in composition of the material. The predominant mode of failure of the compressive strength specimens was vertical splitting along the high-angle contact surfaces, hairline fractures, and streaks. The average compressive strength is somewhat lower than that of the better granite in the Bergstrom Area, but is typical of a gneissic material.

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. 3, 11, and 21. Stress-strain curves are given in plates 1, 2, and 3. Specimens 3 and 21 were cycled at 10,000 psi. Results are given below.

Specimen	Modulus, psi x 10^6			Shear	Poisson's
No.	Young's	Bulk	Shear	Velocity, fps	Ratio
		Dynamic Tests			
3	8.1	6.7	3.1	9,340	0.30
11	9.9	8.0	3.9	10,250	0.29
21	8.9	7.6	3.4	9,860	0.31
		Static Tests			
3	7.5	4.3	3.1	--	0.21
11	9.7	6.5	3.9	--	0.25
21	7.8	6.2	3.0	--	0.29

Agreement between the test methods is rather good considering the foliated nature of the rock.

Conclusions

6. The core received for testing from hole BG-CR-34 was identified as gneiss by the field log received with the core. All of the core was gray or pink colored; many pieces were pink and gray banded. There were large differences in the specific gravity determinations, but the strength results were very consistent. Compressive strength failure was predominantly along the bands and contact surfaces. Average results are given below.

Property	Results
Specific Gravity	2.647
Schmidt No.	45
Compressive Strength, psi	13,180
Compressional Wave Velocity, fps	17,535
Young's Modulus, psi x 10^6	8.5

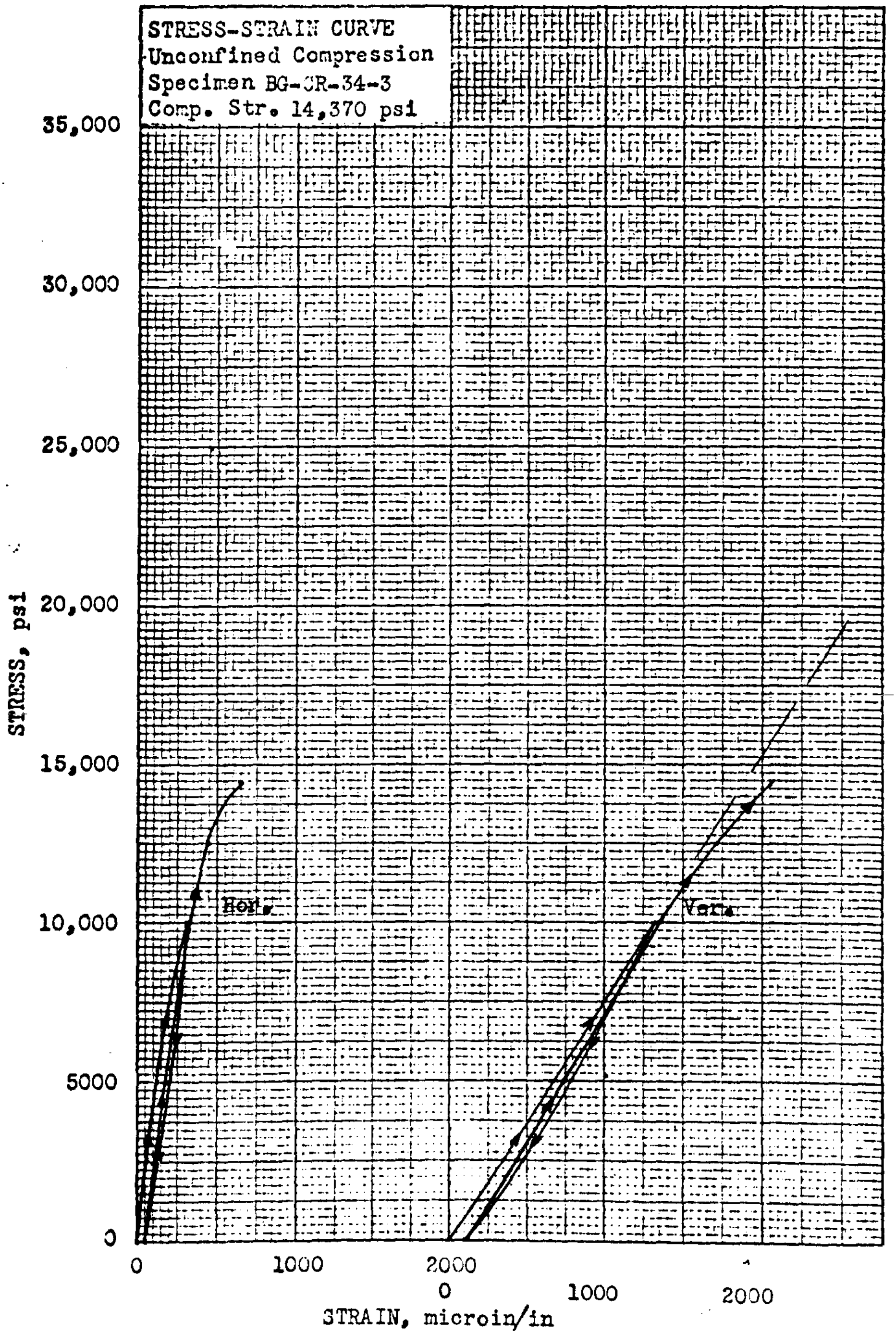
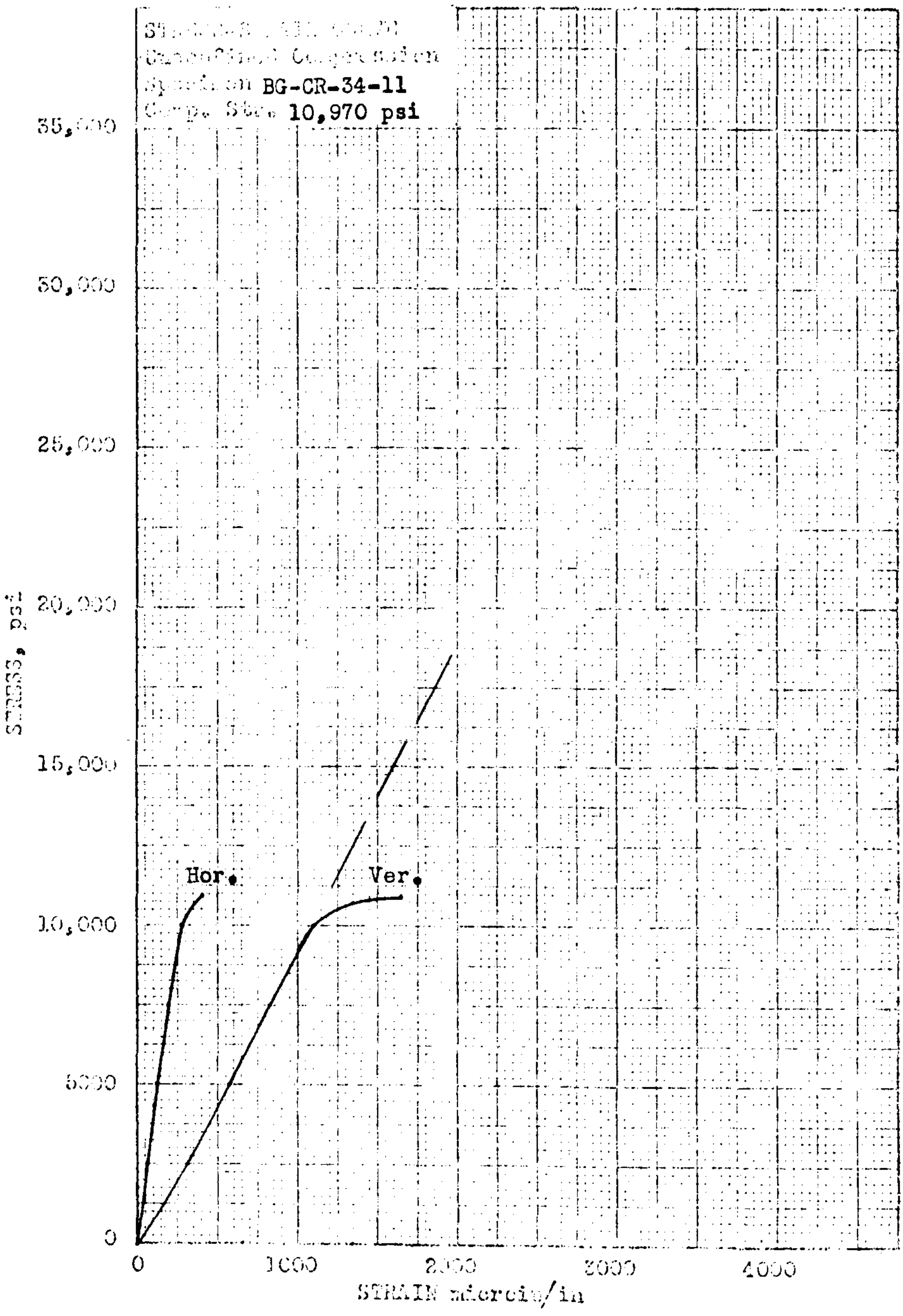
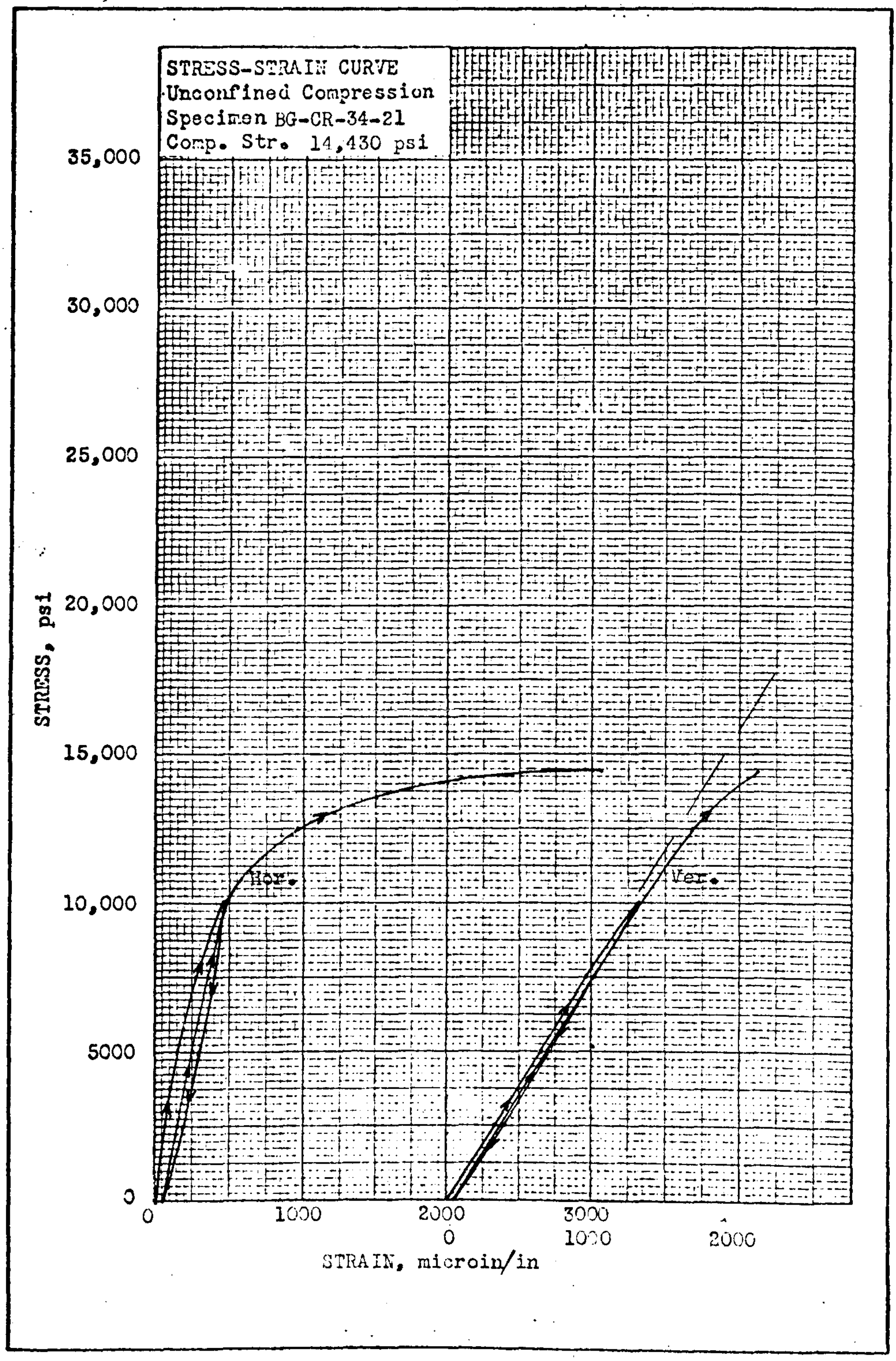

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-34-3
Comp. Str. 14,370 psi
STRESS, psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Hor.
Ver.
0
1000
2000
0
1000
2000
STRAIN, microin/in

PLATE H1



BG-CR-34-11
10,970 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE H2



STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-34-21
Comp. Str. 14,430 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
0
1000
2000
STRAIN, microin/in

PLATE H3

APPENDIX I

DATA REPORT

Hole BG-CR-39

29 May 1969

Hole Location: Llano County, Texas

Longitude: 98° 53' 30" West

Latitude: 30° 32' 35" North

Core

1. The following core was received on 26 May 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	22
2	32
3	42
4	52
5	61
6	64
7	76
8	82
9	91
10	99
11	109
12	112
13	118
14	124
15	138
16	145
17	147
18	153
19	162
20	172
21	175
22	177
23	187
24	198

Description

2. The samples received were all pink to rose-colored rock identified as hornblende biotite granite porphry by the field log received with the core. The only obvious differences in the samples received were the shade of coloring and the extent of high-angle sealed fracturing, both of which varied in no definite pattern throughout the depth sampled.

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* of Compressive Breaks	Core Depth	Sp Gr	Schmidt No.	Comp Strg, psi	Comp Wave Vel, fps
2	Vertical Split	32	2.648	46	18,400	18,250
6	On Jointed Surface	64	2.630	37	4,800	15,090
10	Vertical Split	99	2.651	--	14,200	19,060
15	Vertical Split	138	2.640	--	12,110	13,080
17	Vertical Split	147	2.645	38	13,970	17,320
21	Vertical Split	175	2.646	--	16,600	19,850
24	Conical	198	2.644	60	24,690	18,010
Avg Jointed Surface (1)			2.630	37	4,800	15,090
Avg Vertical Splitting (5)			2.646	42	15,050	17,510
Avg Conical (1)			2.644	60	24,690	18,010

* All of the core was described as hornblende biotite granite porphry. The predominant mode of failure was obviously the vertical splitting failure which was probably induced by the high-angle vertical fracture pattern prevalent in most of the core. The fractures were apparently sealed but many contained a dark filler material, possibly clay.

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. Stress-strain curves are given in plates 1, 2, and 3. Specimens 18 and 24 were cycled at 10,000 psi. Results are given below:

Specimen	Modulus, psi x 10^6			Shear	Poisson's
No.	Young's	Bulk	Shear	Velocity, fps	Ratio
6		Dynamic Tests			
6	6.6	4.6	2.6	8,555	0.26
15	5.3	3.2	2.2	7,805	0.22
24	10.4	5.7	4.4	11,090	0.20
		Static Tests			
6	3.5	2.3	1.4	--	0.25
15	6.5	2.7	3.0	--	0.10
24	11.0	9.2	4.2	--	0.30

Agreement between the two methods, static and dynamic, is fairly good except for specimen 6 in which a high-angle healed fracture apparently induced failure at a very low stress, 4800 psi. The relatively low Poisson's ratio obtained on the static test of specimen No. 15, also possibly due to the fracturing, resulted in erratic bulk and shear moduli determinations.

Conclusions

5. The core received for testing from hole BG-CR-39 was identified as hornblende biotite granite porphry on the core log. The core varied in color (pink to red) and degree of healed vertical fracturing throughout the depth sampled. The high-angle fractures apparently induced failure in the compressive tests in a vertical splitting mode. Where the fracture actually resulted in a clean break on a joint, the strength was very low, and where the fracturing apparently did not influence the results and a conical break occurred, a relatively high strength was obtained. Typical properties are given below:

	Failure		
Property	On a Jointed Surface	By Vertical Splitting	Conical Break
Specific Gravity	2.630	2.646	2.644
Schmidt No.	37	42	50
Compressive Strength, psi	4,800	15,050	24,690
Compressional Wave Velocity, fps	15,090	17,510	18,010
Young's Modulus, psi x 10^6	3.5	6.5	11.0

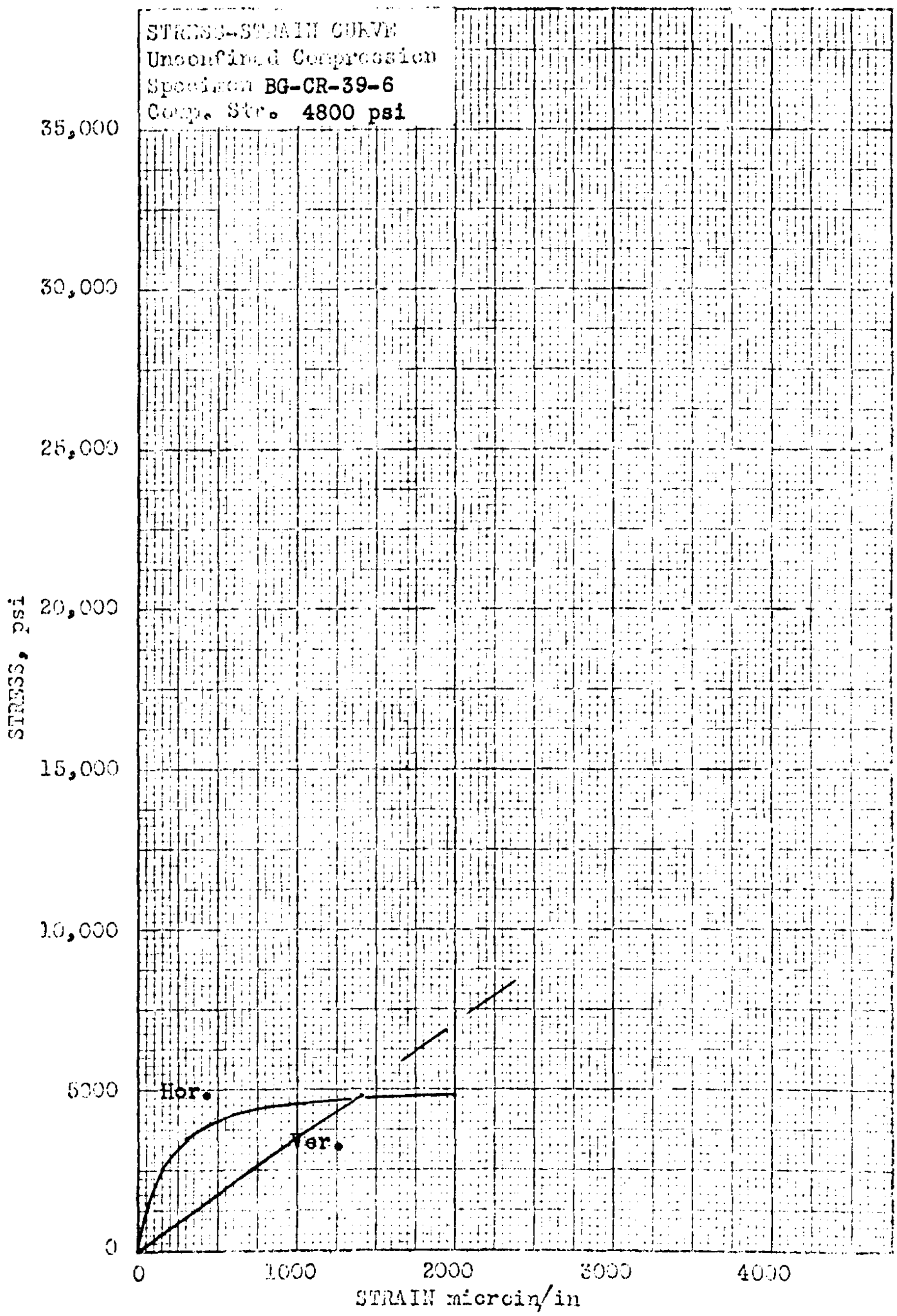

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-39-6
Comp. Str. 4800 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
4000
STRAIN microin/in

PLATE II

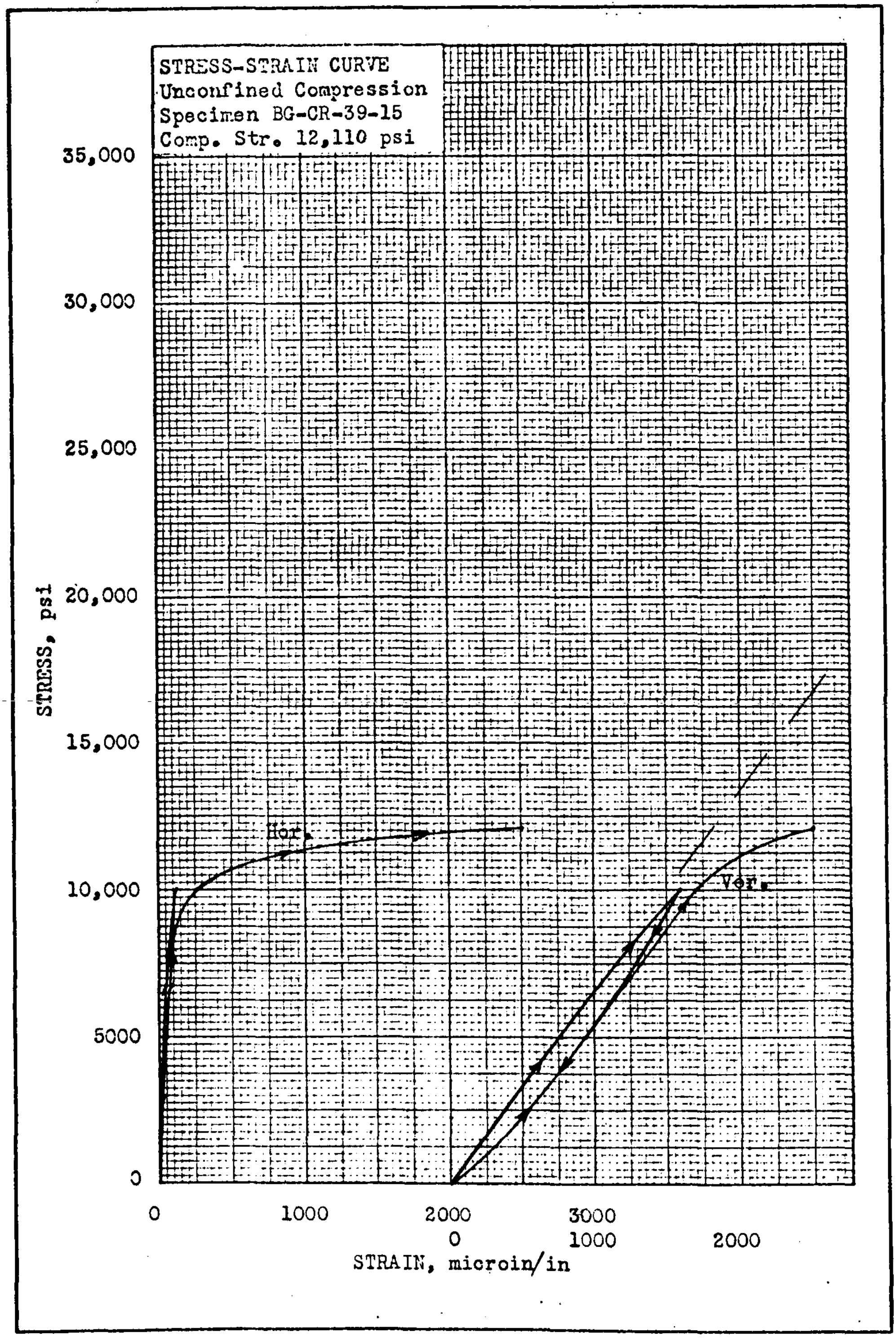

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-39-15
Comp. Str. 12,110 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
1000
2000
3000
0
1000
2000
STRAIN, microin/in

PLATE I2

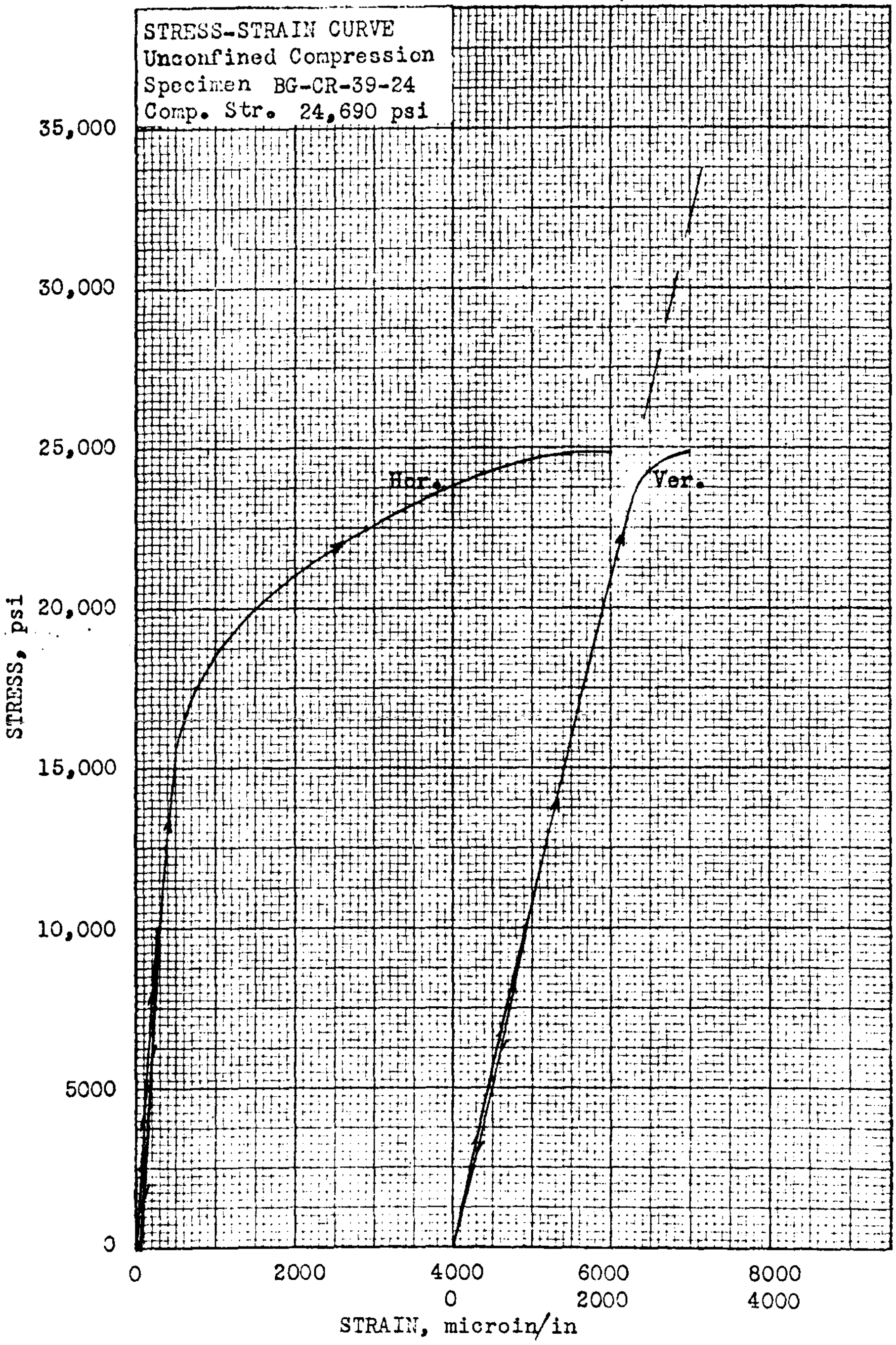

STRESS-STRAIN CURVE
Unconfined Compression
Specimen BG-CR-39-24
Comp. Str. 24,690 psi
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS, psi
Hor.
Ver.
0
2000
4000
6000
8000
0
2000
4000
STRAIN, microin/in

PLATE I3

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13. ABSTRACT Laboratory tests were conducted on rock core samples from nine core holes in the Bergstrom area of Mason, Llano, Gillespie, and Burnet Counties, Texas. The results were used to determine the quality and uniformity of the rock to depths of 200 feet below the ground surface. Petrographic examination indicated that the samples represented a very complex geologic area. Five general groups of material were identified: red granite, light gneiss, dark gneiss, schist, and contact zone rock. The predominant material was red granite. Based on physical characteristics (specific gravity, Schmidt hardness, wave velocity, and compressive strength), four groups of material were present: poor, marginal, good, and excellent quality rock. Although the better quality rock is predominant, the poorer quality rock is scattered throughout the upper elevation, and one may expect to remove up to 50 feet of material in some areas before competent rock is reached. The wide area represented by the drill holes and the complex nature of the material preclude assessment of the area on a hole-to-hole basis. In general, however, the Bergstrom area appears to be one of complex geologic nature, but one yielding sufficiently competent physical test results to merit further study as a competent hard rock medium.

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